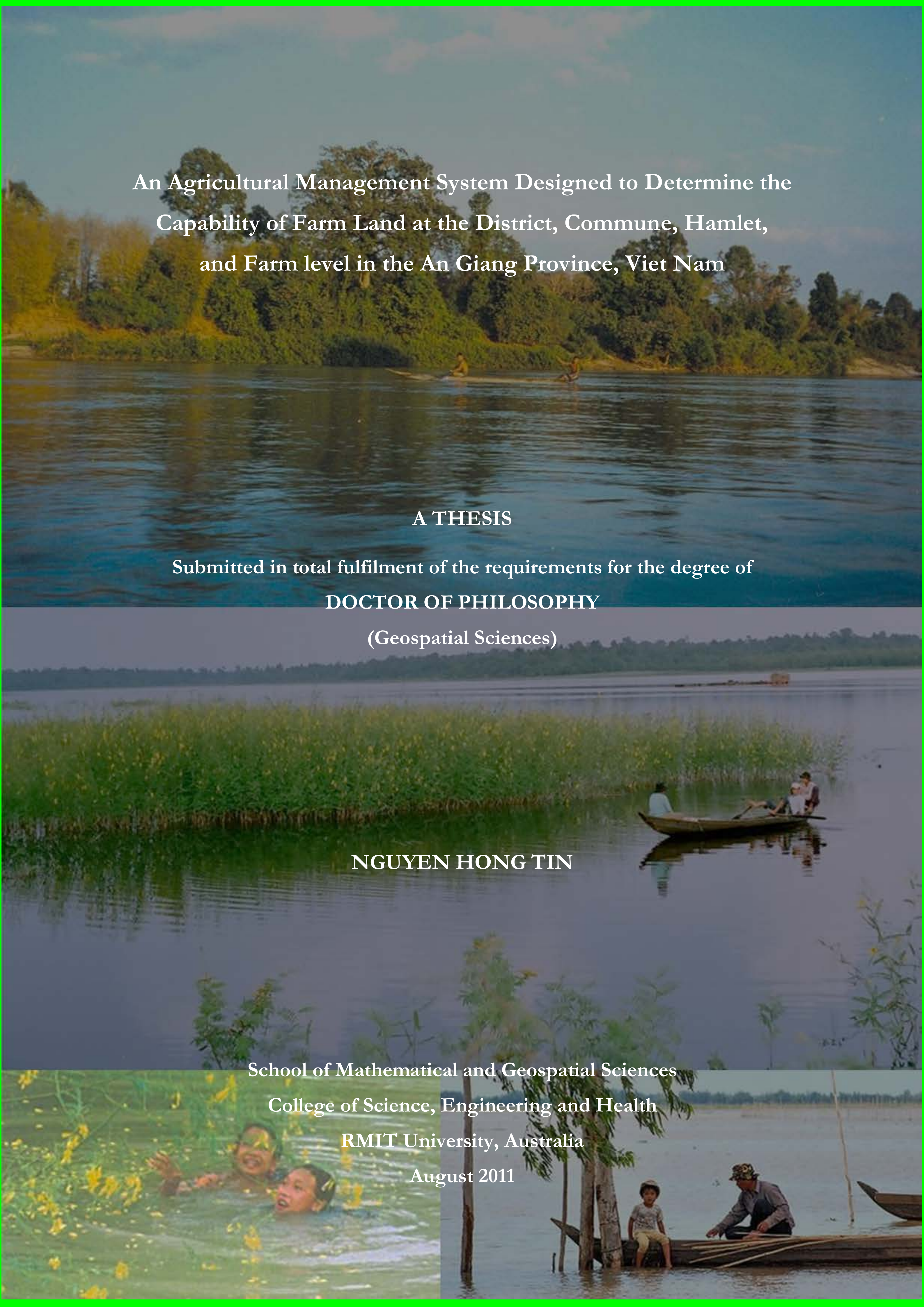

An Agricultural Management System Designed to Determine the Capability of Farm Land at the District, Commune, Hamlet, and Farm level in the An Giang Province, Viet Nam

A THESIS

Submitted in total fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

(Geospatial Sciences)

NGUYEN HONG TIN

School of Mathematical and Geospatial Sciences

College of Science, Engineering and Health

RMIT University, Australia

August 2011

An Agricultural Management System Designed to Determine the Capability of Farm Land at the District, Commune, Hamlet, and Farm level in the An Giang Province, Viet Nam

A THESIS

Submitted in total fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

(Geospatial Sciences)

NGUYEN HONG TIN

School of Mathematical and Geospatial Sciences

College of Science, Engineering and Health

RMIT University, Australia

August 2011

Abstract

The aim of this study is to develop a theoretical model for land capability assessment. The study investigates components and factors, which are required for an effective agricultural management system, and considers relationships, and interactions within and between those components and factors in contributing to the capability of farmland. The theoretical model incorporates theory from a range of disciplines relating to agricultural management and agricultural land, including the bio-physical, technical and management, land development and improvement, land conservation and environmental, socio-economic, and institutional and policy. The contribution of the components and factors, and their interactions are key considerations in analysing the capability of farmland.

The theoretical model is tested through undertaking a case study in the Mekong Delta, Viet Nam, based on suitable farming systems. The results from the case study confirm the adaptability, flexibility and applicability of the theoretical model, as well as providing useful feedback for the theoretical model.

Declaration

This is to certify that

(i) The thesis includes only my original work towards the PhD.

(ii) Except where due acknowledgement has been made in the text to all other materials used.

(iii) The work has not been submitted previously, in whole or in part, to qualify for any other academic award.

(iv) The content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program.

(v) The thesis is less than 90,000 words in length, exclusive of cover pages, references, and appendices.

Nguyen Hong Tin
Melbourne, 17/08/2011

Papers based on Research for this thesis

1. Nguyen Hong Tin, Tran Thanh Be and David Fraser. 2011. Determining the capability of farmland for agricultural land use planning in the Mekong Delta, Vietnam. Scientific journal of the University of Can Tho. It will be printed on November 2011.

2. Nguyen Hong Tin, Ngan Collins and David Fraser. 2011. An agricultural management system designed to determine the farmland capability for sustainable land use planning in the Mekong Delta, Vietnam. *Proceedings of the Twelfth International Conference of the Society for Global Business & Economic Development (July 21-23, 2011, Singapore)*. Pages 212-226.

3. Nguyen Hong Tin, David Fraser & Tran Thanh Be. 2010. An agricultural management system designed to determine the farmland capability for sustainable rice production in the Mekong Delta. Paper presented at the third International Rice Congress. *08th-12rd November 2010, National Convention Centre, Ha Noi, Vietnam.*

4. Nguyen Hong Tin, David Fraser & Tran Thanh Be. 2010. GIS and AHP-based qualitative and quantitative land capability assessment for rice production systems in the Mekong Delta. Paper presented at the third International Rice Congress. *08th-12rd November 2010, National Convention Centre, Ha Noi, Vietnam.*

5. Nguyen Hong Tin, David Fraser and Ngan Collins. 2010. Agricultural Management System and Sustainable Land Use in the Mekong Delta. Paper presented at the *'Engaging with Vietnam: An Interdisciplinary Dialogue' Conference 23rd-24th February 2010, Monash University, Melbourne, Australia.*

Acknowledgements

The PhD studies and the writing of this thesis were long journeys for me, sometimes with challenging and hard experiences. This dissertation is the output of sincere help, encouragement and supports from many institutions, and caring people around me. Without the help of various institutions and people, the thesis would have been impossible to complete. I wish to express sincere thanks to whom I was immeasurably inspired and who helped academically toward the completion of this thesis, with all humility and sense of acknowledgement:

The Ministry of Education and Training of Viet Nam (MOET) and the University of RMIT, for awarding me a PhD Research Scholarship to study in Australia;

The Board of Directorate of the Mekong Delta Development Research Institute and the Board of Managers of Cantho University, who offered a full-time study leave for me, without which, graduate schooling could not have been possible; and

My colleagues at the University of Cantho and the Mekong Delta Development Research Institute, for assuming my responsibilities at the Institute, and for encouragement, help, and supports during my studies. Particularly, I would like to thank Ms. Kim Thoa, Ms. Kim Don, Ms. Pha, Ms. Phan, Dr. Nhan, Mr. Quoc Nam, Dr. Quang Tin, Associate Professor Dr. Ngoc De, Associate Professor Dr. Thanh Loc, Dr. Sanh and Dr. Hieu Trung. I am greatly indebted to all of you.

I am extremely grateful to my principal supervisor, Associate Professor Dr. David Fraser for his unselfish, encouragement, help, living and academic supports and enthusiasm, training, comments, guidance and intelligent suggestions throughout my study period. I was very fortunate to have David Fraser as my beloved Supervisor. I appreciate his many constructive and incisive comments during the course of my thesis writing, in particular the many useful hours of work which him contributed though my long period of PhD study. I absorbed his marvellous knowledge in the field and extensive supervision experience as well as his hard work and moral and generous life style. His facilitation of opportunities to create and expand knowledge is unique and has been of great value to me. His continued support and belief in my ability have been essential for my output today, without David Fraser' support, I would not have completed the thesis on time. I also would like to express the heartfelt gratitude and thanks to David Fraser for his patience to correct English grammar throughout my thesis.

I would like to thank my transferred supervisors, Dr. David Silcock and Associate Professor Dr. Christopher Bellman, for the motivational help and support to overcome writer's block in the important phases of my study. Particularly, I wish to thank Dr. David Silcock, for his feedback and comments on my English writing style.

I would like to thank Dr. Tran Thanh Be, and Dr. Ngan Collins (RMIT University) as my honour supervisors, for his and her directions and supports to my study journey, particularly financial supports from Dr. Ngan Collins for my fieldwork, and for participating in the international conferences as well.

I wish to express sincere thanks to Ms. Kathryn Thomas, Ms. Bhavika Agnihotri, Ms. Erin Schembri, and Ms. Rania Zain (RMIT) as my study advisers, for their administrative helps and supports during the time I am an international student at RMIT University.

I would also like to thank all my colleagues and Vietnamese friends in Australia, especially Dr. Danh, Hong, Tram, Nam, Ba, Bao, Kim, Luan, Phong, Hung, Tuyet, Bac Kim, Chi Tanh, Chi Ly, Chi Phuong, Anh Lu, Anh Tam Tan, Nuong, Chi Xuan, Trinh, Ba Hai, Chu Nhan, Co Hai Yen, Lien, Dao, Chi Be, and Chu Thai. I valued their friendship and the joy of being with Vietnamese community in Australia.

In Viet Nam, I wish to acknowledge the assistance of people who were involved the fieldwork, especially Ut Y, Nguyen, Giang, Dang, Van Anh, Phuong, and Thanh.

I am grateful to my family, particularly my late Farther Nguyen Hong Phuc and Sister Nguyen Kim Thu, who devoted all their life to my study and helped me to become what I am today. My thanks and happiness, also go to my dearest Mother Nguyen Thi Mieng, brothers Hong Tam, Hong Tan, and sisters Kim Toi, Thu Hong.

Finally, I wish to thank my beloved wonderful wife Huynh Thi Thuy Loan and my dearest daughter Nguyen Huynh Bao Nguyen for their love, sacrifices, support, patience, inspiration and understanding. This humble work is dedicated to both you.

Table of contents

Abstract i
Declaration ii
Acknowledgements iv
Table of contents vi
List of Tables xi
List of Figures xiii
List of Abbreviations xvii

CHAPTER 1: **Introduction** 1
1.1 Overview 1
1.2 Statement of the issues 2
1.3 Aim and objectives 5
1.4 Expected outcomes 7
1.5 Scope and limitation of the study 8
1.6 Organisation of the study 8

CHAPTER 2: **The agricultural sector's role and agricultural land use distribution (Literature Review)** 11
2.1 Introduction 11
2.2. Agriculture's contributions to socio-economic development: Global context 12
2.2.1 Contribution to economic growth 12
2.2.2 Job opportunities and income generation for rural inhabitants 16
2.2.3 Hunger elimination and poverty reduction 19
2.3 Agriculture's contributions to socio-economic development: Asian context 23
2.3.1 Diet improvement 23
2.3.2 Contributing to export value and socio-economic development 25
2.4 Agriculture's contributions to socio-economic development: Viet Nam context 28
2.4.1 Brief introduction to the Viet Nam agricultural history 28
2.4.2 The roles of the agricultural sector 31
2.4.3 Investments in agriculture 34
2.5 Agriculture's contributions to socio-economic development: Mekong Delta and the An Giang Province context 35
2.5.1 Mekong Delta context 35
2.5.2 An Giang Province context 38
2.6 Negative impacts of agricultural practices: International context 41

2.6.1 Environmental degradation: soil, water, and diversity 41
2.6.2 Human health problems 46
2.6.3 Deforestation 47
2.7 Negative impacts of agricultural practices: Viet Nam Mekong Delta context 50
2.8 Agricultural land use distribution 59
2.8.1 The concepts in relation to agricultural land 59
2.8.2 Global agricultural land use distribution 60
2.8.3 Viet Nam Mekong Delta agricultural land distribution 68
2.9 Summary 70

CHAPTER 3: **Approaches and support tools for land evaluation (Literature Review continued)** 72
3.1 Introduction 72
3.2 Approaches to land evaluation 72
3.2.1 Land capability and suitability 72
3.2.2 The importance and purpose of land capability assessment 74
3.2.3 The USDA Land Capability Classification-LCC technique 78
3.2.4 The FAO method for land evaluation 83
3.2.5 Land evaluation systems originating from the FAO method 86
3.2.6 A theoretical framework for land evaluation 90
3.3 Land capability assessment trends 92
3.3.1 Combined qualitative and quantitative evaluation 92
3.3.2 Combined experts and local community knowledge 92
3.3.3 Multi-disciplinary land evaluation 93
3.4 The common principles of land capability assessment 94
3.5 The procedure of land capability assessment 96
3.5.1 Defining the alternative land uses: land use types or farming systems 97
3.5.2 Defining land use requirements 97
3.5.3 Describing land mapping units 98
3.5.4 Matching land use requirements and land conditions 98
3.5.5 Presenting the results of land capability assessment 98
3.5.6 The notable points in land capability assessment 98
3.6 Land capability classification systems 101
3.6.1 The USDA land capability system 101
3.6.2 The FAO land suitability classification system 104

3.7 Support tools for land capability assessment........ 107
3.7.1 Computerised land evaluation systems........ 108
3.7.2 GIS for land capability assessment........ 113
3.8 Multi-Criteria Decision Analysis for land capability assessment........ 122
3.8.1 Analytical Hierarchy Process........ 125
3.8.2 Steps of the AHP technique........ 126
3.9 Examples of GIS and MCDA-based land evaluation........ 128
3.10 Land capability assessment in Viet Nam's Mekong Delta........ 133
3.11 Summary........ 136

CHAPTER 4: **A theoretical model development for farmland capability determination**.. 137
4.1 Introduction........ 137
4.2 Conceptual framework........ 137
4.2.1 Agricultural management concept........ 137
4.2.2 System concept........ 139
4.3 Theoretical framework........ 141
4.4 Developing a theoretical model........ 142
4.4.1 Defining land utilisation types (proposed farming systems)........ 144
4.4.2 Determining key components in the AMS........ 146
4.4.3 Identifying land characteristics of each component in the AMS........ 148
4.4.4 Developing a farmland capability classification system........ 151
4.4.5 Determining the farmland capability........ 154
4.5 Summary........ 154

CHAPTER 5: **Background of the study area**........ 155
5.1 Introduction........ 155
5.2 General introduction to Viet Nam........ 155
5.3 The Mekong Delta........ 160
5.3.1 Soils in the Mekong Delta........ 161
5.3.2 Topography in the Mekong Delta........ 164
5.3.3 Economic conditions in the Mekong Delta........ 164
5.4 The An Giang Province........ 166
5.4.1 Natural conditions........ 167
5.4.2 Landform and soils........ 172
5.4.3 Hydrological regime and floods........ 175
5.4.4 Socio-economic and infrastructural conditions........ 180

5.4.5 Agricultural land use 181
5.5 The Cho Moi District 184
5.5.1 Soil characteristics in Cho Moi 185
5.5.2 Agricultural production in Cho Moi 186
5.6 Summary 193

CHAPTER 6: **Case study implementation** 195
6.1 Introduction 195
6.2 Key steps for undertaking the case study 197
6.2.1 Determining the proposed farming systems 197
6.2.2 Adjusting the model design and standardising the capability classes 197
6.2.3 Weighting the importance of farmland characteristics using the AHP 200
6.2.4 Surveying and investigating land characteristics 205
6.2.5 Matching actual land characteristics with land use requirements 210
6.2.6 Indices modelling to improve the capability of farmland 214
6.3 Summary 215

CHAPTER 7: **Findings from the theoretical model adjustment and case study implementation** 216
7.1 Introduction 216
7.2 Results of converting the theoretical model to a practical model 216
7.2.1 Proposed farming systems for land capability assessment 216
7.2.2 Proposed scales for land capability assessment 219
7.2.3 Land capability consideration in land assessment 224
7.2.4 Selected components for land capability assessment 224
7.2.5 Selected factors for land capability assessment 227
7.2.5.1 Factors' contribution to the land capability 231
7.2.5.2 Determination of dominant factors 233
7.2.5.3 Selected factors for farming systems at the commune scale 237
7.2.5.4 Selected factors for farming systems at the farm scale 239
7.2.6 Land capability classification system 241
7.2.6.1 Classes for land capability classification 241
7.2.6.2 Standardised capability values for factors 243
7.2.7 Weight of components and factors 252
7.3 Results of the case study implementation 258

7.3.1 Farmland capability analysis at the district scale.......... 260
7.3.2 Farmland capability analysis at the commune scale.......... 265
7.3.3 Farmland capability analysis at the farm scale.......... 274
7.4 Summary.......... 280

CHAPTER 8: **General discussion**.......... 283
8.1 Introduction.......... 283
8.2 Conversion of the theoretical to the practical model.......... 284
8.2.1 Selection of suitable farming systems and administrative scales.......... 284
8.2.2 Consideration of the land capability.......... 286
8.2.3 Selection of components and corresponding factors in the practical model.......... 287
8.2.4 Standardised capability value for factors.......... 289
8.2.5 The importance of components and factors in the AMS.......... 290
8.3 Feedback from the case study implementation.......... 293
8.4 Summary.......... 296

CHAPTER 9: **Summary and conclusion**.......... 298
9.1 Introduction.......... 298
9.2 Overview of the thesis.......... 298
9.3 Responding to the research questions.......... 303
9.4 Distributions of the study.......... 309
9.5 Limitations of the study and further recommendations.......... 312

Reference.......... 314
Appendices.......... 340

List of Tables

Table 1.1: The land area by regions and kinds of use ... 3
Table 2.1: Several agricultural indicators of agro-ecological zones in Viet Nam, 2008. ... 37
Table 2.2: Extent and change of global forest area between 1990 and 2005 ... 48
Table 2.3a: Number of agricultural farms formed in Viet Nam, 2000-2008 ... 51
Table 2.3b: Paddy planted area and aquaculture area in Viet Nam, 2000-2008 ... 51
Table 2.4: Agricultural land use distribution in some countries ... 61
Table 2.5: Agricultural land distribution in the Mekong Delta, Viet Nam ... 70
Table 3.1: Land capability matrix ... 100
Table 3.2: The fundamental scale of absolute numbers ... 128
Table 3.3: Examples of GIS-based and (or) MCDA-based land evaluation ... 130
Table 4.1.1: Bio-physical factors in the AMS ... 149
Table 4.1.2: Technical and management factors in the AMS ... 149
Table 4.1.3: Technical and management factors in the AMS (continued) ... 150
Table 4.1.4: Conservation and environmental factors in the AMS ... 150
Table 4.1.5: Socio-economic factors in the AMS ... 150
Table 4.1.6: Policy/institutional factors in the AMS ... 150
Table 4.2: Farmland capability rating classes for a specific land use ... 152
Table 4.3: Factor capability rating classes with respect to the farmland ... 153
Table 5.1: Major characteristics of the eight agro-ecological zones in Viet Nam ... 157
Table 5.2: Soil types in the An Giang Province ... 172
Table 5.3: Land use of the An Giang Province in 2005 ... 182
Table 6.1: Standardising indices of physical farmland characteristics for several farming systems in the Can Tho Province, Mekong Delta, Viet Nam. ... 199
Table 6.2: The fundamental qualitative scale used in pair-wise comparisons ... 202
Table 6.3.1: The matrix of pair-wise comparisons ... 203
Table 6.3.2: An example of the pair-wise comparison matrix of criteria in the AHP ... 203
Table 6.3.3: The matrix of pair-wise comparisons in decimal numbers ... 203
Table 6.3.4: The normalized matrix of pair-wise comparisons ... 204
Table 6.4: Average Random consistency Index (RI) ... 204
Table 6.5.1: Actual value classifications for capability classes and indices ... 211
Table 6.5.2: Illustration of factors and components in the AMS and their weightings/scores for calculating the farmland capability index ... 213
Table 7.1: Components and factors selected in the practical model ... 230
Table 7.2: Land capability aspects that factors impact upon ... 232

Table 7.3: Dominant and ordinary factors for selected farming systems 236
Table 7.4: Factors required for selected farming systems at the commune scale...........................238
Table 7.5: Factors required for selected farming systems at the farm scale 240
Table 7.6: Factor capability rating classes with respect to the farmland...242
Table 7.7: District level - Requirements for growth of overall agricultural systems 245
Table 7.8.1: Commune level - Requirements for growth of rotational rice-vegetables system....246
Table 7.8.2: Commune level - Requirements for growth of rice system 247
Table 7.8.3: Commune level - Requirement for growth of vegetables system 248
Table 7.9.1: Farm level - Requirements for growth of rotational rice-vegetables system 249
Table 7.9.2: Farm level - Requirements for growth of rice system..250
Table 7.9.3: Farm level - Requirements for growth of vegetables system......................................251
Table 7.10: Weights of components for the land capability 253
Table 7.11: Weights of factors for the general farmland capability at the district level.................257
Table 7.12: Classifying the actual value of factors for the capability classes and indices 260
Table 7.13: Current capability ratings of diagnostic components and overall capability for generally agricultural systems in the An Giang Province. 261
Table 7.14: Current farmland capability ratings for selected farming systems in the Cho Moi District 266
Table 7.15: Solutions and assumptions proposed to improve the land capability at the commune scale, for rice cultivation in the Cho Moi District...271
Table 7.16: Several main characteristics of thirty surveyed farmers (farms) 275
Table 7.17: Component and overall capability indices of farming systems at the farm scale.......276
Table 7.18: The results of the land capability analysis at the commune and farm scales 277

List of Figures

Figure 2.1: Agriculture's share in GDP (left graph) and agricultural productivity (right graph 13
Figure 2.2: Agricultural production indices, total and per capita 15
Figure 2.3: Cereal yields in developed and developing countries 1960-2005 15
Figure 2.4: Annual growth in employment and labour productivity, 1993-2005 17
Figure 2.5: Impact of sources of income on developing countries. 18
Figure 2.6: Percentage of rural households participating in agriculture. 19
Figure 2.7: World Cereal production, utilisation and stocks. 20
Figure 2.8: Poverty rate between 1981 and 2002 in China 22
Figure 2.9: Cereal yields compared to poverty in South Asia 22
Figure 2.10a: Consumption of rice in Asia, 1995 compared to 2005. 24
Figure 2.10b: Consumption of pork in Asia, 1995 compared to 2005. 24
Figure 2.10c: Consumption of fish in Asia, 1995 compared to 2005 25
Figure 2.10d: Consumption of chicken in Asia, 1995 compared to 2005. 25
Figure 2.11: Agricultural export value in Asia between 2000 and 2007 26
Figure 2.12: Agricultural import value (1000$) in Asia between 2000 and 2007 27
Figure 2.13a: Structure of employed population and GDP share by economic activity (%) in year 2008 32
Figure 2.13b: Viet Nam GDP at current prices by economic sectors, 2008 32
Figure 2.14: Several indicators in the agricultural sector of Viet Nam 33
Figure 2.15a: Export value of the Viet Nam agricultural sector between 2000 and 2007 33
Figure 2.15b: Viet Nam rice export quantity and value, 1990 – 2007 34
Figure 2.16: Distribution of agricultural farms by agro-ecological zones in Viet Nam, 2008 36
Figure 2.17: Aquaculture production share by agro-ecological zones in Viet Nam, 2008 37
Figure 2.18: An Giang Province GDP at current prices by economic sectors in 2006 39
Figure 2.19: Labour distribution by economic activity in the An Giang Province, 2006 39
Figure 2.20: Increase in production area and quantity of rice and fishery in the An Giang Province between 1995-2005. 40
Figure 2.21: Total global consumption in nutrients (N, P_2O_5 fertilizer) 43
Figure 2.22: Total global pesticide imports (import value) 43
Figure 2.23: Global cereals' yield stabilized in recent years 48
Figure 2.24: Direct causes of forest area changes in different tropical regions, 1990–2000 49
Figure 2.25: Consumption of Agro-chemicals in Viet Nam, 1994-2001. 53
Figure 2.26: An example of natural ecological balance in the rice farming system in the MD 56
Figure 2.27a: Area under arable and permanent crops in specific regions (million ha) 64

Figure 2.27b: The world agricultural land area distribution 64
Figure 2.28a: World agricultural land use distribution in 2009. 66
Figure 2.28b: Asian agricultural land use distribution in 2009. 67
Figure 2.28c: World agricultural land distribution by cropland and grazing land 69
Figure 3.1: The USDA land potential classification systems 104
Figure 3.2: The FAO land potential classification system 106
Figure 3.3: Conceptual design and component integration of the MicroLEIS DSS system 110
Figure 3.4: Main functional components of a GIS 116
Figure 3.5: Flowchart of GIS application to physical land suitability 121
Figure 4.1: The management functions in an agricultural production system 138
Figure 4.2: The hierarchy of systems in the rice seed supply system in the Mekong Delta, Viet Nam 140
Figure 4.3: The conceptual flowchart of the research approach 143
Figure 5.1: Viet Nam map 156
Figure 5.2: Terraced rice fields in Viet Nam's northern mountains 156
Figure 5.3: Map of the eight agro-ecological zones in Viet Nam 157
Figure 5.4: Farmers in the Mekong Delta transplanting rice 158
Figure 5.5: The Mekong Delta, south Viet Nam 160
Figure 5.6: Administrative map of the Mekong Delta 161
Figure 5.7: Soil map of the Mekong Delta 162
Figure 5.8: Agro-ecological zones of the Mekong Delta 163
Figure 5.9: Topographic map of the Mekong Delta 164
Figure 5.10: Administrative map of the An Giang Province 166
Figure 5.11: Temperature regime between 2001-2009 in the An Giang Province 168
Figure 5.12: Number of average sunshine hours per month between 2007-2009 in the An Giang Province 169
Figure 5.13: Average rainfall in months between 2007-2009 in the An Giang Province 170
Figure 5.14: Mean relative humidity in months between 2007-2009 in the An Giang Province 171
Figure 5.15: Soil map of the An Giang Province 173
Figure 5.16a: The highest water level of the Hau River, measured at the Chau Doc hydro-meteorological station 176
Figure 5.16b: The average water level of the Hau River, measured at the Chau Doc hydro-meteorological station 176
Figure 5.16c: The highest water level of the Tien River, measured at the Cho Moi hydro-meteorological station 176

Figure 5.16d: The average water level of the Tien River, measured at the Cho Moi hydro-meteorological station 177
Figure 5.17a: Farmer fishing in the flood season, in the An Giang Province 177
Figure 5.17b: Farmer gathering cork flower in the flood season, in the An Giang Province 178
Figure 5.18: Traditional rice fields-loss of productivity due to drought 179
Figure 5.19: Shadow drilled well that farmers dig to take water to supply their farms 180
Figure 5.20: Change of planted land area of paddy between 1995-2006 in the An Giang Province 182
Figure 5.21: Administrative map of the Cho Moi District 184
Figure 5.22: The Cho Moi District soil map 185
Figure 5.23: Seasonal calendar of rice farming systems in the Cho Moi District 186
Figure 5.24: Planted land area and gross output of paddy between 1995-2009 in the Cho Moi District 188
Figure 5.25: Sown land area of paddy for three different cropping seasons between 2001-2009 in the Cho Moi District 188
Figure 5.26: Average yield of paddy between 2001 and 2009 in the Cho Moi District 189
Figure 5.27: Rice seed fields in the Cho Moi District 189
Figure 5.28: Seasonal calendar of vegetables and some important temporary crops 190
Figure 5.29: Planted area, yield, and gross output of vegetables between 2001 and 2009 in the Cho Moi District 190
Figure 5.30: Intensive vegetables system in upland areas in the Cho Moi District 191
Figure 5.31: Rotational rice and vegetables/temporary crops in the Cho Moi District 191
Figure 5.32: Planted area, yield, and gross output of corn between 2001 and 2009 in the Cho Moi District 192
Figure 6.1: The conceptual flowchart of the case study approach 196
Figure 6.2: Weighting factors and components for farmland capability determination 201
Figure 6.3: Format for pair-wise comparisons 202
Figure 6.4.1: Flowchart of farmland capability analysis using AHP 212
Figure 6.4.2: Flowchart of factors and components undertaken in the AMS for farmland capability assessment 212
Figure 6.5: Flowchart of farmland capability analysis using a GIS 214
Figure 7.1: Capability ratings of components in the AMS for the overall agricultural systems at the district scale 262
Figure 7.2: Land capability map and percentage of present land use, planning and capability levels in the An Giang Province 263

Figure 7.3: Capability ratings of components in the AMS for selected farming systems at the commune scale 268
Figure 7.4: Current farmland components and overall capability ratings for selected farming systems at the commune scale 272
Figure 7.5: Modelled farmland capability for the rice system........ 273
Figure 7.6: Comparison between the current and modelled farmland capability levels in the Cho Moi District according to area percentage 273

List of Abbreviations

%: Percentage

<: Less than

=: Equal to

>: Greater than

≤: Less than, or equal to

≥: Greater than, or equal to

°: Degree

°C: Degrees Celsius

°E: Degrees East

°N: Degrees North

AEC: Agricultural Extension Centre

AEZ: Agro-Ecological Zones

AGR: Annual Growth Rate

AHP: Analytical Hierarchy Process

ALES: Automated Land Evaluation System

ALUP: Agricultural Land Use Planning

AMS: Agricultural Management System

CEC: Cation Exchange Capacity

Ci: Capability index

CI: Consistency Index

CR: Consistency Ratio

ESRI: Environmental Systems Research Institute

et al.: et alia (and others)

FAO: Food and Agricultural Organisation of the United Nations

FGD: Focus Group Discussion

FS: Farming system

GDP: Gross Domestic Product

GIS: Geographic Information System

GPS: Global Positioning System

ha: hectare(s)

ISLE: Intelligent System for Land Evaluation

LMU: Land Mapping Unit(s)

LUPAS: Land Use Planning and Analysis System

LUTs: Land Utilisation Type(s), Land Use Type(s)

MDI: Mekong Delta Development Research Institute

MCDA: Multi-Criteria Decision Analysis

MD: Mekong Delta

PFS: Proposed Farming System(s)

PLUP: Participatory Land Use Planning

PRA: Participatory Rural Appraisal

USDA: United States Department of Agriculture

wp: web page

CHAPTER 1: INTRODUCTION

1.1 Overview

Currently, there are approximately 2.6 billion people worldwide living on less than $2 per day (World Bank, 2007b). Most live in the rural areas and depend directly or indirectly on the agricultural sector for their livelihood (Nancy *et al.*, 2003; WRI, 2008; World Bank, 2008a). Taking a long-term perspective, agriculture undoubtedly will continue to play a key role for sustainable development and poverty reduction, because it stimulates economic growth, particularly for the agriculture-based countries. This makes them less vulnerable to climate change, generates raw materials, and creates more livelihood opportunities for rural inhabitants, and provides more environmental services as well (World Bank, 2008a).

To illustrate this, agriculture feeds approximately three-quarters of the population in developing countries, and offers new job opportunities for around one hundred-million rural poor allowing them to move out of their poverty situation. Moreover, it still makes up about 13% of the economy, and employs 57% of the labour force (World Bank, 2008a).

However, aspects of agriculture and the agricultural system are vast, varied and always changing rapidly (Shoup, 2004). Today world agriculture in general, and agricultural land use in particular, are facing many emerging problems such as climate change, sea level increase, floods, land degradation, soil erosion, water and soil pollution, land desertification, and exhaustion of natural resources, (Tilman *et al.*, 2002; Wassmann *et al.*, 2004; Oosterberg *et al.*, 2005).

In other words, besides positive impacts on socio-economic development already recognised, agriculture also impacts negatively on the environment, ecological systems, bio-diversity and other natural resources. The "Green Revolution[1]" in Asia between 1970 and 1995, and intensive agricultural systems later that have accelerated the excessive and inappropriate applications of agro-chemicals (fertilizers, insecticides,

[1] *The effort organized by the United Nations in the 1960s to increase world food production by introducing high-yield varieties of rice, wheat, and maize and new techniques, including irrigation and use of pesticides. (Scott Frey, 1996, p.12)*

herbicides) are testimony to this. Such excess creates water pollution, water scarcity, and frequent droughts and flooding, poisons people, upsets ecosystems, and degrades agricultural land as well as creating health problems (Pioram, 1997; UNEP, 2000; Malkina-Pykh *et al.*, 2003; World Bank, 2008a).

In other fields, humanity is currently facing global challenges of population increase, industrialisation, and urbanisation. The world population, increased from about 2.5 billion in 1950 to 6.8 billion in 2009, and will pass 7 billion in 2011 or 2012 (Population Reference Bureau, 2008; 2009). As a result, a higher competition in terms of housing, manufacturing, planting and other social services is created (Vandermeulen *et al.*, 2009). This means natural land areas in general, and farmland in particular, are reduced in area and extent.

For example, about 400,000 hectares (ha) of farmland in the United States were lost to urbanisation annually and approximately 5 million ha of farmland in China were lost to towns and cities during 1987-1992 (UNFPA, 2001). Similarly, about 1.95 million ha of land is estimated to be degraded by industry and urbanisation (FAO, 1996a). Additionally, land degradation is caused directly or indirectly by human activities such as poor soil and water management practices, removal of natural vegetation, deforestation and extremely important, unsuitable agricultural land use (UNEP, 2002).

1.2 Statement of the issues

The land area of the Earth covers a total of more than 140 million km^2. Land resources are finite, fragile, and non-renewable, including a number of different land components. Agricultural land is one of the most important components of the land. It is defined as land under arable use and permanent crops, which has an area of 4,931,862,000ha and occupies approximately 37.8% of the world land area (Table 1.1).

Data in Table 1.1 show that the agricultural land area in Asia, Southeast Asia, and Viet Nam[2] (research site) dominates in the range of 30-40% of the total natural land area for these regions. This confirms that agricultural land plays an important role for socio-economic development in Asia, Southeast Asia, and Viet Nam.

[2] *Refer to the background of the study area (Chapter 5)*

Agricultural land is mainly important for agricultural production, the environment, human habitation and welfare, and therefore has direct impacts on human life (UNEP, 2002). Therefore, inappropriate land use, particularly for agricultural land, results in inefficient exploitation of natural resources, destruction of the land resource, poverty and other social problems (Rossiter, 1996).

Table 1.1: The land area by regions and kinds of use

(Unit: 1000ha)

Region	Land area	Agricultural area	Arable land and permanent crops	Arable land
Viet Nam	31,007	10,072	9,430	6,350
Southeast Asia	434,093	117,660	100,596	66,171
Asia	3,093,949	1,662,869	573,284	504,537
World	**13,009,115**	**4,931,862**	**1,553,689**	**1,411,117**

Source: FAO (2009a), compiled by the Author. Data are for year 2007, and subject to rounding

On the other hand, the demands for arable land, permanent crops, grazing, forestry, wildlife, tourism, urban development and other services are greater than the availability of the land resources. These demands become more pressing in the developing countries every year as humans have an increasing dependency on the land for food, fuel and employment (FAO, 1993).

First of all, the issues mentioned above give agronomists, agricultural scientists, land managers and community producers the challenges of exploring new and relevant paradigms, solutions or policies in agricultural development to equalise social and economic outcomes, and the environmental benefits that have become more pressing and complex than ever (McRae *et al.*, 2000).

There have been several solutions proposed by researchers; but one of suitable and useful approaches for sustainable agricultural development suited to the present era, could be Agricultural Land Use Planning (ALUP). ALUP allows the integration of goals, including environmental health, economic profitability, and social and economic equity. The conflicting interests of industry, urban areas and land degradation can be partly solved through the application of ALUP to generate the balance in responsibility and profitability for actors in the production system including farmers, labourers, policy makers, researchers, retailers and consumers (Sands & Podmore, 2000; Gold, 2009).

A range of approaches to land use planning is available. The main ones are the Land Use Planning guidelines by the FAO (FAO, 1993), the Participatory Land Use Planning (PLUP) methodology (FAO, 1991; Jones and Sysomvang, 2005; Beall and Zeoli, 2008), the Land Use Planning and Analysis System (LUPAS) (Van Ittersum *et al.*, 2004 and Rotter *et al.*, 2005), and the Conversion of Land Use and its Effects (Veldkamp and Fresco, 1996; De La Rosa *et al.*, 2009). The advantages and disadvantages of the FAO, PLUP and LUPAS approaches have been compared in a case study in the Mekong Delta, Viet Nam (Trung, 2006).

The most important activity in the land use planning procedure is selecting land use alternatives based on land evaluation. Land evaluation can be summarised as the process of matching land use requirements with land characteristics in terms of land quality to assess the suitability of land use (FAO, 1976; 1985; 1993; Laborte *et al.*, 1999; Liu *et al.*, 2007; Ritung *et al.*, 2007).

Similarly, evaluating farmland suitability (land use requirements) is an extremely important activity in the agricultural land use planning procedure (FAO, 1985). It provides guidance for agricultural land managers and users on how to exploit land resources in a way that leads to sustainable agriculture. Land and farmland suitability evaluation are studied, applied and described by the FAO (1976; 1985; 1993), Indonesian Soil Research Institute and World Agroforestry Centre (Ritung *et al.*, 2007), Jaruntorn Boonyanuphap *et al.* (2004), Lingjun *et al.*(2008) and Mongkolsawat *et al.* (1997).

Land suitability is a statement of the adaptability of a given area for a specific kind of land use (e.g. rice, or soybean farming system) rather than the performance of the inherent capacity of the land at a given level for a general use (FAO, 1976; 1993; Rowe *et al.*, 1981). Nevertheless, so far, there has been no study on determining the capability of farmland through an Agricultural Management System (AMS) designed to integrate components[3] such as the bio-physical, technical, socio-economic and others components, and explore the interactions between those variables which relate to the prosperity of farms. Therefore, this research titled "An Agricultural Management System designed to determine the capability of farmland at the district, commune, hamlet, and farm level in the An Giang Province, Viet Nam" has been undertaken.

In brief, the research attempts to answer the following questions:
Question 1: What are the major components required for an effective agricultural management system that contribute to farm land capability?
Question 2: How are the major components in the agricultural management system important to the farmland capability?
Question 3: What are the key factors that impact upon the economic viability and the prosperity of farms?
Question 4: How do the key factors relating to agricultural production impact upon the economic viability of farmland?
Question 5: Can a Geographic Information System (GIS) based agricultural management system be developed to effectively measure the capability of farmland in the study area?
Question 6: Can a GIS be used effectively to map and monitor agricultural production in the study area?

1.3 Aim and objectives

The aim of this research is to develop a geographically referenced agricultural management system that is designed to determine the viability of farming practices in order to recommend technical solutions and revised management for the optimisation of agricultural land potential. The discipline areas to be integrated into this research are farm management, financial management, land capability, socio-economic management, environmental impact assessment, Geographic Information System development and spatial-temporal data management.

This research involves the integration and analysis of geographically referenced socio-economic and physical attributes relating to the farms in the An Giang Province,

[3] *Refer to Appendix 1*

Mekong Delta, Viet Nam as a case study. This integration allows the relationships within and between the datasets to be analysed, revealing factors that impact upon the agricultural production and the prosperity of farms.

The research uses existing and proposed agricultural data sets, such as farm practices, economic factors, and environmental control factors, physical characteristics, stored in a geographically based information system. The management system allows the production capability of the farming in the An Giang Province to be determined.

Additionally, an investigation has been conducted in several communes of the An Giang Province as a case study. Specifically, the study is guided by the following objectives:

Objective 1: To develop the theoretical model for an agricultural management system.

Objective 2: To gather environmental and agricultural data sets relating to the agricultural land use in the An Giang Province, Mekong Delta, Viet Nam.

Objective 3: To manipulate the data sets to align them to a geographical coordinate system which allows geographical relationships between the data sets to be analysed?

Objective 4: To merge the farm attributes data sets and analyse the data using statistical techniques.

Objective 5: To determine suitable geographical analysis techniques which, when applied to the data sets, allows new information products to be created as an aid to decision making in agricultural policies.

Objective 6: To develop an agricultural land capability management system, suitable for capability analysis at five administrative levels: Province, District, Commune, Hamlet, and Farm for use in determining the effectiveness of existing farming practices.

A holistic approach to the agricultural land capability management system development involves geospatial modelling of the relationships between the different characteristics of the farms in the province based on land data, crop data, the application of chemicals, on-farm and off-farm income, demographic data and agricultural production.

The research uncovers existing datasets which are incorporated into a new capability model designed to determine the viability of the farming based on a five level capability rating from very low capability through to very high capability.

An agricultural management system, designed to determine the capability of farm land at the province, district, commune, hamlet and farm level, provides available tools for agricultural policy makers and producers in the development of global sustainable agriculture. The creation of the Agricultural Management System also supports an objective in the convention of collaboration and sustainable development for the Mekong River Basin of Viet Nam National Mekong Committee (Decision N^0 114/QĐ-TTg of the Prime Minister of Viet Nam, 2010). Moreover, the research will produce invaluable data sets for further research in the Mekong Delta.

1.4 Expected outcomes

First, the study results in the production of a GIS-based agricultural management system, underpinned by a sound theoretical and logical structure. The application of computer based land use modelling tools and geographical analysis tools help in the understanding of the factors influencing the viability of agricultural land.

Second, the study will develop a procedure for analysing the viability of the agricultural production using selected spatial and temporal datasets stored in a Geographic Information System. Spatial data relating to characteristics of the agricultural land and the physical environment will be acquired in a suitable form for spatial modelling.

Third, the study will develop techniques and procedures for spatial analysis and multi-variety analysis based on datasets relating to soil, demographics, agricultural production, land cover and crop cycles. These techniques and procedures will be integrated into the agricultural land capability system being developed.

Fourth, the study will provide the theoretical and empirical evidence relating to agricultural land capability use by policy makers and rural development planners as a basis for program development and policy formulation.

Fifth, the study will identify important components and factors in the AMS as well as their contribution to the farmland capability in the study area.

Finally, the study will generate current and potential farmland capability classification maps at different scales, as well as offering necessary solutions and external inputs to improve the land capability in the study area.

1.5 Scope and limitation of the study

The study provides important baseline information on bio-physical parameters and socio-economic characteristics for input to an agricultural management system that is designed to determine the capability of farmland. The case study is confined to several communes in the An Giang Province. The study uses both primary and secondary data through household interviews, key informant panels, participatory rural appraisal and existing data available at the Mekong Delta Development Institute, Can Tho University, Viet Nam and the An Giang Agricultural Extension Centre. The study focuses on the capability of farmland and is based only on distributions of key factors stored in the agricultural management system.

1.6 Organisation of the study

The following text summaries the content of each chapter in the thesis. This is provided to help the reader in understanding the context during the reading of the thesis.

Chapter 1 Introduction

This chapter outlines the general status of the research project and defines the problems relating to the research theme that is agricultural land and it's potential. Moreover, different approaches to land use planning and land evaluation activity are also briefly mentioned. The research hypotheses, objectives and questions are formed and the significance, expected outcomes, and organisation of the study, are presented.

Chapter 2 Literature review

The chapter describes the overall role of the agricultural sector in socio-economic development, and presents constraints on agricultural practices. Then the status of agricultural land use and factors limiting its potential are explored at the global, Asian, Viet Nam, and the Mekong Delta (An Giang Province) levels.

Chapter 3 Literature review, continued

It reviews techniques, methods and approaches to land evaluation that are applied worldwide and in the study area. Further, support tools such as the Analytical Hierarchy Process (AHP) and a Geographic Information System (GIS), and their application in land assessment, are discussed.

Chapter 4 Development of a theoretical model

It presents the process of designing an Agricultural Management System (AMS) (theoretical model) for land capability assessment. First, the chapter introduces the concept of system, components, and relations as well as the interactions among them in the system. Second, it identifies bio-physical, technical and management, land improvement, policy and institutional, and socio-economic factors in the AMS that impact upon the capability of farmland, and the prosperity of farms. Third, the conceptual framework and key steps to develop the theoretical model are reported.

Chapter 5 Background of the study area

This chapter briefly introduces the background of the study area including climate and land conditions, agricultural land use, agricultural production and several main socio-economic traits in Viet Nam, the Mekong Delta, the An Giang Province, and the Cho Moi District.

Chapter 6 Case study implementation

The chapter reports on the case study implementation by testing the theoretical model. Activities such as identifying promising farming systems for farmland assessment, theoretical model adjustment, standardisation of values for farmland capability classes, factors weighting, farmland investigation, matching land use requirements and identifying land characteristics, modelling of farmland capability and screening the capability of farmland in the research area, are included in this chapter.

Chapter 7 Findings

It summarizes the findings from the research.

Chapter 8 General discussion

The chapter presents a general discussion relating to the findings from chapter 7.

Chapter 9 Summary and conclusion

This chapter presents a summary of the thesis, conclusions and recommendations.

CHAPTER 2: THE AGRICULTURAL SECTOR'S ROLE AND AGRICULTURAL LAND USE DISTRIBUTION (Literature Review)

2.1 Introduction

Globally, up to 3.0 billion poor people are depending on agriculture for their livelihood, particularly for the rural areas in agriculture-based countries, such as Asia and Africa (World Bank, 2007a; World Bank, 2008a). Agriculture contributes to development in many ways, such as economic development, livelihood opportunities, and environmental services (World Bank, 2008a). But, agriculture and agricultural land use are facing land, water and forest degradation, with significant negative impacts for the countries' agricultural sectors, natural resource base, and environmental balance (World Bank, 2006a; Tilman *et al.*, 2002; Wassmann *et al.*, 2004; Oosterberg *et al.*, 2005). This stated circumstance indicates that the potential of agricultural land is being threatened, and hence, a multi-functional agricultural model, for enhancing the agricultural sector's role while simultaneously preserving the land resources, is essential. "Sustainable Agriculture" (as defined by the FACT Act, 1990; Gold, 2009) seems to be a reasonable solution; because it integrates three main goals, environmental health, economic profitability, and social and economic equity.

Sustainable agriculture is "An integrated system of plant and animal production practices having a site-specific application that will, over the long term (a) satisfy human food and fibre needs; (b) enhance environmental quality and the natural resource base upon which the agricultural economy depends; (c) make the most efficient use of non-renewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls; (d) sustain the economic viability of farm operations; and (e) enhance the quality of life for farmers and society as a whole." (FACT Act, 1990; Gold, 2009, wp[4]). To achieve these goals, it is clear that the potential of agricultural land has to be assessed and considered carefully prior to strategic solutions for sustainable agricultural land use being identified.

[4] *Page number is not placed because references (referred articles) that the Author refers are published on the internet web-pages (wp), where page numbers of articles are not shown*

This chapter describes the role of the agricultural sector in socio-economic development and the negative impacts of agricultural practices. The agricultural land use distribution in the global and Viet Nam context is then presented. The purpose of this chapter is to systematize and integrate fundamental knowledge relating to agricultural management, and the capability of farmland, to form a foundation of knowledge for the development of theoretical model for farmland capability assessment presented in Chapter 4.

2.2. Agriculture's contributions to socio-economic development: Global context

2.2.1 Contribution to economic growth

The agricultural sector is defined and described in a range of disciplines, using different dimensions. Primarily, agricultural activity is concerned with cropping and animal husbandry. A broader view is that, it is a vital part of any economy, embracing crop and animal production, forestry and logging, fishing, aquaculture, hunting and trapping, and the support activities for agriculture and forestry (U. S. Census Bureau, 1997; World Bank, 2008a), which have been contributing to the world's development in terms of socio-economics, poverty reduction, and welfare improvement (FAO, 2008a).

Commonly, the agricultural sector combines with many other sectors to enable a country to grow a macro-economy faster, reduce poverty significantly, and stabilise the environment. It plays an important role in the development of three distinct country types, agriculture-based (include most of Sub-Saharan Africa); transforming (include most of South and East Asia and the Middle East and North Africa); and urbanised (include most of Latin America and much of Europe and Central Asia) (World Bank, 2008a).

Agriculture is a key economic component for many countries, as it promotes national economic development, provides opportunities and an investment environment for the private sector and state economic organizations, as well as driving agriculture-related industries and the rural non-farm economy (World Bank, 2008a).

Agriculture occupied more than one-third of the world's area, and contributed up to 5% of the world's total Gross Domestic Product (GDP) in 2006 (FAO, 2009a). The industries and services related to agriculture in value chains often make up more than 30% of the GDP in transforming and urbanized countries (World Bank, 2008a). Moreover, it contributed to economic growth and made up a fifth of the economy in the transforming economies of Asia, mainly China, India, and Indonesia. In the urbanising economies of Latin America and some countries of Eastern Europe and Central Asia, agriculture contributed 10% to the economic growth. It is a way of life for many people throughout the world, with 2.5 billion of 3 billion rural people tied to agricultural activities, particularly food production (World Bank, 2007b; World Bank, 2008a).

As a long-term prospect, agriculture remains strong and significant in many agriculture-based countries (FAO, 2008a) because it generates on average 29% of the GDP. For example, the share in the total GDP by agricultural sector of Indonesia, Thailand, Philippines, and Viet Nam was 14.2, 7.8, 15, and 19.7% respectively in 2006 (FAO, 2009a). In some agriculture-based economies of Sub-Saharan Africa, it contributed a third of the economic growth in 1990-2005 (Figure 2.1).

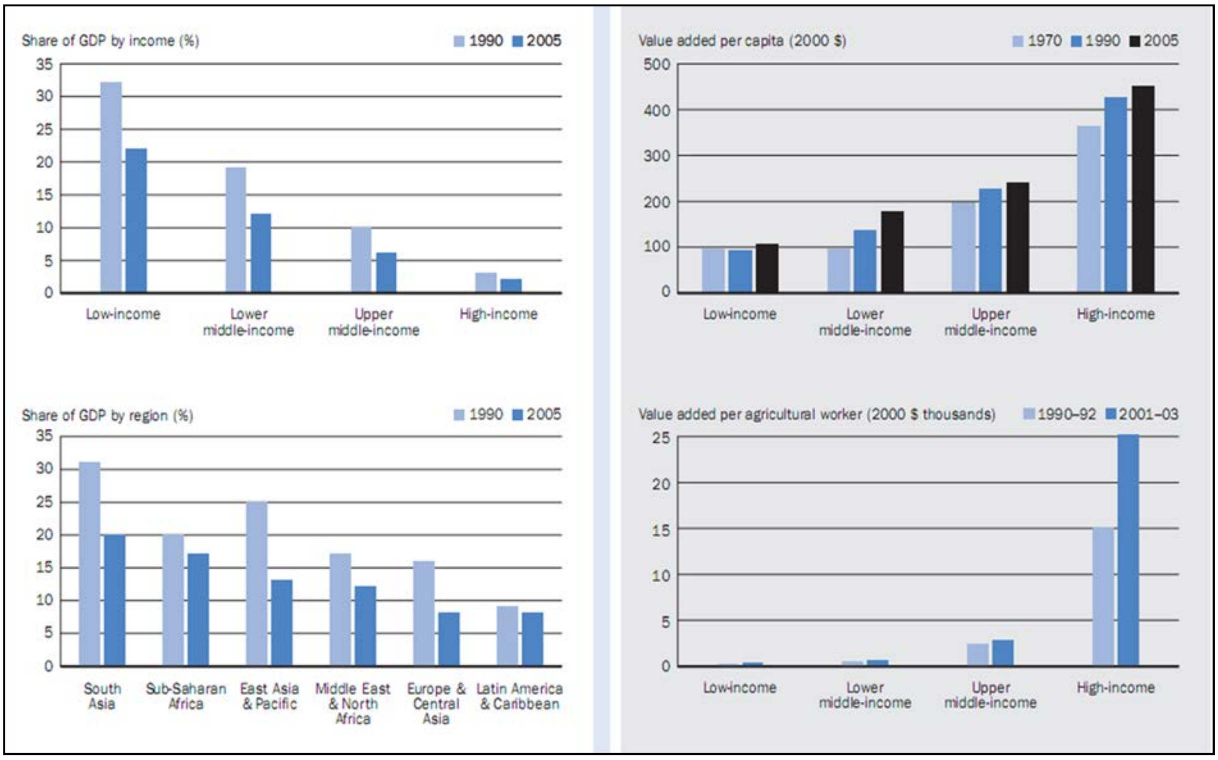

Figure 2.1: Agriculture's share in GDP (left graph) and agricultural productivity (right graph). *Source: World Bank (2007b)*

Figure 2.1 shows that the value added per capita by agricultural sector (four income groups: low-income, lower middle-income, upper-middle income, and high income) climbed steadily between 1970 and 2005. Value added per agricultural worker also increased between 1990-1992 and 2001-2003, especially for the high-income group. While, despite the share of the GDP by region, and by income, being vital, it fell slightly between 1990 and 2005.

In recent years, the world agricultural production fluctuated, and faced difficulties because of the financial crisis and climate change (World Bank, 2008b). Statistics from the FAO (2008c) on the index of total agricultural production between 1990 and 2006 showed that, the output for the whole world, and most country groups, rose, except developed countries, where output has been flat during most of the period (Figure 2.2). In per capita terms, the world's output levelled off after year 2004, and declined in the least-developed countries in 2006 after nearly a decade of modest growth.

Between 1980 and 2004, the GDP of agricultural sector expanded globally by an average of 2.0% per year, it is more than the population growth of 1.6% per year. This growth is the result of increasing productivity pushing down the real price of grains in world markets by about 1.8% a year over the same period (World Bank, 2008a).

The developing countries achieved agricultural growth (2.6% a year) much faster than industrial countries (0.9% a year) in 1980-2004. Actually, developing countries accounted for 79% of the overall agricultural growth during this period. Their share of world agricultural GDP, rose from 56% in 1980 to 65% in 2004. By contrast, they accounted for only 21% of non-agricultural GDP in 2004 (World Bank, 2008a).

The transforming economies in Asia accounted for two-thirds of the developing world's agricultural growth. The major contributor to growth in Asia and the developing world in general was productivity gains, rather than expansion of land devoted to agriculture.

Cereal yields in East Asia rose by 2.8% a year in 1961-2004, much more than the 1.8% growth in industrial countries (Figure 2.3). Due to rising productivity, prices have been declining for cereals, especially for rice, the developing world's major food staple, and for traditional developing-world export products, such as cotton and coffee.

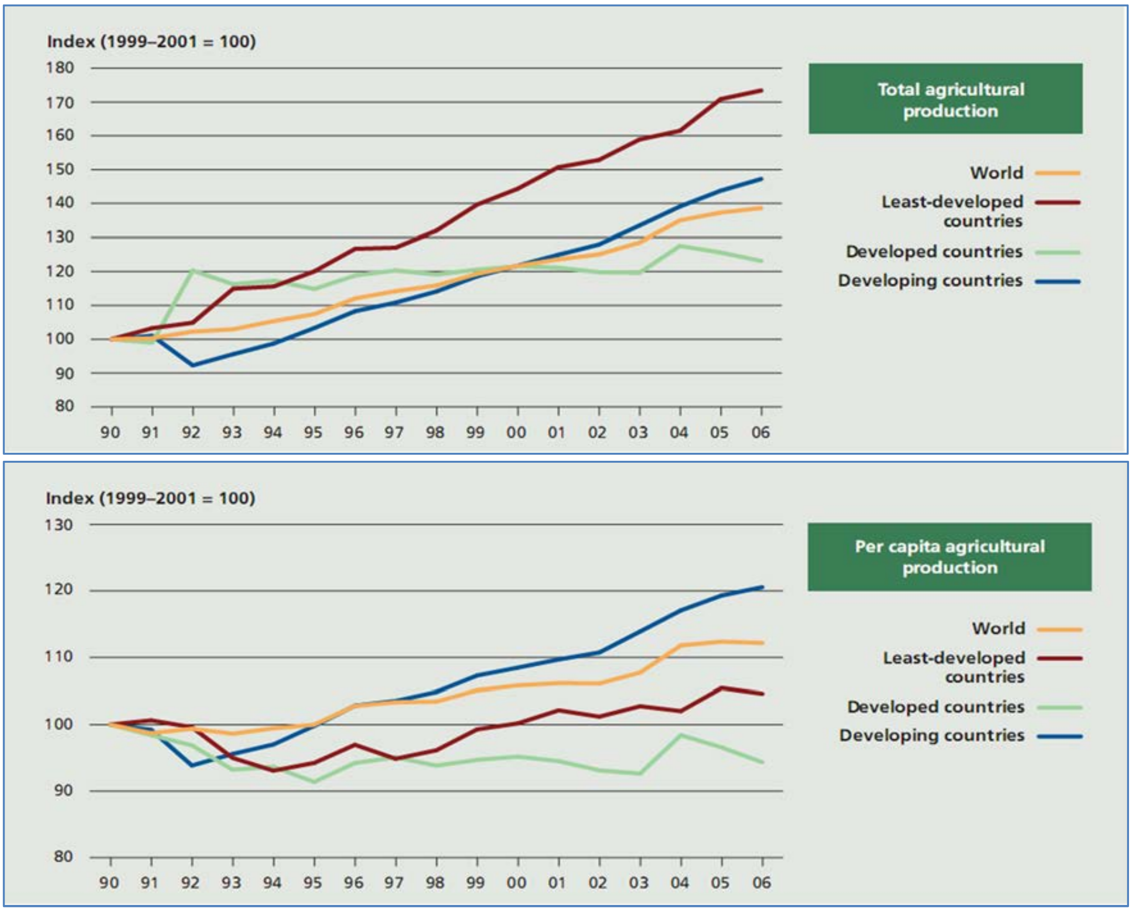

Figure 2.2: Agricultural production indices, total and per capita. *Source: FAO (2008c)*

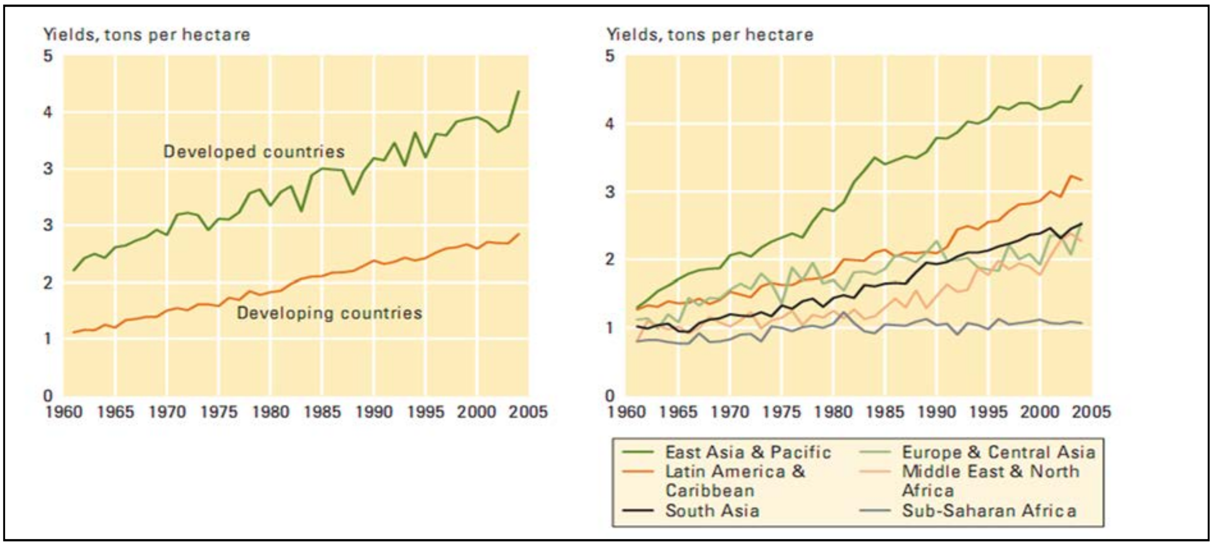

Figure 2.3: Cereal yields in developed and developing countries 1960-2005

Source: FAO (2006b)

2.2.2 Job opportunities and income generation for rural inhabitants

Agriculture is a major source of income and employment for more than the 70% of the world's poor in rural areas. It provides job opportunities for 1.3 billion small landholders and landless workers and forms a foundation for viable rural communities (World Bank, 2008a); and employs 50% of the labour force in the transforming economies of Asia, mainly China, India and Indonesia, and 65% of the labour force of agriculture-based countries (World Bank, 2008a; FAO, 2008a).

The reports "Agriculture for Development" (World Bank, 2008a), and "State of Food and Agriculture-BIOFUELS: prospects, risks and opportunities" (FAO, 2008a) reveal that there are about 5.5 billion people in the developing world, nearly half (3 billion) live in rural areas and, of these rural inhabitants an estimated 2.5 billion are involved in agriculture, and 1.5 billion are in small land holder households.

Agriculture has been the backbone of many rural societies providing employment for the labour force. Labour productivity growth in agriculture impacts upon the level of employment and hence it is a concern in agriculture-based countries.

The Annual Growth Rate (AGR) (Figure 2.4) in agricultural employment of agriculture-based economies (1.79%) is higher than transforming (0.65%) and urbanised economies (-0.63%). This confirms that the agricultural sector is a generous employer of agricultural workers in agriculture-based economies. It is more significant for the economically poor, highly populated countries, where itinerant and abundant labour are always available (FAO, 2006a; World Bank, 2008a).

The AGR in non-agricultural employment in agriculture-based (4.39%) and transforming countries (3.16%) is higher than urbanized countries' (1.96%); also the AGR in non-agricultural labour productivity of transforming countries (3.68%) is larger than agriculture-based (-1.01%) and urbanized countries' (0.55%).

This could be due to the three country groups trying to improve labour productivity while converting the labour force from agriculture to non-agriculture. However, the labour productivity improvement in the non-agriculture sector in transforming countries is greater than the other two categorises of country.

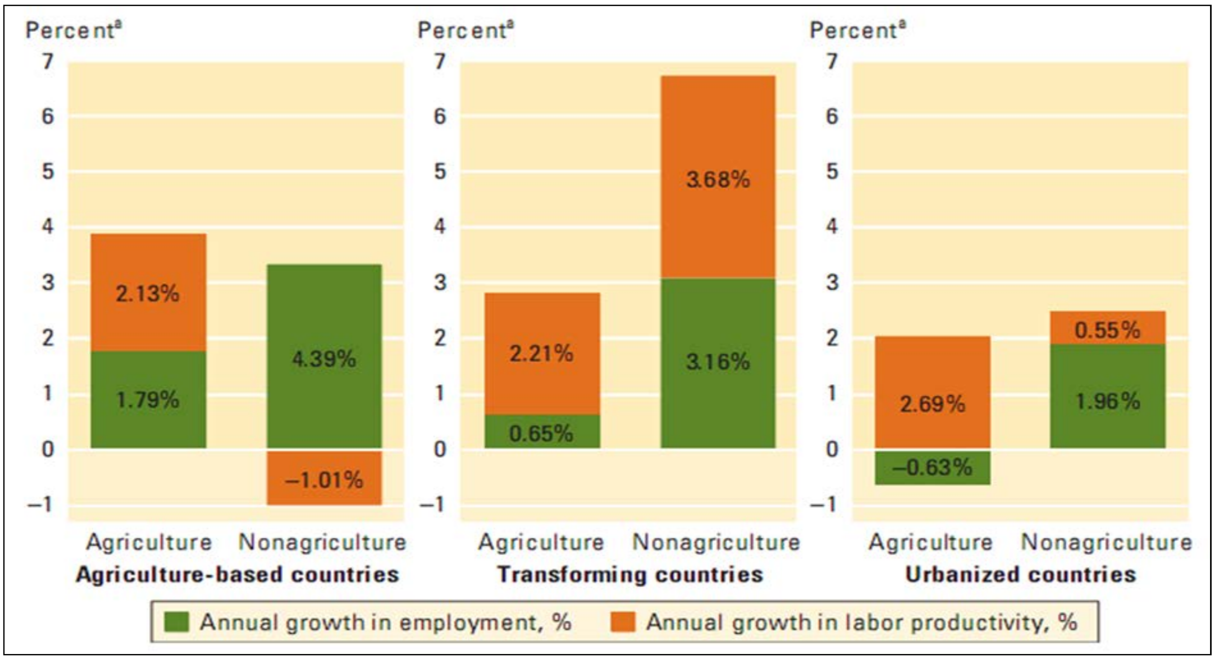

Figure 2.4: Annual growth in employment and labour productivity, 1993-2005

Source: FAO (2006b)

In a study into the impact of income type on wealth it was revealed that the poorest section showed income from on-farm activity where agricultural wages typically accounted for a larger share of the total household income, ranging from 59% in Guatemala in 2000 to around 65% in Viet Nam, and approximately 77% in Ghana in 1998 (Figure 2.5).

Consistently, the income source from on-farm activities, in the four countries presented in Figure 2.5 dominates the poorest section, whilst, the main income source of the richest section has come from non-agricultural activities. The older agriculture-based economies consist of a labour force that does not have the skills, techniques, opportunities, or accessibility for recruitment into the non-agricultural sectors. They remain employed in the agricultural sector to earn an income. By contributing approximately 56% (Viet Nam, in 1998) and 76% (Ghana, in 1998) to the income source, agriculture is still a valuable source of income for the poorest section in agriculture-based countries.

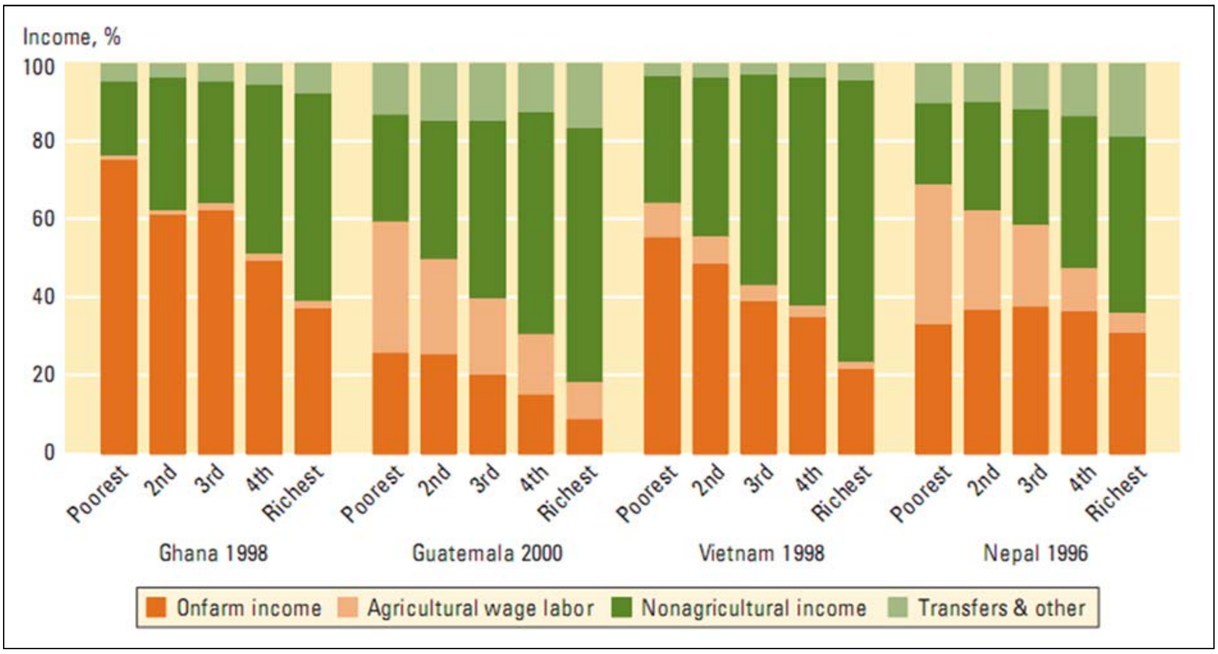

Figure 2.5: Impact of sources of income on developing countries

Source: Davis et al. (2007)

In many countries, approximately 60-90% of rural households have income sources in the agricultural sector and its services. Figure 2.6 indicates that, from the late 1990s and early 21st century there is a large population in the developing world participating in agriculture. Participation in agriculture for rural households in Malawi in 2004, Nepal in 1996, Viet Nam in 1998, Albania in 2005, and Nicagarua in 2001 is more than 90%.

As a result, the most significant income share for rural households is from agriculture. Farm crop and livestock income together with agricultural salaries contributes between 55 and 75% to rural income in agriculture-based countries, such as those in Sub-Saharan Africa. While, the income share for agriculture in several countries in South Asia, East Asia and the Pacific, Europe and Central Asia, and Latin America and Caribbean fluctuates in a range of 28% (Indonesia in 2000) to 52% (Nepal in 1996). This status impresses the importance of agriculture to inhabitants in rural areas in terms of survival.

However, participating in agricultural activities does not always give high agricultural income, because both self-consumption and sales of agricultural products to the market are counted as on-farm income (World Bank, 2008a).

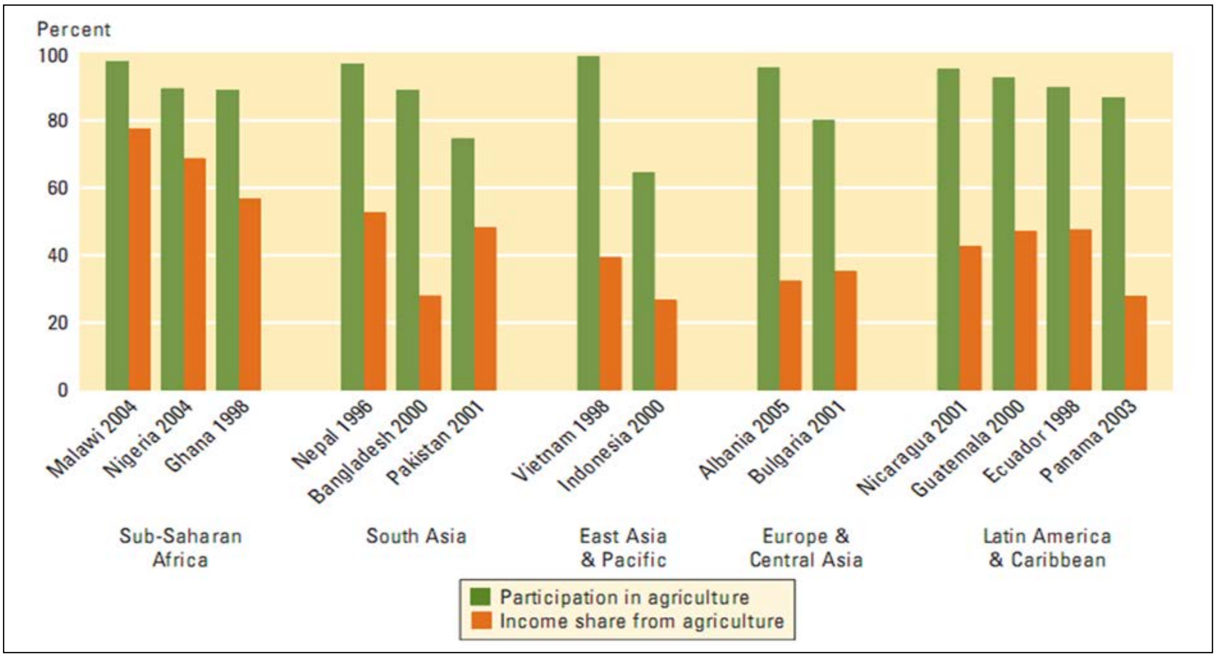

Figure 2.6: Percentage of rural households participating in agriculture

Source: Davis et al. (2007)

In Asia, Latin America, and some countries in Africa (Malawi and Nigeria), agricultural income is much more important for low-income household when compared with richer income households (World Bank, 2008a). The recent decline in poverty, with low income in developing countries falling from 28% in 1993 to 22% in 2002, has been mainly due to falling rural poverty (from 37% to 29%) precipitated by agricultural growth (World Bank, 2008a).

2.2.3 Hunger elimination and poverty reduction

The agricultural sector has an important responsibility for food security. The majority of poor people in the rural areas base their meal source on the produce from their farms. Studies on the Green Revolution illustrate that, technological innovation has dramatically reduced poverty, although agricultural production, particularly cereal production has declined slightly in recent years (Figure 2.7, FAO, 2009b).

Agricultural innovation has allowed millions of people to escape poverty by generating much more income opportunities not only for farmers, but also for farm labourers, and other farming providers of goods and services, and by reducing prices for consumers (FAO, 2004a).

In China and India, agricultural development has historically been one of the most effective solutions for poverty reduction through government spending (Fan, 2002). This situation is also found to be the case in Uganda (Fan *et al.*, 2004).

Figure 2.7: World Cereal production, utilisation and stocks. *Source: FAO (2009b)*

In developing countries, nearly 830 million people live in rural areas and their livelihood mostly rely on agriculture. Hence, a more dynamic and inclusive agricultural sector could dramatically reduce rural poverty, helping to meet the Millennium Development Goals[5] on poverty and hunger (World Bank, 2008a).

There are many examples of agriculture being used as an efficient way to reduce poverty. Most recently, China, India, and Viet Nam's rapid growth in agriculture, thanks to responsible farming, the liberalization of markets, and rapid technological change, has been largely responsible for the decline in rural poverty from 53% in 1981 to 8% in 2001 (World Bank, 2008a).

[5] *The Millennium Development Goals (MDGs) are eight international development goals that 192 United Nations member states and at least 23 international organizations have agreed to achieve by the year 2015. They include reducing extreme poverty, reducing child mortality rates, fighting disease epidemics such as AIDS, and developing a global partnership for development.*

In other words, changes of policies, introduction of advanced technologies, and the application of new promising crop varieties in agriculture, have opened the way for the agricultural sector to address food security and poverty reduction that have been problems for a long time. Land policy reform in China in 1978, Viet Nam in 1986, and the introduction of semi-dwarf varieties of wheat and rice in the Green Revolution (1960s and 1970s) in India are evidence of these changes. In research relating to agriculture and poverty, Ravallion and Chen (2007) indicate that poverty overall in China dropped from 53% in 1981 to 8% in 2001, pulling about 500 million people out of poverty.

In China, rural poverty decreased from 76% in 1980 to 12% in 2001, accounting for three-quarters of the total (Figure 2.8). The sharp decline in poverty from 1981 to 1985 was spurred by agricultural reforms that started in 1978. The role of agricultural growth in poverty reduction remained important in subsequent years (World Bank, 2008a). Inspecting the entire period, Ravallion and Chen (2007) concluded that growth in agriculture did more to reduce poverty than did either industry or services.

Similarly, success in poverty reduction by agricultural growth has been recorded in many agricultural countries in Sub-Saharan Africa, developing countries in Asia, and transforming countries as well (World Bank, 2008a). Recent studies show that there is a close correlation between agricultural growth and poverty reduction in South Asia (Ravallion and Chen, 2004; World Bank, 2006b). Typically, the increased yield of approximately 1 ton of cereal from 1984 to 2002 (left axis of Figure 2.9), has resulted in a reduction of nearly 15% in poverty (right axis of Figure 2.9).

Studies into the roles of agriculture (FAO, 2004b; FAO, 2007a) identified four main channels for agricultural growth that can alleviate poverty: (i) directly raising incomes; (ii) reducing food prices; (iii) raising employment; and (iv) through higher real wages. Land distribution is very important for the first channel; a more equitable land distribution leads to a more equal distribution of agricultural growth benefits (Lopez, 2007). Similarly, the wage and employment channels are more effective when labour markets between urban and rural areas are closely combined (Anríquez and López, 2007).

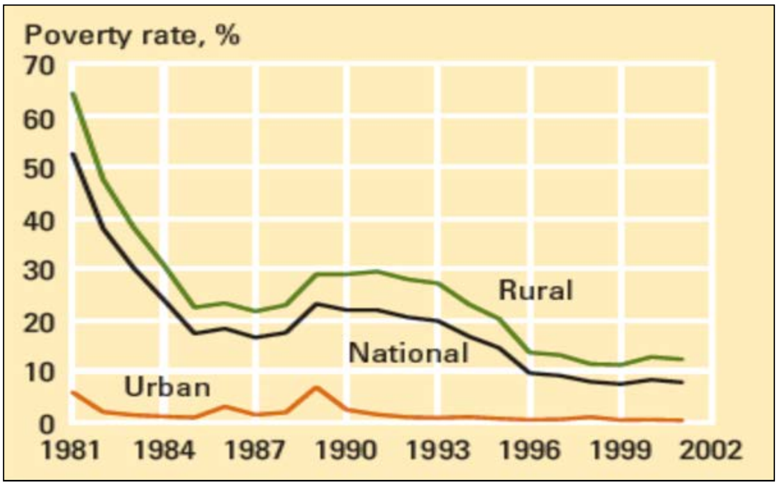

Figure 2.8: Poverty rate between 1981 and 2002 in China. *Source: Ravallion and Chen (2007)*

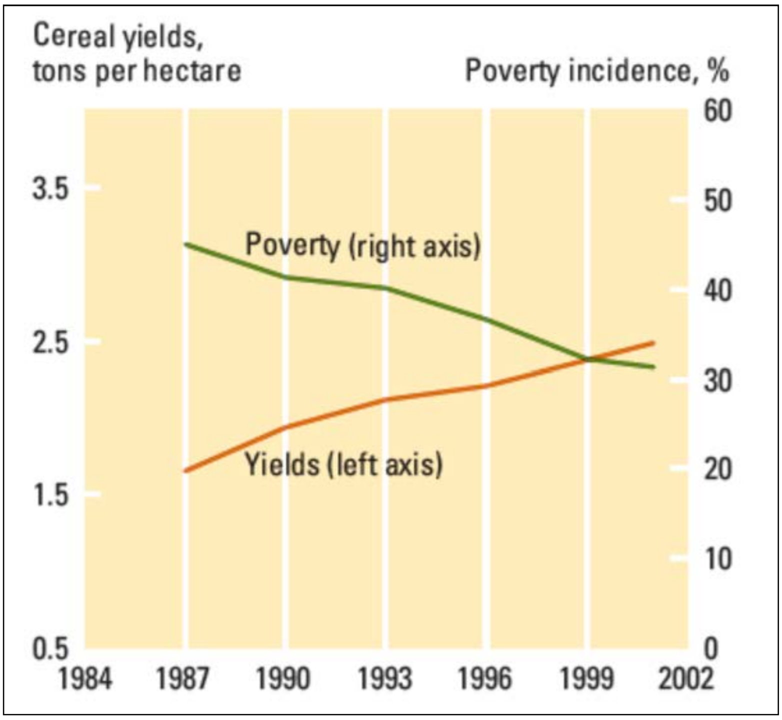

Figure 2.9: Cereal yields compared to poverty in South Asia

Source: Ravallion and Chen (2004) and World Bank (2006b)

With the role of agriculture being extremely important, in recent years official development assistance to agriculture has been increased. The private donors and foundations (e.g. the Gates Foundation) are identifying concerns, and transferring their resources to agriculture. Major multilateral donors, for example the World Bank, are also looking at agriculture as an engine for poverty reduction in most developing countries and regions, and as a fundamental component of a growth and poverty reduction strategy for the poorest, and agriculture-based economies (FAO, 2008b).

In addition, agriculture is a provider of environmental services. Indeed, agriculture can create good and bad environmental outcomes based upon the use of natural resources by humans. The agricultural industry is the largest user of water, contributing to water scarcity, underground water depletion, agrochemical pollution, soil exhaustion, and global climate change. However, agriculture is also a major provider of environmental services indicated by sequestering carbon, managing watersheds, and preserving biodiversity (World Bank, 2008a).

2.3 Agriculture's contributions to socio-economic development: Asian context

The generally key contributions of agriculture to socio-economic development have been discussed in the previous section in the global context. In the Asian context only the typical roles of agriculture in Asia are discussed.

2.3.1 Diet improvement

In Asia, and the Pacific region, agriculture has an important role to play in reducing the incidence of poverty (UNESCAP, 2007). The Green Revolution in the 1980s, associated with later changes in agricultural policies, generated significant advances in the agricultural development of Asian countries. Thanks to this development, many developing countries, such as Viet Nam and Thailand, escaped poverty to become the main rice exporters for the world's rice consumers (World Bank, 2008a).

In Asia, agriculture not only generates agricultural products to meet the food demands of local inhabitants, it also provides a basic livelihood for them to earn and improve their income. In recent years, it has led to dramatic changes in dietary patterns in the region, by replacing traditional carbohydrate-dominated diets (cereals-based) with distinctly healthier, and protein content diets (animal and fish protein diets) (FAO, 2008b).

When hunger and poverty are addressed and household income is improved, humans will have time to focus on their life quality. Dietary change for the poor in Asian countries between 1995 and 2005 is one aspect of this change. In 1995, most inhabitants in Asia's poor countries relied on rice and wheat as their main diets. At that time hunger and poverty were two hardships people had to constantly contend with. In 2005, residents in those countries improved their quality of life by changing their diet to include the consumption of more animal proteins (e.g. fish, pork, chicken), rather than carbohydrate (rice) or vegetable proteins (Figure 2.10a, 2.10b, 2.10c, 2.10d). The relevant reason for this is the achievements in agricultural growth. Increased food security and an increase in income allowed poor farmers to improve their life quality by diversifying their diet.

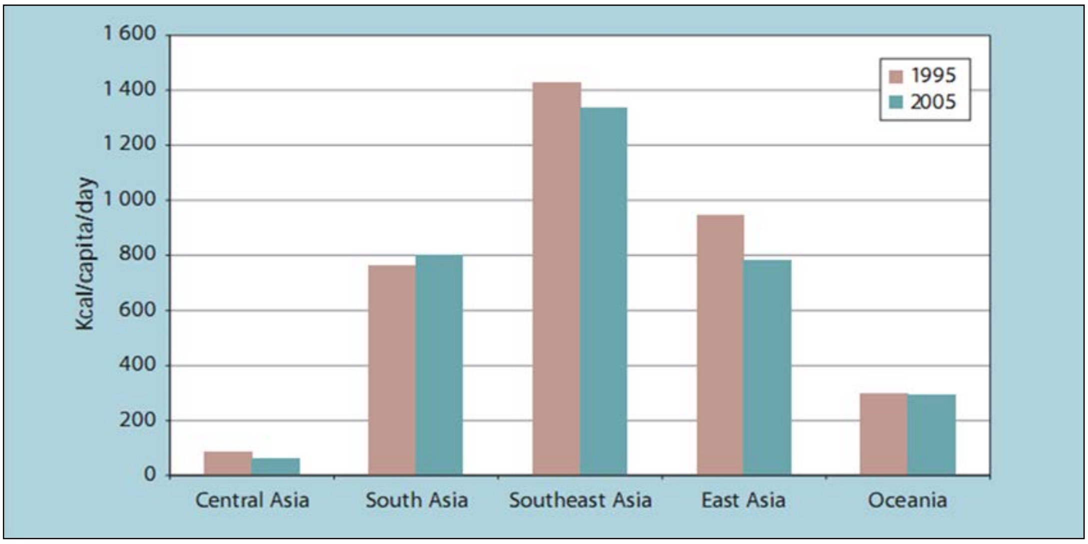

Figure 2.10a: Consumption of rice in Asia, 1995 compared to 2005. *Source: FAO (2008b)*

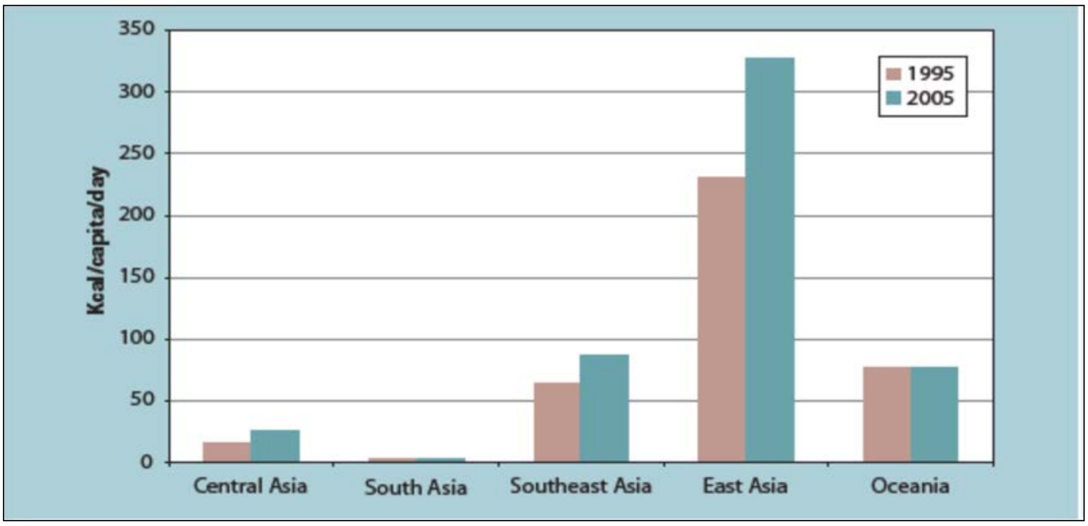

Figure 2.10b: Consumption of pork in Asia, 1995 compared to 2005. *Source: FAO (2008b)*

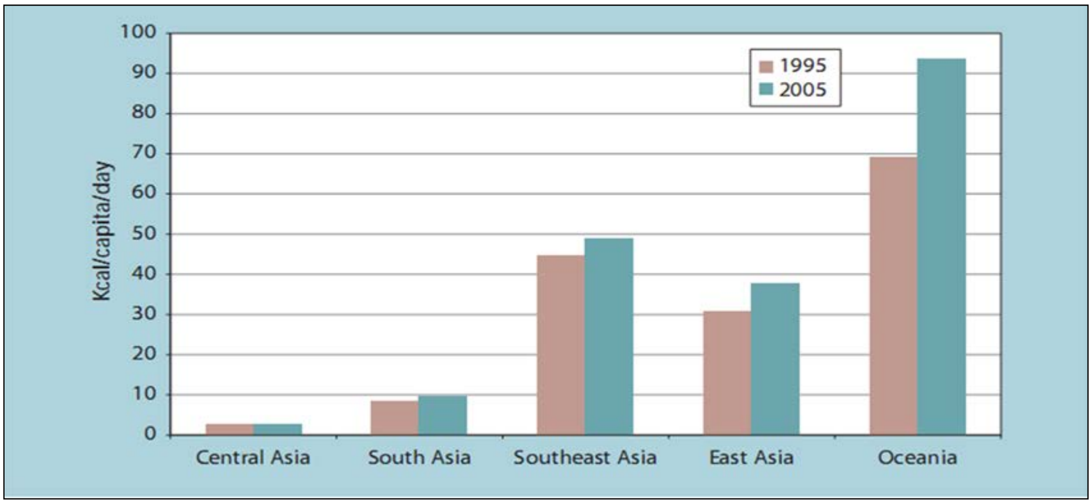

Figure 2.10c: Consumption of fish in Asia, 1995 compared to 2005. *Source: FAO (2008b)*

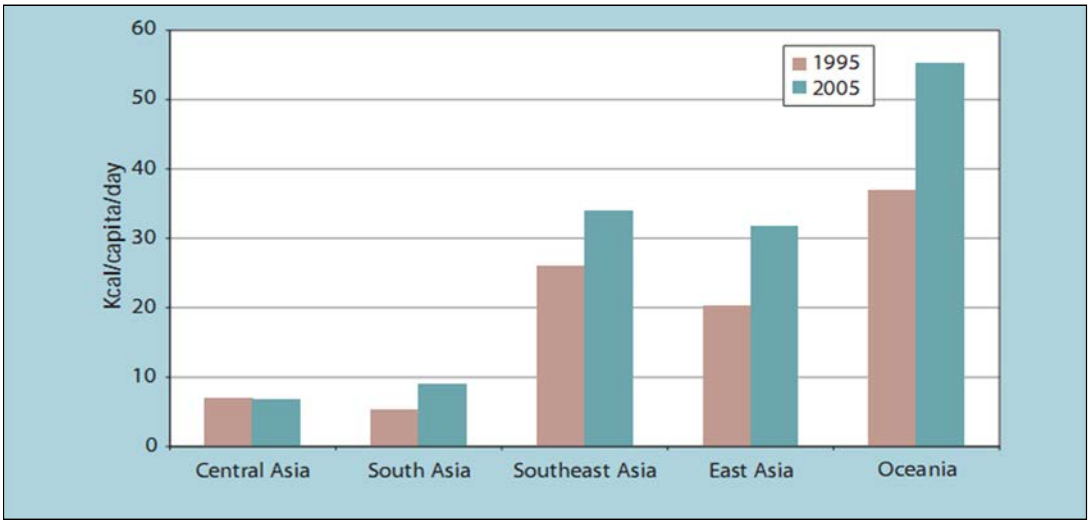

Figure 2.10d: Consumption of chicken in Asia, 1995 compared to 2005. *Source: FAO (2008b)*

2.3.2 Contributing to export value and socio-economic development

Currently, agriculture in the Asian and the Pacific region is steadily shifting to product commercialization and diversification. This differs from the previous focus which was cereal crops production, e.g. rice (FAO, 2008b). Thus, agriculture now has strong links with other sectors leading to an increase in economic activity and employment opportunities in rural areas (Anríquez and Stamoulis, 2007), as well as earning foreign currency by exporting agricultural outputs (Figure 2.11, FAO, 2009a).

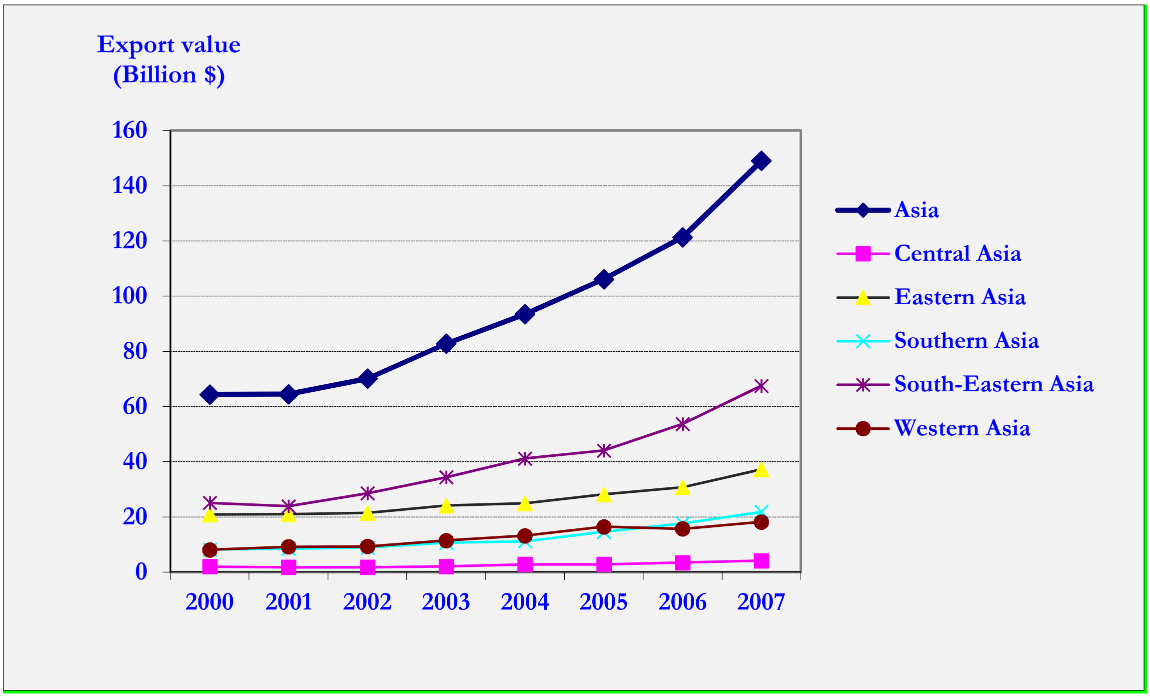

Figure 2.11: Agricultural export value in Asia between 2000 and 2007

Source: FAO (2009a), compiled by the Author

According to estimates from the FAO (2009a), the export of agricultural products in Asia increased significantly between 2000 and 2007. In 2000, the export value was 64 USD billion; it then increased steadily to peak at 149 USD billion in 2007. Typically, in South-Eastern Asia (e.g. Thailand, Viet Nam), the export value rose considerably from 25 USD billion in 2000 to reach 68 USD billion in 2007. Hence, agriculture not only contributes to the export value of Asian countries, but it also is a major contributor to the economic growth of the region.

The increase in the value of exports has allowed Asian countries to re-invest in agriculture. This is extremely beneficial since in a long-term economic development strategy, agriculture is one of most important sectors for the economic growth of Asian countries. Agricultural development is seen as a priority. An indicator is that the import value for agricultural investment in Asian has increased gradually over the period 2000 to 2007. In 2000, the agricultural import value in Asia was approximately 124 USD billion and it climbed up to 238 USD billion in 2007 (Figure 2.12, FAO, 2009a).

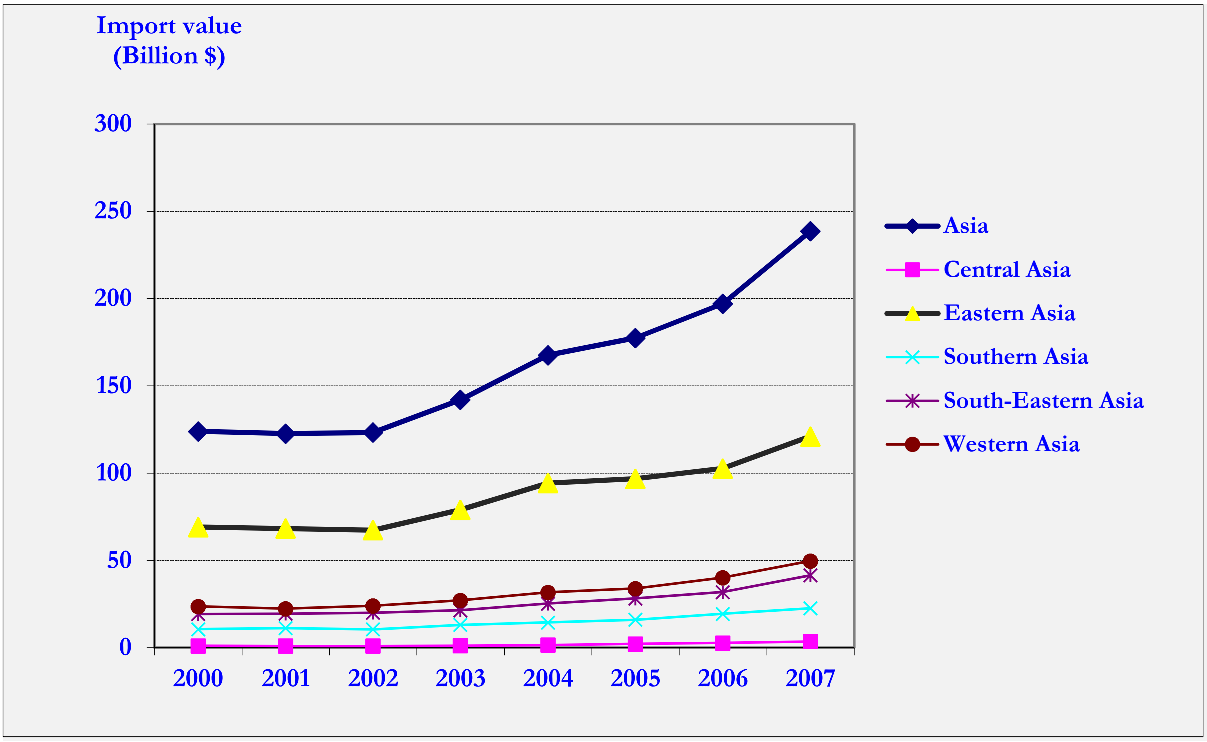

Figure 2.12: Agricultural import value (1000$) in Asia between 2000 and 2007

Source: FAO (2009a), compiled by the Author

Agricultural materials dominate a large part of the import value. Market materials are primarily fertilizers, pesticides (insecticides, fungicides, and herbicides), seeds, machines, and many facilities serving agricultural production. The export and import value of agriculture is extremely high in Asia, indicating that agriculture has a substantial role in Asia.

At the same time, there is an increased interest from domestic and foreign firms (including multi-national agro-industrial firms) for investment (upstream and downstream) in the agricultural sector. The potential of agriculture as a source of bio-energy has added attractiveness to the sector given its perceived ability to address global food and energy needs simultaneously (FAO, 2008b). When the agricultural economy develops, it obviously generates many more job opportunities for farmers, producers, and offers services for workers and others as well. It directly, or indirectly, provides an income source, helping inhabitants to diversify their income.

The recent research results of Davis *et al.* (2007) indicate that income diversification by rural households is apparent in Asia. Households in the lower income categories still derive a larger share of their total income from agriculture compared to households in higher income groups. This suggests the need to accord continued attention, and increased resource allocation, to the agriculture sector over the long term (FAO, 2008b).

2.4 Agriculture's contributions to socio-economic development: Viet Nam context

Viet Nam has made incredible achievements in agricultural growth over the past decades. Viet Nam is also where the case study site for this research is located. Today, Viet Nam is one of the top three world rice exporters, and it is one of the world's primary agricultural producers. In order to explore the role of agriculture in the research site, in Viet Nam, a brief introduction to the agricultural history of Viet Nam needs to be provided prior to a discussion of the role of agriculture.

2.4.1 Brief introduction to the Viet Nam agricultural history

For Viet Nam, agriculture has been the main sector in the national economy for many decades. The impressive milestone for Viet Nam agriculture could be highlighted by the sixth Party Congress of the Communist Party in 1986, which designed an economic re-direction, announcing its program of innovation (Doi Moi), first in agriculture. A range of agricultural policies have been launched such as the upgraded "Contract 100" to "complete contract to household"[(6)]; accelerating the first Foreign Investment Law Open-door policy; enacting Land Law, which established agricultural land-use rights; introducing a more market-determined exchange rate in 1987. It identified that the responsibility of Viet Nam agriculture between 1986 and 1988 was "overcoming poverty".

On the 5th April, 1998, Resolution 10, with the content of reforming the management of Viet Nam agricultural economy, had been promulgated; launching the Doi Moi reform process, a breakthrough in economic development thinking, promoting a

[6] *Under "contract 100", farmers were entitled to be master of three production stages (planting, caring and harvesting), others stages (land use, crop choice, land preparation, irrigation, and input supply) were still under the cooperative's control; contract level was not stable and subject to be adjusted every crop and year (individual household got only 20% of contracted output) (De, 2005).*

multi-sector economy with the leading role of the state sector, and starting the transition to a market economy with state management (De, 2005).

These initiatives have a distinct impact on agriculture in Viet Nam by encouraging farmers to take more control into decision making relating to their farm production and main inputs as well. As a result, Viet Nam agriculture improved markedly. Yields and the quantity of crops increased and the number of animals also increased. Local inhabitants prospered with more food being available and with an increased income.

Unfortunately, unfavourable weather in 1987 brought about a huge loss of harvest; food output was 1 million tons lower than that of 1986. Viet Nam suffered an on-going food shortage, borrowing around 800,000 tons of food and importing 322,500 tons of rice (Son *et al.*, 2006).

Later, in the period 1989 – 2000, Viet Nam agriculture changed to extensive commercial and export-oriented production. Agricultural in Viet Nam had been influenced by the open economic policy through the liberalization of domestic and foreign trade of agricultural products in general and rice in particular.

Subsequently, the gap between international and domestic prices of agricultural output narrowed significantly, this led to improvement of farmers' income. In 1989, food output increased dramatically to more than 21 million tons, food output per capita recovered to 300 kg and this year was the first year that Viet Nam exported rice after a long time of being a net rice importer.

From this time, agricultural output increased 1 million ton annually and the rice export volume kept increasing. In three years, from 1988 to 1991, the rice area expanded by nearly 10%, from 5,726,400 to 6,302,700 ha; rice output climbed up from 17 to 19.6 million tons. Since 1990, Viet Nam has become the world's third largest rice exporter, with the export volume of 1.5 million tons (GSO, 2001; Son *et al.*, 2006).

During this early phase of development the agriculture sector faced new opportunities. The fact that farmers could make their own plan for using their land, and other inputs in production together with trade liberalization, created favourable conditions for commercial agriculture production, to meet both domestic and export demand.

Government investment in the agriculture sector accelerated absolutely, the investment amount was increased from 3,495 to 3,712 and then 4,591 billion VND in 1995, 1997, and in 1998. Investment in agriculture and rural development was 25% of the state budget in 2000, being more than 10 thousand billion VND.

The 1990s became the critical period of agriculture development in Viet Nam, as the sector switched from self-sufficiency to commercial production. In ten consecutive years since 1989, annual agriculture growth rate was 4.3 % on average. The sector development has been relatively comprehensive and sustainable.

Productivity of many crops and animal husbandry increased: rice went up 33%, coffee 6-7 times, rubber 2 times, pig 27%. Food had been secured. Before 1989, Viet Nam had to import 0.6 to 1 million tons of food annually. Since 1989, Viet Nam has turned to be a rice exporter with the record of 4.5 million tons per year in 1999. In 2000, the total food output was 35.64 rice-equivalent million tons (Son *et al.*, 2006; GSO, 2003).

Under the development trend towards commercial production, many specialized production zones developed, such as intensive rice areas in the Mekong Delta (MD) and the Red River Delta; coffee areas in the Central Highlands and South East; tea areas in the North East and North West; rubber areas in the South East; fruit areas in the South East, MD, and some provinces in the North; vegetable areas in the Lam Dong province and Red River Delta; sugarcane areas in the Central area and the South.

Many commodities have a high rate of export in total output, for example coffee 95%, cashew nut 100%, rubber 80-85%, pepper 90%, tea 50%. In 1999, the share of the commercial product in total agricultural output reached over 40%. Agricultural export value accounted for 38-40% of the national annual export turnover (Son *et al.*, 2006).

The stage of intensive development from 2000 to the present has meant that Viet Nam agriculture is shifting to intensive production with the goal of higher productivity and quality, focusing on effectiveness, job generation and income improvement. Reduced production costs, upgraded of the quality of products, and production at an industrial scale to compete, was the trend for agricultural development in this period.

Today, the current responsibility of Viet Nam agriculture is to help her farmers to join in the environment of the World Trade Organization (WTO).

2.4.2 The roles of the agricultural sector

Presently, agriculture employs up to 50% of the labour force, shares approximately 20% of the total GDP (2008) and 16.6% of the export value (excluding aquatic products) and occupies up to 30% of the national land area (Figure 2.13a and 2.13b, GSO, 2008).

Agricultural production has grown 3.5-3.8% a year over the past years, in which food production and paddy production increased steadily (MARD, 2008). Despite offering lower income levels compared with other economic sectors in the national economy, agriculture contributes positively to the effective use of leisure time and added income diversification for farmers in Viet Nam, as well as reducing the poverty household rate in the whole of Viet Nam from 58% in 1993 to 14.8% in 2007 (MLWISW, 2008).

Agriculture generates job opportunities and decreases the unemployment rate sharply in rural areas (1.53% in 2008) compared with urban areas (4.65% in 2008) (GSO, 2008). Viet Nam is an agriculture-based country, with nearly two thirds of the population having lived in rural areas (Figure 2.14) with their livelihoods dependent directly or indirectly on agriculture. The main activity in Viet Nam's agricultural sector is production, not so much services.

Agricultural outputs are influenced by macro-policies, regional factors and global prices, and hence farmers' income usually fluctuates even though they gain high yields for agricultural products. Fortunately, due to the reasonable macro-economic management policy of the government, along with a change of the world's agricultural market, there has been a constant growth in the quantity and export value of agricultural products, particularly rice (Figure 2.15a, 2.15b).

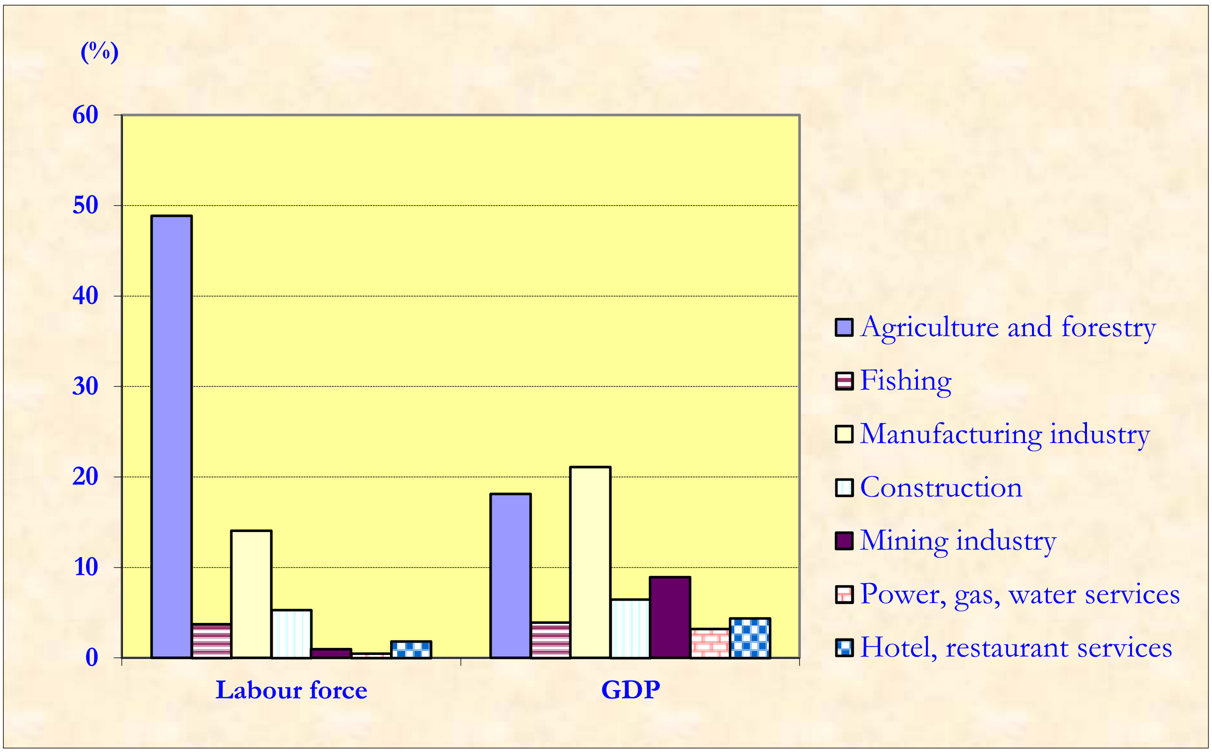

Figure 2.13a: Structure of employed population and GDP share by economic activity (%) in year 2008. *Source: GSO (2008), compiled by the Author*

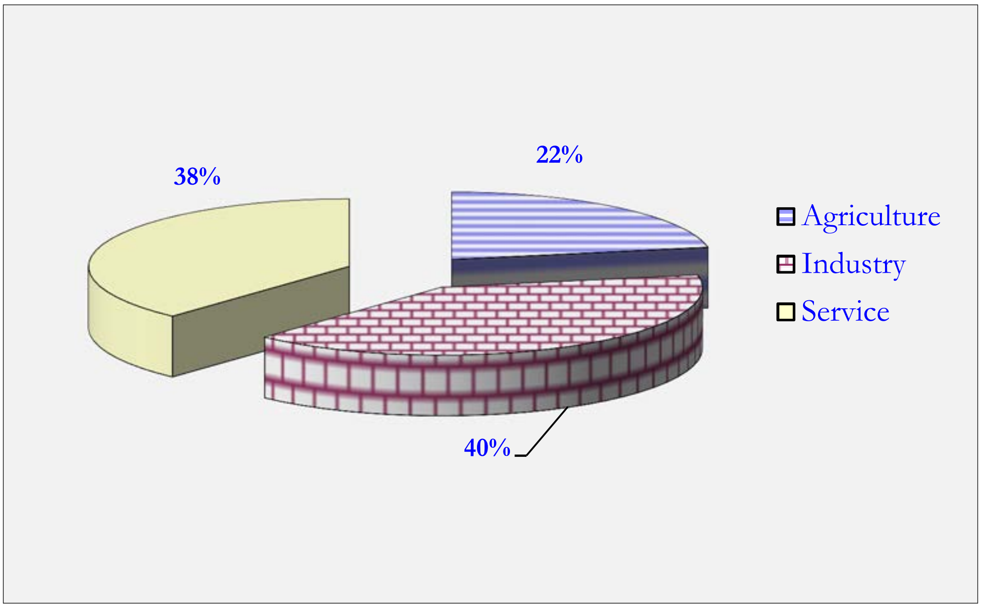

Figure 2.13b: Viet Nam GDP at current prices by economic sectors, 2008

Source: GSO (2008), compiled by the Author

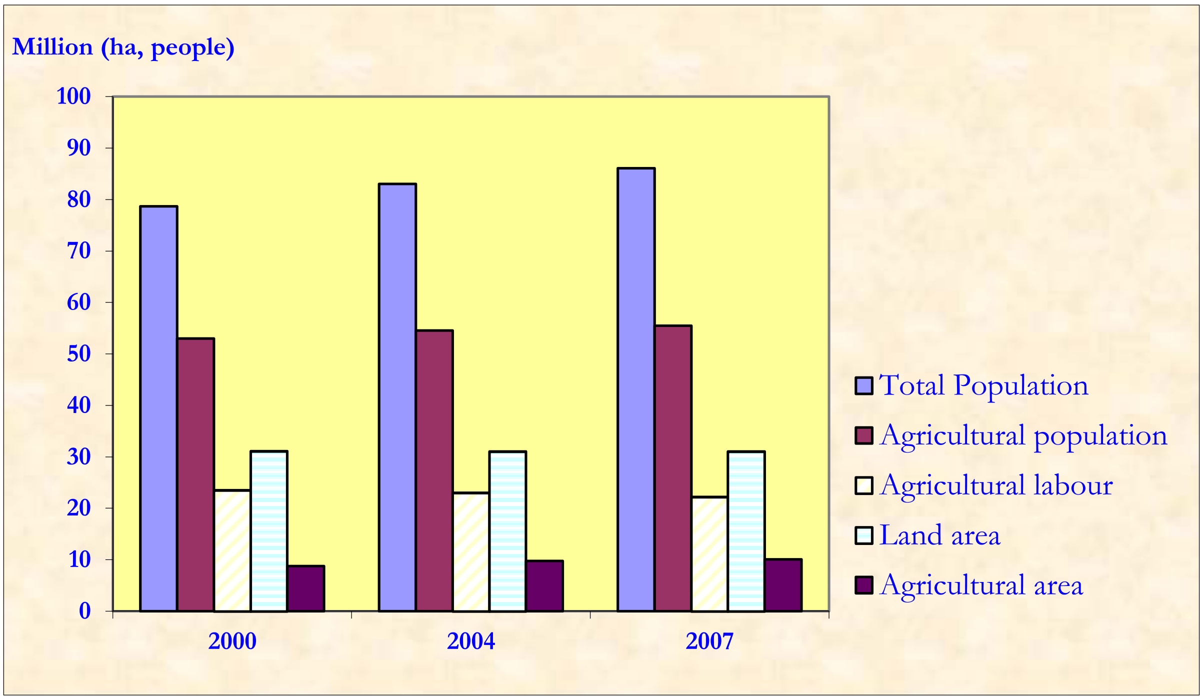

Figure 2.14: Several indicators in the agricultural sector of Viet Nam

Source: FAO (2009a) and GSO (2008), compiled by the Author

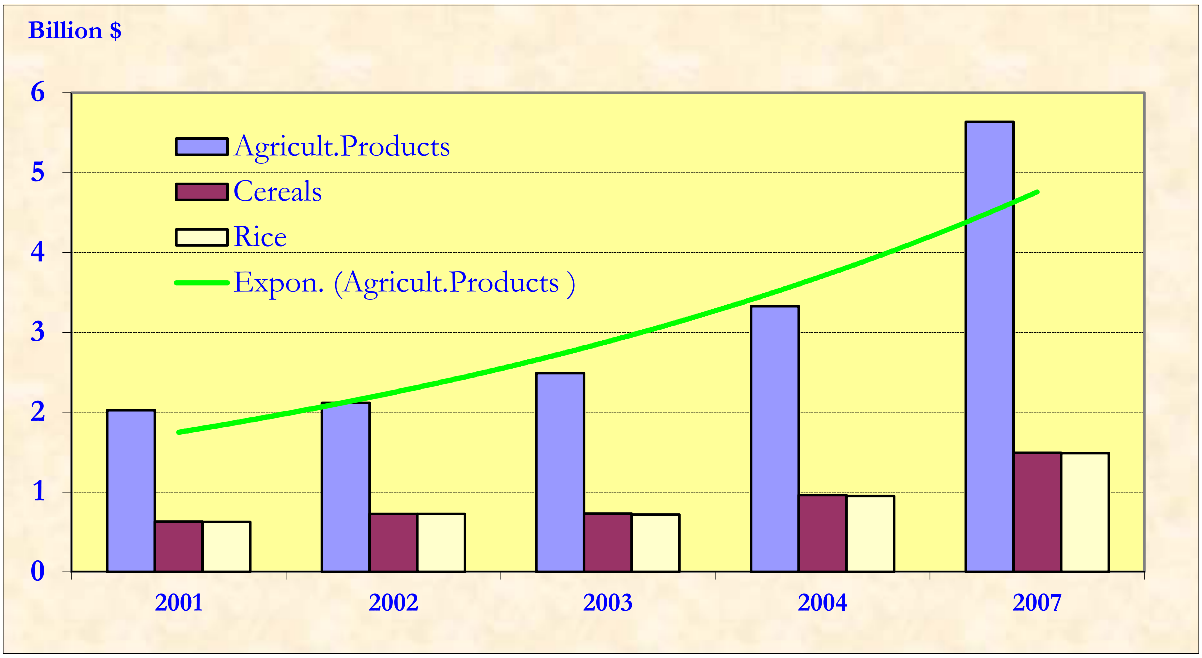

Figure 2.15a: Export value of the Viet Nam agricultural sector between 2000 and 2007

Source: FAO (2009a), compiled by the Author

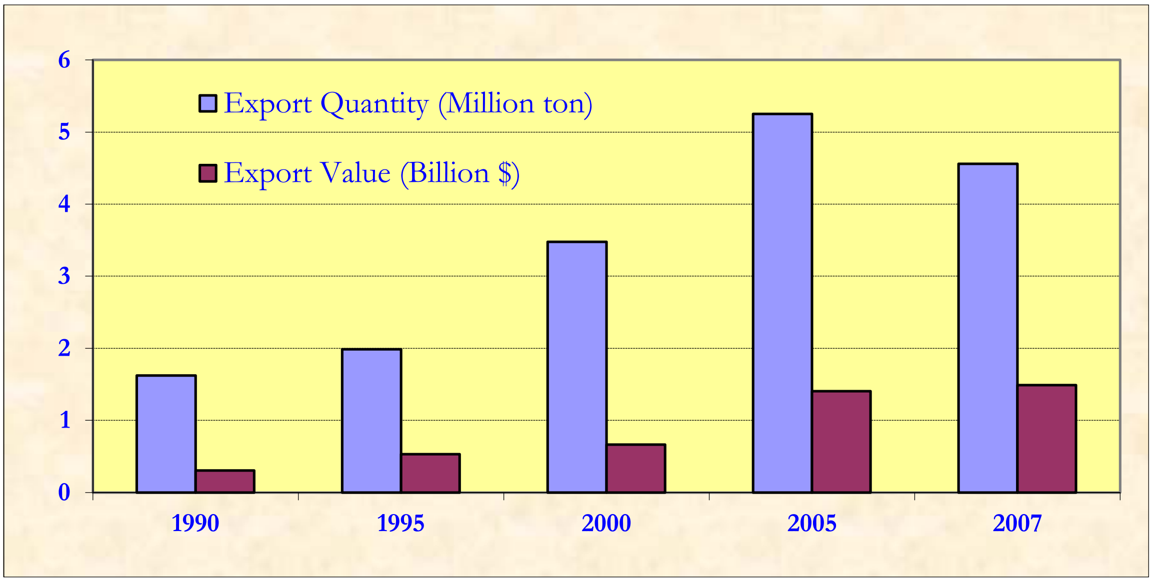

Figure 2.15b: Viet Nam rice export quantity and value, 1990 – 2007

Source: FAO (2009a), compiled by the Author

2.4.3 Investments in agriculture

Recently, recognition of the importance of agriculture in the national economic development, by the 10th Party Congress of the Central Politburo of Viet Nam communist party (18/4/2006-25/4/2006) has confirmed that "the strengthening of industrialization and the modernization of agriculture and the rural environment together can solve agricultural, farmer and rural problems". The congress impresses that, in the next 10-20 years, "the Viet Nam government will offer a priority investment for agriculture, farmer and rural issues". To consolidate the Resolution of the assembly above, the Viet Nam government has established a project named "Tam Nong-Agriculture, Farmer and Rural issue". The project was first developed in 2007 and adjusted until 2009, and then executed up to 2020.

The project objectives are to (1). Evaluate entirely the status of Viet Nam agriculture and the rural environment; (2). Create realistic goals for agriculture, farmers and rural issues and development indicators for 2020 and (3). Organize and conduct the project with the ultimate objective being "industrialization and modernization for agriculture and the rural environment focusing on orientations such as quantity, quality and diversity of goods; agriculture and rural development have sustainability, effectiveness, and high competitive capability" (IPSARD, 2007). Undoubtedly, these objectives show that agriculture is a core sector in Viet Nam's present economic development, as well as in its future outlook.

2.5 Agriculture's contributions to socio-economic development: Mekong Delta and the An Giang Province context

2.5.1 Mekong Delta context

The Mekong Delta is known as a main agricultural production area of Viet Nam. It generates agricultural products not only for Viet Nam, but also for many regions worldwide (e.g. rice export to African, catfish export to European, American).

Compared to other agro-ecological zones of the nation, the MD has natural conditions such as soil, water, and the topography that are more suitable for agricultural development. In this region, farmers can introduce diversified farming systems with high yield, and productivity of crops.

Beside traditional production systems, e.g. three rice crops per year, intensive cash crops, and industrial aquaculture, many integrated production patterns of rice-fish, rice-upland crop, or intercultural systems have also been developed, and are becoming more and more popular.

In 2008, agricultural gross output in the MD accounts for 33% of the national total. It plays an important role in the national GDP structure. The export value of rice in the MD is more than 80% of the national total, the quantity of fruits (e.g. mango, durian, citrus) and the export value of aquaculture make up around 70% of the national total. These contribute significantly to the national economic development (GSO, 2008).

In recent years, the importance and potential of agriculture in the MD have been recognized and exploited. For example, a thousand hectares of inundated waste land in the Long Xuyen Quadrangle region were converted to agricultural and aquaculture fields. More than 300,000ha of planted rice area with less economic efficiency were transferred to aquaculture and upland crop systems, which have higher net benefits. Such projects lift substantially the gross output of farming per hectare in the region (Long *et al.*, 2008).

Agricultural production systems, which oriented to a commercial and industrial scale, are performed in the MD. Nearly 50% of agricultural farms are located in the MD (Figure 2.16), and farmers can earn up to 600 USD per ha (2008).

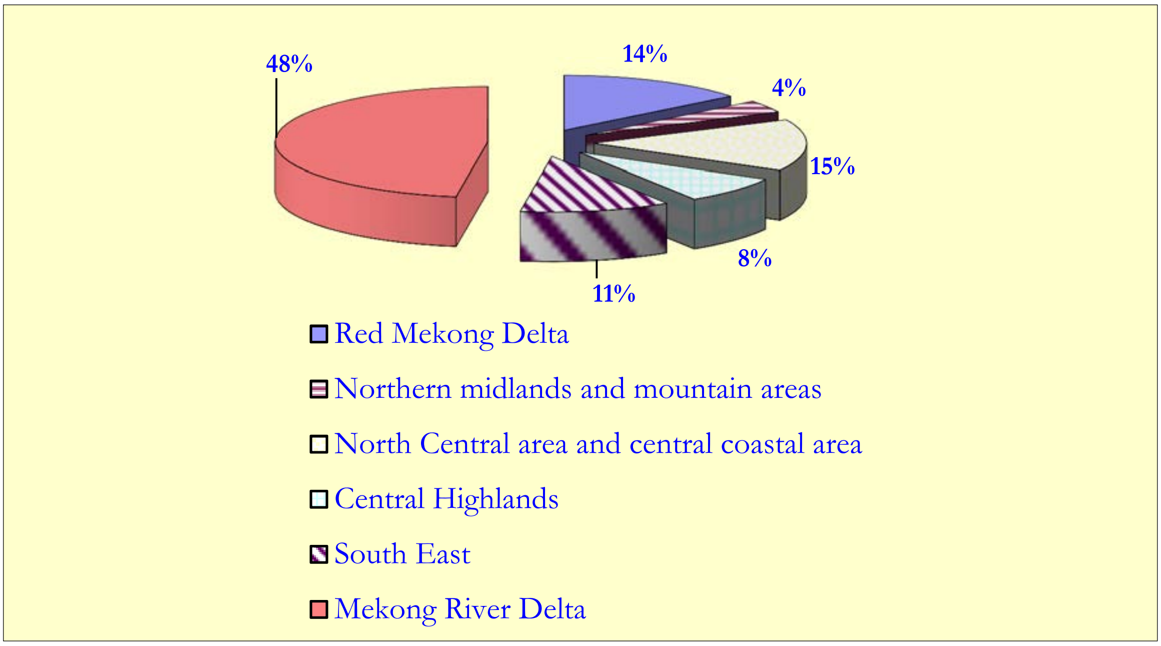

Figure 2.16: Distribution of agricultural farms by agro-ecological zones in Viet Nam, 2008

Source: GSO (2008), compiled by the Author

The key responsibility of agriculture in the MD is to guarantee the strategy of food security for the 87 million people in the whole country, create job opportunities for 80% of the 18 million inhabitants in the region and to contribute to the goal of economic growth for Viet Nam through the export of agricultural products.

Basically, the strength of agriculture in the MD consists of rice production, aquaculture (catfish, snakehead, and shrimp), fruit, sugarcane, and vegetable production (Table 2.1). Rice is the main crop. The planted area and productivity of paddy, dominate more than 50% of the nation (3,859,000ha and 20,628,000 tons).

With a diversity of river and channel systems in the MD, aquaculture is also a strength second to rice production. In 2008, production of aquaculture in the MD was 1,838,638 tons, being more than 75% of the national aquaculture production (Figure 2.17).

Table 2.1: Several agricultural indicators of agro-ecological zones in Viet Nam, 2008

Agro-ecological zones	Paddy		Sugarcane		Aquaculture production	
	Planted area *1,000* ha	Quantity *1,000* ton	Planted area *1,000* ha	Quantity *1,000* ton	Fish ton	Shrimp ton
Red Mekong Delta	1,153	6,776	2.3	130.4	243,818	14,511
Northern midlands and mountain areas*	669	2,896	24.6	1,327.4	48,590	294
North Central area and central coastal area**	1,213	6,126	113.4	5,958.8	77,664	51,216
Central Highlands	212	938	34.1	1,778.8	14,702	61
South East	308	1,307	31.4	1,848.3	59,531	15,207
Mekong River Delta	3,859	20,682	65.3	5,084.3	1,419,010	307,070
Whole Viet Nam	7,414	38,725	271	16,128	1,863,315	388,359
MD/Viet Nam (%)	**52**	**53**	**24**	**32**	**76**	**79**

*Source: GSO (2008), compiled by the Author. Note: *Northern midlands and mountain areas = North West + North East, **North Central area and central coastal area = North Central coast + South central coast*

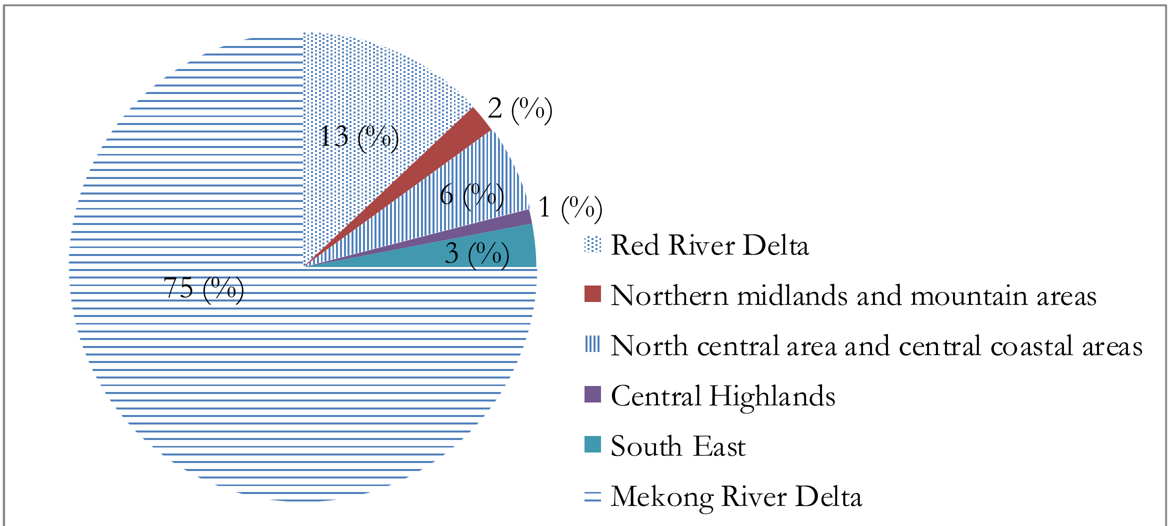

Figure 2.17: Aquaculture production share by agro-ecological zones in Viet Nam, 2008

Source: GSO (2008), compiled by the Author

Aquaculture production (fish) in the MD is 1,419,010 tons, makes up 76% of the national output; production of aquaculture (shrimp) is 307,070 tons, being 80% of the national output. They are two important value chains in Viet Nam. Hence, the Vice-minister of Trade of Viet Nam said that the MD is a major agricultural region of Viet Nam; its rice commodity allows Viet Nam to be a "top" rice exporter in the world (Long *et al.*, 2008).

The MD's potential is not matched by its current development. In the process of economic integration, its agricultural development faces many difficulties and challenges. Agriculture in the MD has no long-term master plan, it is developed in isolation, does not link regionally, has no planned transformation of farming systems, has limitations in product quality control, and there is less co-operation between producers and companies than in other areas. As a result, pests, and disease in crops and animals usually occur, causing a a crisis for agricultural products, and a loss of harvest (Liberation Saigon, 2008).

The remedy is to identify and evaluate the genuine potential of agriculture and natural resources of land in the MD. This will allow the exploitation and development of a stable agriculture in the MD, which has a unique comparative advantage, due to its productive agricultural land.

2.5.2 An Giang Province context

Similar to other provinces in the MD, agriculture is the key sector that contributes to the economic development of the An Giang Province, which occupies approximately 84% (298,146ha) of the total natural land area (An Giang Statistical Bureau, 2005). Agriculture contributes to nearly 30% of the total GDP of the Province and creates job opportunities for more than 60% of population (Figure 2.18 and Figure 2.19). Local inhabitants could earn a net profit of 3,000USD/ha/year by cultivation or husbandry in 2006 (DARD, 2007).

Agriculture in the An Giang Province includes many activities relating to crops, fish and animals. First, and most important, is rice production and catfish culture. The planted area, quantity and gross output of paddy per capita, and the surface area for breeding aquatic products increased steadily between 1995 and 2005 (Figure 2.20).

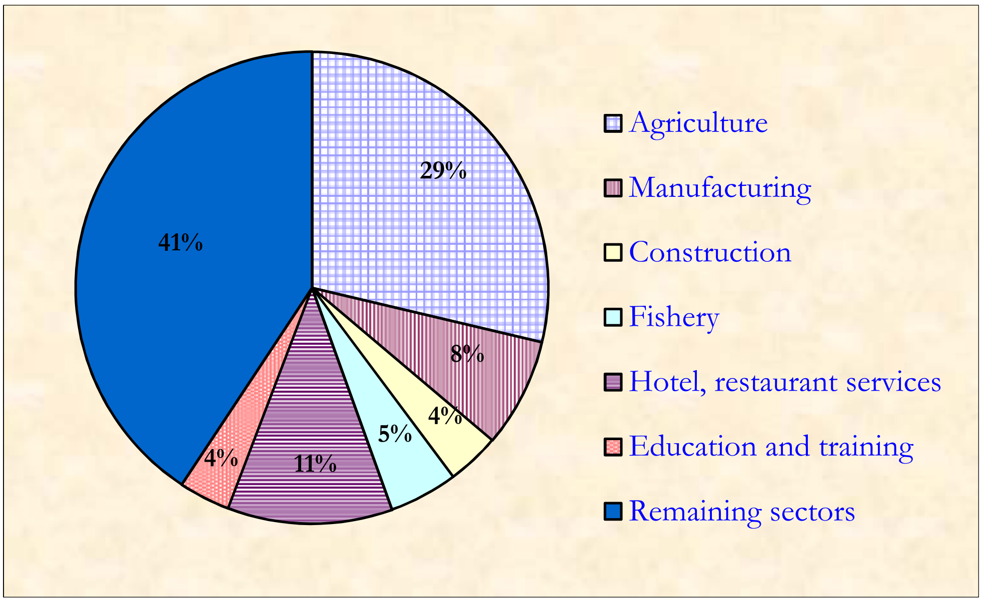

Figure 2.18: An Giang Province GDP at current prices by economic sectors in 2006

Source: An Giang Statistical Bureau (2007), compiled by the Author

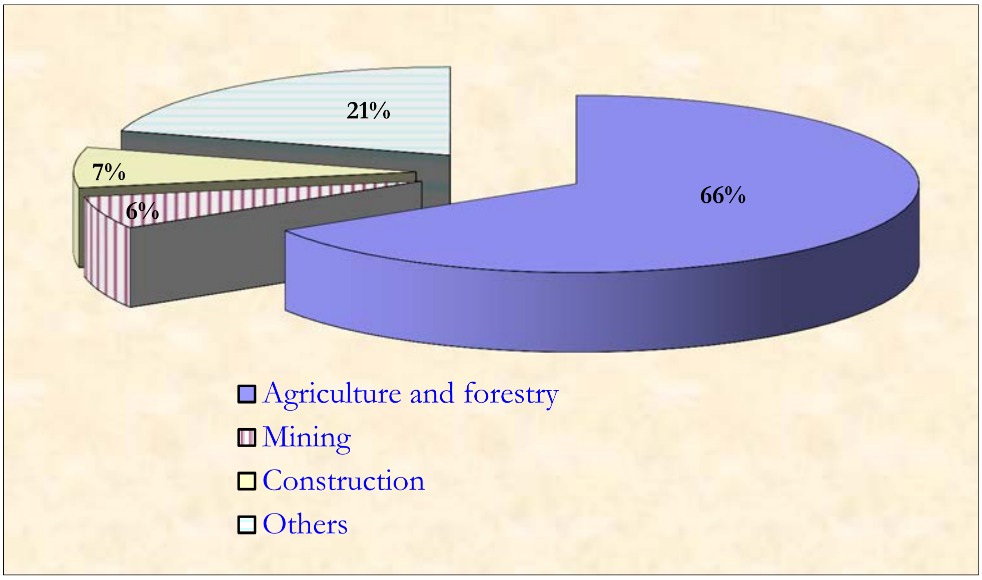

Figure 2.19: Labour distribution by economic activity in the An Giang Province, 2006

Source: An Giang Statistical Bureau (2007), compiled by the Author

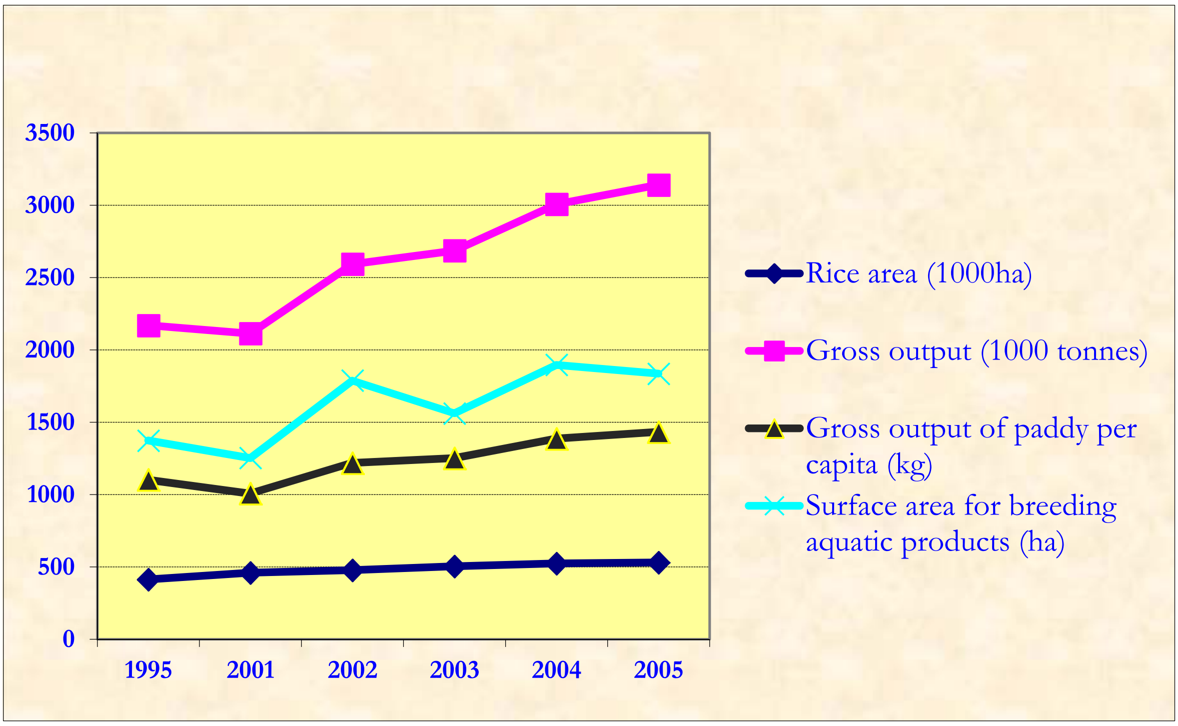

Figure 2.20: Increase in production area and quantity of rice and fishery in the An Giang Province between 1995-2005. *Source: An Giang Statistical Bureau (2007), compiled by the Author*

Rice production occupies 92% of the total crop area with output of over 3 million tons, increasing by 778 thousand tons compared with the year 2000. Additionally, catfish aquaculture is also a main product of the An Giang Province, its export value is 1.5 USD million, and it dominates 70% of the total catfish quantity in the MD, with 2,854 farms involved.

Furthermore, agriculture in the An Giang Province has a significant role to play in eliminating hunger, reducing poverty, and achieving livelihood goals for the poor and minorities in rural areas bordering Cambodian. In recent years, due to the importance in many sectors of the society, the agricultural sector in An Giang has seen investment in a number of projects focusing on agricultural infrastructure, such as the upgrading of irrigation systems, dike systems, enlarging channel systems and inside irrigation works. This will definitely increase the existing and future capability of farmland in the An Giang Province.

2.6 Negative impacts of agricultural practices: International context

Agriculture is essential to human existence and quality of life. Its native role is to generate food, products and services to meet human demands. Despite considerable achievements being recognized, agriculture also has detrimental impacts on the environment and natural ecological systems, and the costs and benefits of various agricultural practices may vary based on local values and constraints (Tilman *et al.*, 2002).

2.6.1 Environmental degradation: soil, water, and diversity

Over the last 5 decades, one of the driving forces behind environmental degradation in many parts of the world is the dramatic development of agricultural practices (Zalidis *et al.*, 2002). The negative impacts of agriculture often result from the adopted practice, with the impact existing for a long time after, typically unmeasured and consisting of related consequences.

Agricultural impacts on the environment are usually identified in terms of surface and ground water pollution and the deterioration of water quality (Nikolaidis *et al.*, 2008; Michael D. Dukes and Robert O. Evans, 2006; Maticic, 1999) from agro-chemicals added to the soil through running-off and leaching during agricultural practices, or the erosion of contaminated soil particles, causing problems to the water and soil resources (Zalidis *et al.*, 2002, Beare *et al.*, 1997).

For example, the main impacts of agriculture on soil quality include erosion, salinization, and the reduction in organic matter, compaction and non-point source pollution. Ultimately, soil degradation impacts water quality through pesticide leaching and excess nutrients infiltrating into the surface and groundwater along with seawater infiltration into aquifers (Zalidis *et al.*, 2002). Such processes exist and could be of major importance, because of the possibility of nutrient and pesticide leaching (Sequi, 1999). This is less important where agricultural practices consume a limited amount of pesticides and fertilizers per unit of arable land.

More important impacts resulting from agricultural practices have a significant cost to agriculture such as the disturbance of the nutrient cycle in the soil environment, existence of chemical toxins and bio-antitoxin in agricultural products (fruit, vegetable and fish). More complex is deforestation, desertification, reduction of bio-diversity, and the imbalance of ecological systems (Zalidis *et al.*, 2002, Beare *et al.*, 1997).

Nearly 50% of the world's usable land is already in pastoral or intensive agriculture (Tilman *et al.*, 2001), this results in the loss of natural ecosystems by the wasting of a huge amount of nitrogen and phosphorus to global ecosystems. The natural and managed ecosystems offer valuable benefits to society such as food, fibre, fuel and materials for shelter that could not be quantified and are rarely priced (Daily *et al.*, 2000).

In recent research, Tilman *et al.* (2002) give relevant examples for that; undamaged forests can reduce the impact of floods by slowing snowmelt and water discharge, while removing and storing atmospheric carbon dioxide, a greenhouse gas. Forest and grassland ecosystems can renew or regenerate fertile soils, degrade plant litter and animal wastes and purify water.

Unfortunately, agricultural practices can reduce the ability of ecosystems to act in a positive way on the environment because of the high applications of fertilizers and pesticides (insecticides, herbicides, fungicides and other agricultural chemicals) (Figure 2.21, 2.22). These increase nutrients and toxins in the groundwater and surface waters, incurring health and water purification costs, while decreasing fishery and recreational values.

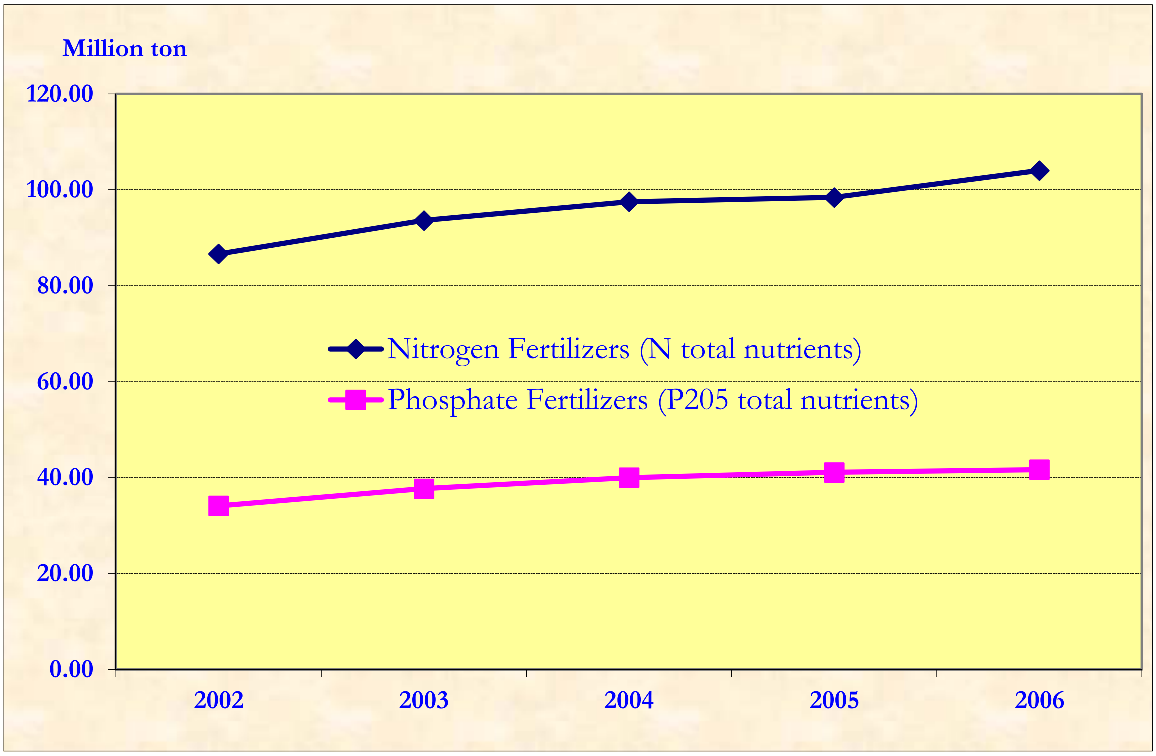

Figure 2.21: Total global consumption in nutrients (N, P_2O_5 fertilizer)

Source: FAO (2009a), compiled by the Author

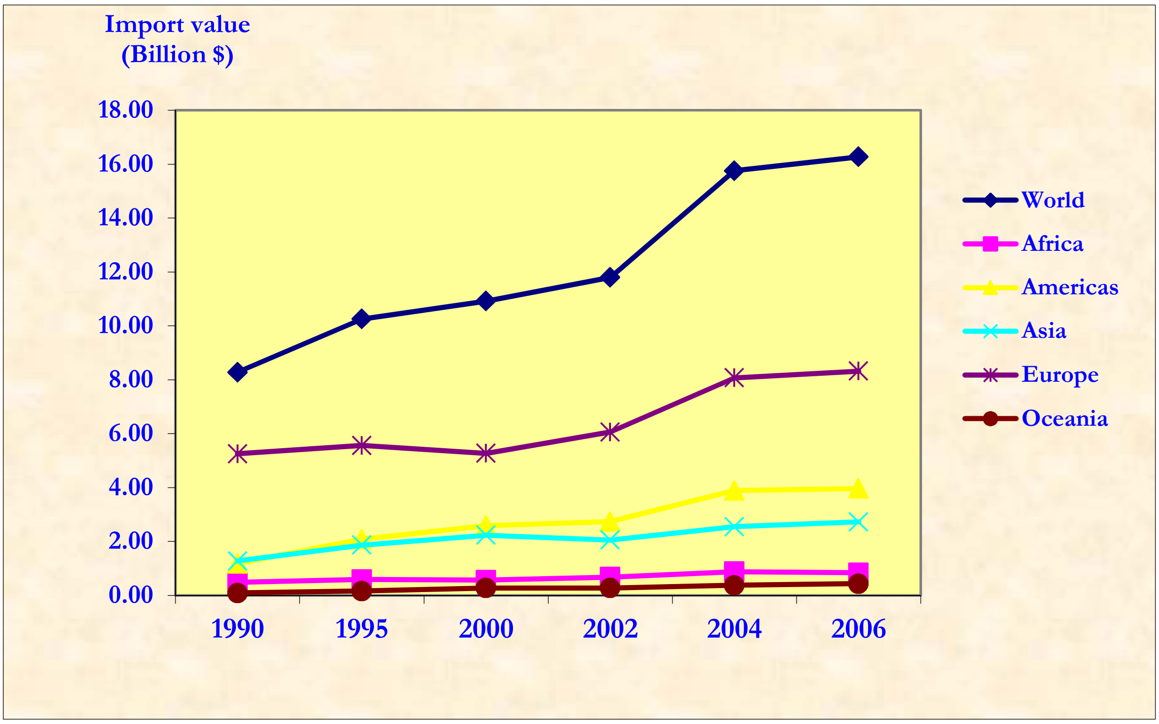

Figure 2.22: Total global pesticide imports (import value)

Source: FAO (2009a), compiled by the Author

Soil is an open system consisting of sub-components e.g. organisms, water, air, and characterized by attributes that both range within limits and interrelate functionally to each other (Zalidis *et al.*, 2002). The function of soil is driven by the physical, chemical and biological processes that can be summarized as follows (Karlen *et al.*, 1997; Seybold *et al.*, 1998; SoilQuality.org, 2009):

- Stores, moderates the release of, and cycles nutrients and other elements. During these biogeochemical processes, similar to the water cycle, nutrients can be transformed into plant available forms, held in the soil, or even lost to air or water (Nutrient Cycling).

- Regulates the drainage, flows and storage of water and solutes, which includes nitrogen, phosphorus, pesticides and other nutrients as well as compounds dissolved in the water. With proper functioning, soil partitions water for groundwater recharge and for use by plants and soil animals (Water Relations).

- Supports the growth of a variety of plants, animals, and soil microorganisms, usually by providing a diverse physical, chemical, and biological habitat (Biodiversity and Habitat).

-Acts as a filter to protect the quality of water, air, and other resources. Toxic compounds or excess nutrients can be degraded or otherwise made unavailable to plants and animals (Filtering and Buffering)

- Has the ability to maintain its porous structure to allow the passage of air and water, withstand erosive forces, and provide a medium for plant roots. Soils also provide anchoring support for human structures and protect archaeological treasures (Physical Stability and Support).

Many farming systems (agricultural practices) cause alteration of soil attributes that lead to damage of soil functions and, ultimately the degradation of soil and water resources (Zalidis *et al.*, 2002). In other words, agricultural practices degrade soil quality resulting in the destruction of habitats and may require an increase in payment, irrigation and energy costs to maintain productivity on degraded soils.

In the early 20th century, agricultural intensification has been applied and is now widespread in many regions of the world. This comes from a shortage of suitable farmland and food required for the population increase. As a result, this leads to serious environmental impacts, and degradation, particularly in tropical regions.

The most important and common impacts may include: (1) deforestation due to the lack of systematic and permanent forest protection, and savannization of forest land owing to excessively high population densities; (2) destruction of savannas and deterioration of forests and grasslands by intensified livestock farming, resulting in soil erosion and desertification; (3) soil degradation in medium to high mountain areas after deforestation and severe erosion, leading to the loss of natural soil fertility (Egger, 1989).

Along with the arguments above, Beare *et al.* (1997) expose that many of the agricultural practices involved in converting natural ecosystems to farmland e.g. clear-cutting, burning and cultivation, leading to considerable loss of biodiversity. In term of diversity reduction caused by agricultural practices, Goulart *et al.* (2009) assess the ecological impacts of agricultural intensification through qualitative reasoning, and compare this with non-intensification. The results show that, despite the low-input materials (fertilizer, insecticide, low density of seeding) for non-intensification, total production increases and the environmental services are kept functioning. Water quality and spatial heterogeneity do not change, and interestingly the biodiversity of both natural and farmed areas increase.

While, intensive agriculture has the potential to degrade water resources and reduce diversity. Its input materials (fertilizers, pesticides, financial investments) are high; however, the productivity may decrease, when the negative forces are greater than the positive ones, or increase, when environmental services provided by biodiversity have a stronger influence on the farmed area. In this case, intensive agriculture involves very high ecological, social, cultural, public health and economic costs (Perfecto and Vandermeer, 2008; Matson *et al.* 1997). In contrast, non-intensive agriculture has lower costs, is environmentally friendly, and this has been measured empirically in sustainable agricultural systems (Perfecto and Vandermeer, 2008). Exploration of suitable ways to increase the role of agriculture while maintaining the environmental biodiversity is a complex one for humanity. There are however alternative agricultural practices that can harbour biodiversity at high levels, with satisfactory productivity (Vandermeer and Perfecto, 2005).

2.6.2 Human health problems

Agriculture can impact negatively on human health through the application of agricultural chemicals. Farmers, who directly produce, harvest, store, and prepare food and fibres are exposed to many chemicals which will be potentially hazardous to their health. Due to costs, inaccessibility of services, or fear of reporting and loss of employment, their poisoning may not necessarily be reported to the health care system (FAO, 2001b).

Unfortunately, there are many gaps in information about the mechanisms of toxic action, human exposure, and the nature and extent of human health effects. The results of experimental studies indicate that several groups of chemicals in current use are toxic, but very few pesticides have been tested for their effects on human health (Mushak and Piver, 1992).

Studies into the impact of farm chemicals on humans are contradictory. A study of agricultural chemical exposures and birth defects was conducted in South Africa (Heeren *et al.*, 2003). The results show that there is a link between exposure to pesticides and certain birth defects among the children of rural South African women who work on the land.

Similarly, from research into the impacts of intensive agricultural practices on drinking water quality in the Evros region (NE Greece), Nikolaidis *et al.* (2008) state that the deterioration of drinking water quality can be directly linked to excessive fertilizer use from agricultural sources, e.g. nitrates, sulphates, and phosphates.

On the contrary, no epidemiological evidence of pesticides having any effect on the prevalence of congenital malformations has been found in Italy (Clementi *et al.*, 2007). Farmers do not apply pesticides indiscriminately. Careful management and reasonable use of pesticides in agricultural practices should be encouraged, as this brings not only economic efficiency, but also protects the farmers' health and the environment.

Agricultural extension and education programs such as integrated pest management courses, farmers' field schools and farmers' field days need to be included into agricultural practice procedures.

How environmental costs and the negative impacts of agricultural practices can be minimized while simultaneously increasing food production is a difficult equation. Reasonable solutions could be accompanied by the efficient use of nitrogen, phosphorus and water and integrated pest management. But, according to Tilman *et al.* (2002) achieving these outcomes is one of the greatest scientific challenges because of the trade-off between economic benefits and environmental goals combined with a lack of understanding in terms of the key biological, biogeochemical and ecological processes as well.

Most land and water resources suited to agricultural production are already being used. The yield potential of animals and crops, especially cereals, cannot be improved because they have peaked thanks to technological advances in the last decades (Figure 2.23). The future development of agriculture related to food production may require land areas to be expanded and the introduction of intensive farming systems with two or three crops per year applied. This may mean that crops become progressively susceptible to diseases and insect pests because of insufficient diversity in the crop rotation (Tilman *et al.*, 2002).

2.6.3 Deforestation

The further negative impact of agricultural practices is deforestation due to a combination of population pressures, loss of traditional controls, and shifting forest land to farmland. Farmers use fire to clear land for agricultural plantations, raising animals and growing feed crops for animals.

Data in Table 2.2 show that the world forest area has changed significantly between 1990 and 2005. Except in Europe, forest areas in most parts of the world such as Africa, Asia and the Pacific region, and Americas and the Caribbean, have declined.

Africa has seen a dramatic decrease in forest area of 0.64% in the years 1990-2000, and 0.62% between 2000 and 2005.

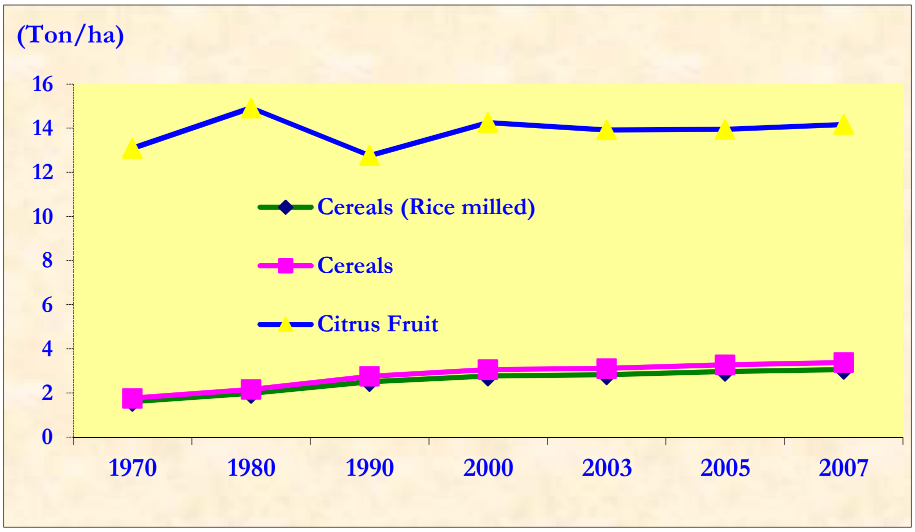

Figure 2.23: Global cereals' yield stabilized in recent years

Source: FAO (2009a), compiled by the Author

The United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) (2000) gives critical evidence that in recent years, farmers destroyed forest areas for agricultural activities more than the commercial timber extraction industry in Asian and Pacific countries. The FAO (2001a) analysed the causes of deforestation in separate continents and concluded that the most important reasons for deforestation originate from agriculture (Figure 2.24).

Table 2.2: Extent and change of global forest area between 1990 and 2005

Sub-regions	**(Area)** (1,000ha)			**Annual change** (1,000ha)		**Annual change rate** (%)	
	1990	2000	2005	90-00	00-05	90-00	00-05
Africa	699,361	655,613	635,412	-4,375	-4,040	-0.64	-0.62
Asia and the Pacific	743,825	731,077	734,243	-1,275	633	-0.17	0.09
Europe	989,320	998,091	1,001,394	877	661	0.09	0.07
Latin America and the Caribbean	923,807	882,339	859,925	-4,147	-4,483	-0.46	-0.51
World	**4,077,291**	**3,988,610**	**3,952,025**	**–8,868**	**–7,317**	**-0.22**	**-0.18**

Source: FAO (2006a). Data are subject to rounding

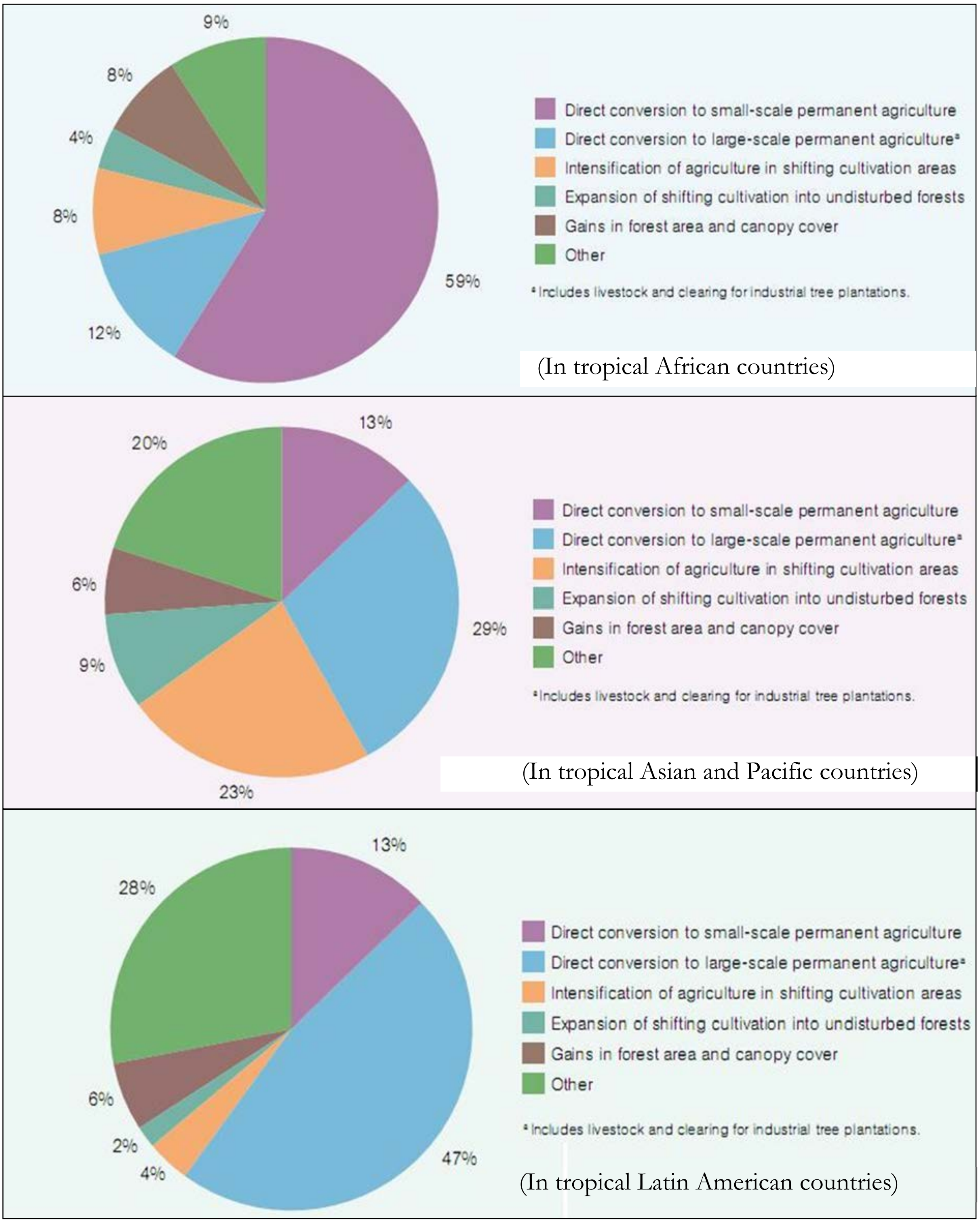

Figure 2.24: Direct causes of forest area changes in different tropical regions, 1990–2000

Source: FAO (2001a)

Direct conversion to small-scale and large-scale permanent agriculture, occurred in more than 70% of the cases of deforestation in tropical African countries, and 50% of cases in tropical Latin American countries between 1990 and 2000. Nearly 45% and

23% of deforestation cases are caused by the intensification of agriculture in shifting cultivation areas in Asian and the Pacific region.

This issue is an emerging challenge for policy makers, forest managers, and for governments of low income countries because it impacts on livelihoods, food security, and the habitats of farmers in the rural areas (FAO, 2009c).

For the Asian and the Pacific regions, the unexpected impacts of agricultural practices are mostly focused on the environment of soil and water similar to many the regions of the world.

Agricultural practices of Viet Nam in general and the MD in particular, also create distinct negative impacts upon the environment. Viet Nam has eight main agro-ecological zones (*see Chapter 5*), distributed from the north to the south. Every zone has specific agricultural production systems, based on specific local resources. The MD is the most important agricultural zone of the nation. The production scale, degree of intensive farming, and the development potential of farming systems, particular in rice and aquaculture in the MD are higher than other zones.

Hence, examining the relative impacts of agricultural practices in the MD, could help researchers to understand the negative impacts of agricultural practices in Viet Nam as a whole. The discussion below focuses mainly on the MD, as a case study for Viet Nam.

2.7 Negative impacts of agricultural practices: Viet Nam Mekong Delta context

So far, there are only a few formal research projects assessing the impacts of agricultural practices on the environment in Viet Nam. The awareness of the environmental impacts caused by agricultural practices is increasing in Viet Nam, but it seems to be a relatively new concept for rural farmers, producers, and agricultural and environmental managers.

Most studies on environmental impacts of agricultural practices in Viet Nam are designed to evaluate the side effects of separate farming systems, and then to find desirable solutions to treat these effects, rather than consider and analyse systematically the negative impacts of agricultural practices.

The common and frequent impacts of agricultural practices in Viet Nam can be identified by implementing farming systems (Huan *et al.*, 2002; Ha Yen, 2008; Dung *et al.*, 2003). The MD has a range of farming systems. Intensive rice production and aquaculture are two substantial systems, which have direct impacts on the environment. These systems can be used as examples for the determination of side effects of agricultural practices in Viet Nam (VNA, 2007; Hong Van, 2007; Dung *et al.*, 2003).

In recent years, the land area used for rice production and aquaculture has increased significantly in the MD. Many farms at an industrial production scale, particularly catfishes (*Pangasius*) and shrimp, have formed and developed considerably (Table 2.3a, 2.3b) GSO (2008). These have helped to increase agricultural production, generate job opportunities and improve income for local residents, as well as contributing markedly to regional economic development, and the prosperity of the nation.

Table 2.3a: Number of agricultural farms formed in Viet Nam, 2000-2008

Unit: farm

	Total farms			**Fishing farms**		
	2000	2005	2008	2006	2007	2008
Whole Viet Nam	57,069	114,362	120,699	34,202	34,624	34,989
Mekong Delta	31,967	56,582	57,483	25,147	25,278	25,311
An Giang Province	8,313	8,403	7,464	1,205	1,164	1,455

Source: GSO (2008), compiled by the Author

Table 2.3b: Paddy planted area and aquaculture area in Viet Nam, 2000-2008

Unit: 1,000ha

	Planted area of paddy			**Area of water surface for the aquaculture**		
	2000	2005	2008	2000	2005	2008
Whole Viet Nam	7,666	7,329	7,414	642	953	1,053
Mekong Delta*	3,946	3,826	3,859	445	680	752
An Giang Province	464	530	564	1,300	1,800	2,800

*Source: GSO (2008), compiled by the Author. *: Area of water surface for the catfish aquaculture in the Mekong Delta on August, 2009 is approximately 5,200ha (MARD, 2009)*

However, these industrial scale farms directly or indirectly impact on the environment. Water and soil pollution, human health risk, diversity destruction, and fresh water shortage in the dry season are considerable concerns in the environmental impact assessment cause by agricultural practices in Viet Nam. The greatest concern comes from residues of agro-chemicals, industrial feeds, and antibiotics that are discharged into the environment from rice production and aquaculture systems (Vietnamese labour newspaper, 2008).

In the production systems of intensive rice, the most negative impact comes from the application of agro-chemicals. Due to the widespread planting of high yielding varieties since the late 1960s, rice farmers in the MD in particular, and in Viet Nam in general, have tended to increase pesticide use, and despite the many achievements in pest management, they still regard pesticides as indispensable over time to sustain the yields under intensive cultivation systems (Huan and Anh, 2002).

A study of insecticide use in Viet Nam by PANUPS (1995) shows that the large amount of pesticides applied on rice fields is unnecessary. Over 95 per cent of the farmers applied at least one type of pesticide during the growing season with the mean number of sprays in Viet Nam being seven (PANUPS, 1995).

Pesticide use in rice accounted for 65.5% of the total market value of pesticides in 1996. Insecticide was the most widely used pesticide (85%) among rice growers in the MD. The high insecticide use in the MD is closely linked to intensive cultivation; most insecticides are sprayed at the initial stages of the rice growing season (Mai, 1995).

A lack of information and subsequent knowledge on the impact (positive and negative) of pesticides and chemical fertilizers is the main reasons for farmers' overuse and indiscriminate application of such chemicals. Additionally, farmers usually discharge the surplus chemicals (after use) into the channels and rivers. As a result, it wastes money and leads to fishery resources (e.g. wild fishes) and biodiversity decline.

For example, Ha Yen (2008) observers that 1.77 million ton of nitrogen, 2.07 million ton of phosphorus, and 244,000 ton of potassium fertilizers were wasted in 2007 because of overdose applications (Dong and Doan, 2008). This has a detrimental impact upon the environment because those substances will exist in the soil and water for a long time; they are one of factors can destroy biodiversity and harmful to human health.

In the 1950s, approximately 100 tons of pesticides were applied each year in Viet Nam; it then rose sharply in the 1980s, and peaked at 25,000 tons in 1995. Pesticide consumption in Viet Nam increased dramatically in the years 1996 and 1997 (Figure 2.25). This is the period of intensive cultivation brought about by the introduction of high yielding rice varieties.

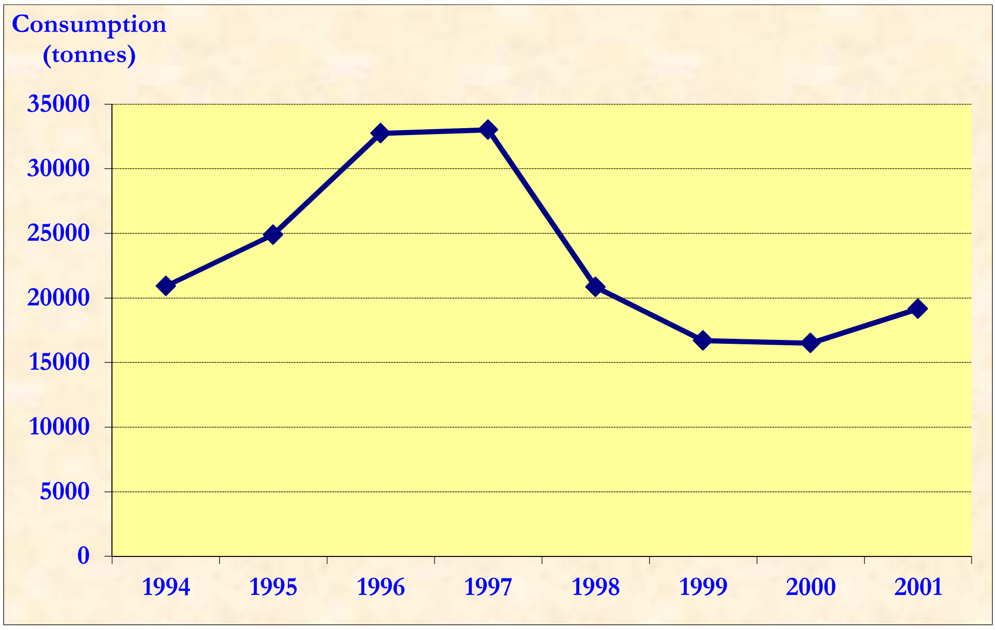

Figure 2.25: Consumption of Agro-chemicals[7] in Viet Nam, 1994-2001. *Source: FAO (2009a)*

The rapid increase in the use of pesticides has had an adverse health effect on farmers and others exposed to pesticides, and has posed threats to the environment through pollution of drinking water and aquaculture. Further expansion and intensification in rice production, therefore, faces the challenge of formulating and implementing an agricultural growth strategy that is both economically and environmentally sustainable (Dung *et al.*, 2003).

Incorrect pesticide use results not only in actual yield loss but also in health and environmental damages such as destroying the rice-fish culture, killing native animals and causing air and water pollution. On the farmers' health aspect, when farmers have to take days off work because of pesticide induced ailments, the rice yield may suffer. Therefore, the problem of farmers' health is an important concern for policymakers when looking at the economic efficiency of rice production (Dung *et al.*, 2003).

[7] *Including Insecticides, Herbicides, Fungicides and Bactericides, Plant Growth Regulators, Rodenticides.*

Several studies have been undertaken regarding the health impacts from agricultural practices, for example, Dasgupta *et al.* (2005) or Tuc *et al.* (2007) conducted a survey on 1,036 rice farmers to assess the effects of pesticide use on semen characteristics. The results show that pesticides use is significantly associated with abnormal semen characteristics. Especially, close proximity of the household to the rice fields, a farming duration of over 10 years, and farmers labouring without personal protective equipment, are high risk factors for having abnormal semen.

Recent investigations on water quality in the MD have determined that hazardous ions like alluvium (Al), iron (Fe), sulphates, and residue of chemical fertilizers, insecticides, herbicides frequently exist. Vietnamese labour newspaper (2008) explains that, the main reason of this is due to chemical fertilizers, pesticides abuse in the process of agricultural practices.

Associated with rice production, aquaculture also contributes to negative impacts on agricultural practices. With the output of 1 million ton of catfish, it is estimated that catfish growers in the MD use at least 3-4 million ton of feed (includes industrial and traditional feed). This means they discharge into the environment 2-4 million ton of waste substances per year (Hong Van, 2007).

When waste substances, created from aquaculture, override the natural cleaning capacity of channel and river systems in the MD, this will cause an imbalance in the fresh water ecology. This results in an increase in environmental improvement costs, diffusion diseases, and water source pollution along with impacting on the living standards of the rural inhabitants. In a report on value chains analysis for sustainable Mekong fisheries, Loc *et al.* (2009) reveal that more than 50% of catfish farmers in the MD face challenges of a polluted water environment and disease in fish. Eventually, they will have to pay a large amount of money for the environmental costs.

In a recent presentation analysing environmental impacts from aquaculture, Ho Hung (2009) cites the phenomenon of catfish dying in many locations in the MD as a consequence of industrial level aquaculture. The author points out that, catfish farmers are guilty due to the high intensification and expansion without waste treatment systems. Thus aquaculture has created a huge amount of waste substances, and they are freely discharged into the rivers and channels to be mixed with natural water sources. Unfortunately, catfish farmers use the water source from these reservoirs for aquaculture production. Ultimately, catfish die because of the unsuitable content of biochemical oxygen demand and NH_3 in the water.

Another side effect of agricultural practices in Viet Nam in general, and the MD in particular, is food poisoning. Many producers ignore the recommendations of agronomists in relation to the safe use of pesticides, and chemical fertilizers at the period of pre-harvest, or during the growing period. Some others are driven by economic desire. The health of customers is not considered and farmers use an overdose of agro-chemicals to maximise their crops' productivity. Consequently, agricultural products have toxic chemical content at a higher level than permitted, and hence harmful to the consumers' health.

The Vietnamese Vice-Minister of Agriculture and Rural Development states "Every day, there are more than two million people in Viet Nam who consume unsafe vegetables" (Ngoc Lam, 2009). To clarify this statement, Ha Linh (2009) gives the example that, more than 10% of "safe" vegetables in Viet Nam have residues of pesticides; of which 4% are higher than the permitted level.

Beside the visible impacts, rice production and aquaculture have invisible impacts on the environmental life of organisms in the MD; such as diversity reduction and ecology imbalance. During rice production and aquaculture practices, many varieties of useful animals (natural enemies) are killed by the application of toxic chemicals. This breaks down the naturally ecological balance, causing diseases or insect outbreaks in the MD.

Kim (2009) argues that, in the natural environment, relations between organisms (e.g. in a micro eco-system) are aligned by the hierarchy of a food chain. When pesticides or toxic chemicals are used, the chain is broken because some susceptible species can be killed. The remaining species, having no natural enemies (predators), will increase in number and become "outbreaks".

Figure 2.26 shows the relationships and the cycle of predation and prey of organisms in the food chain of the rice production system in the MD. In the chain, insects attack the rice field, spiders eat insects, fish feed on spiders, frogs eat the fish, and the snakes are highest predator in the chain that eats the frogs.

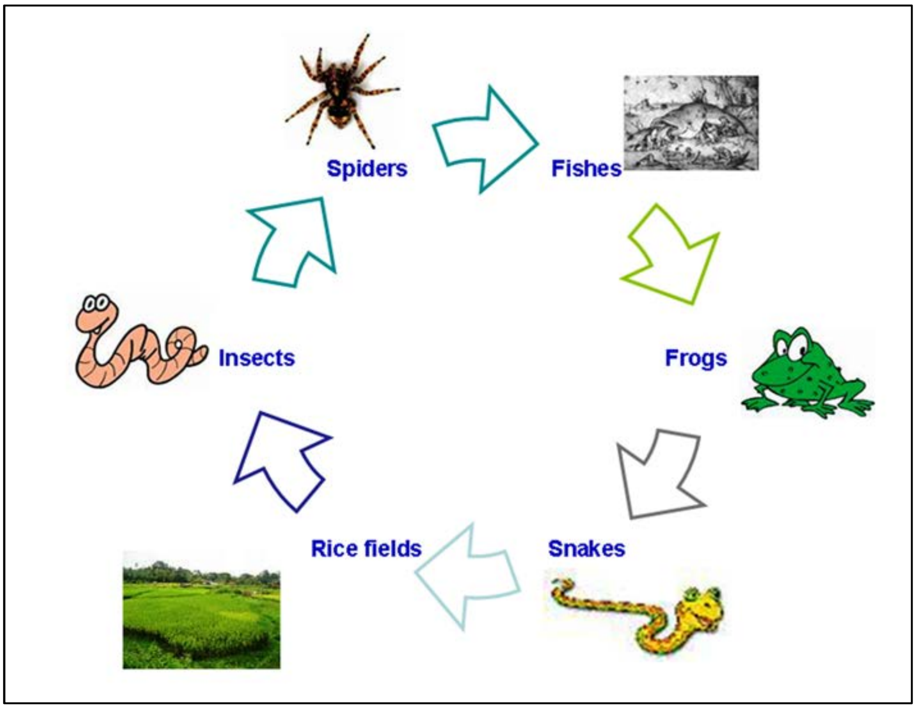

Figure 2.26: An example of natural ecological balance in the rice farming system in the MD

Normally, the rice field can recover and overcome the damage caused by insects to remain productive (Huan, 2006), but when farmers apply agro-chemicals indiscriminately (e.g. to kill a certain pest on the rice field such as golden snails); these chemicals also kill spiders, allowing insects to multiply their population dramatically because their enemy, spiders, do not exist anymore.

Another unexpected impact of agricultural practices in Viet Nam is deforestation that is undertaken to extend the area of farmland. However, it is not a large problem as the financial costs for converting forest lands to agricultural lands are very high, and this conversion takes a long time. According to data from the GSO (2008), forest land areas cleared for farmland purposes in Viet Nam is insignificant. An estimated 2242 ha of forest area was cut in 2008, and the main reasons for this is fibre and wood exploitation, rather than for farmland purposes.

The more substantial side effects of agricultural practices in Viet Nam in general, and in the MD in particular, are existing agro-chemical residues and waste substances from rice production and aquaculture systems. The cycle for the degradation of these residues is very complex (depending on the microbial action and the chemical reactions in the soil; Ritter, 2001; Ritter and Shirmohammadi, 2001) and the degradation may take a long time. Pesticides, which are not degraded, will be immobilized, discharged and accumulated in the environment. This is dangerous toxicity which kills wild fish resources and useful animals, damages eco-systems, reduces biodiversity, and impacts on human health.

Achievements from agricultural intensification in the MD are many, but negative impacts also exist, creating challenges for producers, agronomists, and agricultural policy makers. Therefore, evaluating agricultural land potential systematically to plan and reasonably utilise the land resources is essential for the MD.

In summary, there can be no doubt about the critical role of the agriculture sector in the development of human society. It contributes to development in many ways, such as poverty reduction, food security guarantee, creation of job opportunities, livelihood and income improvement for inhabitants in rural areas, effective exploitation of leisure for the local poor and results in a decline in the unemployment rate, as well as development promotion to related sectors.

Clearly, agriculture has made considerable contributions to the GDP, the export value of agriculture is a substantial part of the economy in many countries, particularly for developing and agriculture-based countries in Asia and Africa. Hence, the most recent section of the Committee on World Food Security called on all parties to "enhance investments in agriculture and rural development and all related institutions"[(8)].

In Viet Nam, the roles of agriculture have been identified for many decades. Today, it still contributes positively to the GDP, export value and it is a main sector in the national economic structure. So far, it continues to play an important role in the Viet

[8] *Report of the 33rd Session of the Committee on World Food Security (Rome, 7-10 May 2007)*

Nam economic development strategies because the livelihood of more than 70% of Vietnamese is dependent on agriculture.

Agriculture, however, in some cases, also has a negative impact on the environment, including conversion of natural ecological systems, forest land to farmland; aquatic nutrient pollution (generated by aquaculture), terrestrial habitat destruction and groundwater contamination, abundance and residue of agro-chemicals, especially chemical toxins and bio-antitoxin accumulation or persistent organic agricultural pollutants. Leaching, volatility and the waste streams of livestock and humans are basic processes transferring agricultural nutrients into other ecosystems, while agricultural chemicals can harm human health, destroy fauna, inject pathogens and poison food as well.

Maintaining a balance between the maximization of economic profit and environmental goals is an emerging challenge for human kind. Agricultural practices and environmental preservation are two complex systems; they are formed from many sub-components, which have interacting relationships within and between the systems.

Success in agricultural practices comes as a result of the integration of many parts of the industry and is driven by the efficient exploitation of the resources, e.g. human capital, social capital and financial capital associated with the agricultural land (natural capital). Therefore, determining and assessing the separate components in an integrated agricultural system is essential for sustainable agriculture. The fundamental principle underpinning sustainable agriculture is to use the resources efficiently, especially the land resource.

It is possible to construct a theoretical model of an agricultural management system which is suitable in determining the capability of farmland. Such a model can be used to determine negative impacts of agriculture and the status of agricultural land use. The model can be used to develop a framework, and support tools, for land evaluation. The development of such a model is discussed in the remainder of this chapter.

2.8 Agricultural land use distribution

2.8.1 The concepts in relation to agricultural land

Land is an invaluable and non-renewable resource positioned in the top layer of the earth's surface, on which, humans, plants, animals, and other organisms exist, survive and develop (UNEP, 2002). The bio-physical and socio-economic environment directly influences the land use.

Land refers not only to soil, but also to plants, animals, landforms, climate, hydrology, geology, topography, vegetation systems and fauna, together with the socio-economic attributes (labour, population, revenue and other human activities), and land improvements such as terraces and drainage works (FAO, 1976; FAO, 1985; FAO, 1993; Rowe *et al.*, 1981, Rossiter. 1996; The State Planning Commission, 1989).

This view of land and land resources takes into account the bio-physical and socio-economic resources of the physical entity (FAO, 2007b). The FAO/UNEP (1997), Sombroek (1996) and FAO (1995) stress the more explicit emphasis on environmental aspects; land as a delineable area of the Earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface including those of the near-surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes and swamps), the near-surface sedimentary layers and associated groundwater reserve, the plant and animal populations, the human settlement pattern and physical results of past and present human activity (terracing, water storage or drainage structures, infrastructure, buildings).

Agricultural land is the land used for agricultural purposes or has the potential for agricultural utilisation (ODTGAUS, 2009), where agricultural activities are practiced upon it. This typically occurs on farms, geared to food production (cereal) for human consumption, animal raising, the growing of plants for fibre and fuels (including wood), and for other organically derived products (pharmaceuticals) as well (ALC, 2009).

Farmland is a concise form of agricultural land, used or suited for farming based on its capability or suitability and determined and categorised by integrating, balancing and matching between the land characteristics in term of land quality and land utilisation types (FAO, 1993; Ritung *et al.*, 2007; Rowe *et al.*, 1981).

2.8.2 Global agricultural land use distribution

Agricultural land is a natural resource, where farming systems practiced to generate products and services, contribute to social development. It, however, is incapable or unsuitable for all production systems, because each system requires different essential inputs such as physical, chemical and biological factors, as well as being affected by relationships and interactions between these factors within the system (MAFF, 1998).

Associated with those factors, the capability of agricultural land is heavily influenced by technical, management, and socio-economic factors (ALC, 2009; Mohamedl *et al.*, 2000; Samranpong *et al.*, 2009). Hence, the FAO (1993), Laborte *et al.* (1999) and Ritung *et al.* (2007) advise that there are many related factors which should be considered and inspected prior to planning, allocating or proposing patterns for agricultural land use types, as well as their distribution.

Normally, the distribution and occupation of agricultural land in the total land area differ between nations, regions, and continents. This is due to many issues. The total land resource available and its natural features (comparative advantages for agriculture) will impact on the percentage used for farmland. The FAO's statistics (FAO, 2009a) indicate that agricultural land is usually allocated over a wide area in the countries occupying a large natural land area.

For example, China, Australia, United States of America, Brazil and the Russian Federation are nations allocating land in a range of 215,463,000-552,832,000ha for agricultural purposes (Table 2.4). In contrast, agriculture–based countries e.g. Viet Nam, Philippines, Indonesia and Thailand have smaller agricultural land areas because of the limited natural land area.

The main activity of agriculture is cropping and animal husbandry (cattle, sheep, goats, poultry and fish). These are present in distinct agro-ecological systems and are always influenced by external natural factors. Thus, the distribution of land for agricultural use also depends on the land's natural characteristics such as climate, soil characteristics, hydrology, and the terrain (Ritter and Shirmohammadi, 2001).

In other words, the distribution of agricultural land use depends on the land suitability (FAO, 1993) for every specific farming system. A farming system (plant or animal) will generate highly effective economic benefits when it is practiced on a suitable plot of land.

Farmers can gain a high net income from rice production in fresh water, fresh alluvium and the flood plain region. Rice will not grow well in mountainous country or variable terrain regions. Here the effectiveness of rice cultivation is very low because of the high production costs in these areas.

To illustrate this, planted rice[9] is distributed with in a large area in countries in the tropical climate region (warm temperature, high moisture) such as Viet Nam, Thailand, and the Philippines. Meanwhile, wheat[10] dominates in cold temperature regions, e.g. in the European Union, USA, and Canada (Table 2.4).

Table 2.4: Agricultural land use distribution in some countries

Countries (Data in 2007)	**Total land area** (1000ha)	**Agricultural land** (1000ha)	**Share in total area** (%)	**Rice, paddy**	**Wheat area**
				Harvested (1000ha)	
China	932749	552832	59.3	29179.1	23721.1
Australia	768230	425449	55.4	20.0	12345.0
USA	916192	411158	44.9	1112.1	20639.7
Brazil	845942	263500	31.1	2890.9	1853.2
Russian Federation	1637774	215463	13.2	157.0	23500.5
Canada	909351	67600	7.4	-	8636.3
Japan	36450	4650	12.8	1673.0	209.7
British	24193	17647	72.9	-	1830.0
EU	418143	190212	45.5	419.4	24794.6
Indonesia	181157	48500	26.8	12147.6	-
Thailand	51089	19750	38.7	10668.9	1.0
Philippines	29817	11500	38.6	4272.9	-
Viet Nam	31007	10072	32.5	7201.0	-

Source: FAO (2009a) and United Nation (2008); compiled by the Author

[9] *Rice (Oryza sativa) grows well in tropical regions such as Asia (De, 2008)*
[10] *Wheat grows well in cold temperature regions, Simmons et al. (1995)*

Moreover, historical issues and wars also impact upon the agricultural land use distribution. The socio-economic development of many countries has been basically linked to the land use since it is often devoted to the production of agricultural products; the exploitation of agricultural land in general, has been the main source of wealth and power in society (Rojas, 1984).

Prior to the Second World War, mostly colonial countries were incorporated into the world economic system as suppliers of agricultural products under an Empires colonial rule. Agricultural land use distribution, therefore, focused mainly on those countries producing and supplying the demands of Empires.

Studies of agricultural land, and its distribution and development, Rojas (1984), and Rojas and Meganck (1987), state that the original land distribution pattern in all the islands of the Eastern Caribbean (Antigua, Dominica, Grenada, Saint Lucia and Saint Vincent) was heavily influenced by the military events in the 17-18th centuries. The dominant wars between France and England created an insecure economic development environment, resulting in the sequential development and abandonment of small plantations devoted mainly to the production of indigo and cotton.

Similar to the Eastern Caribbean, agricultural land use in Viet Nam was dominated by rubber plantations planted by the French in the 1940s. Since 1954, the Geneva Agreement between Viet Nam and France was signed; Viet Nam was divided into two regions: the North under the Democratic Republic of Viet Nam following Socialism, and the South under the Republic of Viet Nam following Capitalism backed by America. Agricultural land use policies were quite different (De, 2005). At that time, agricultural land primarily occupied two deltas, the Mekong Delta and the Red Delta, with rice as the key crop.

After reunification in 1975, and land reform in 1986, agricultural land in Viet Nam has been extended to eight main agricultural zones with many farming systems such as rice, vegetables, aquaculture, and fruit trees.

Recently, the population growth pressure and food security goal also lead to differences in the agricultural land use distribution between nations. Explicitly, more people are using more resources to undertake intensive agriculture than at any other times in human history (UNFPA, 2001). Since the 1970s, the key driving force leading to a pressure on land resources is the need for food production to satisfy the "baby boom" growth in the population.

Rojas (1984) confirms that a high population, limited agricultural land and the concentrated ownership of the best land have forced countries to clear relatively poor agricultural land and put it into production. Once permanent vegetation cover is removed, the land loses fertility due to the erosion caused by heavy rainfall over the steep slopes where the marginal land is normally located. A pattern of shifting cultivation in a small farming community will result in changes of agricultural land use distribution.

The trend between decades 1985–1995 showed that population growth was accelerating faster than food production in many parts of the world, particularly in developing countries in Africa and Asia (UNFPA, 2001). On the other hand, the growing population over the past decades resulted in increasing demands for housing, industry, roads, airports, recreation and, as a result, considerable areas of farmland are being lost (Doos, 2002).

There is a conflict between developed and developing countries in agricultural land distribution and allocation (UNEP, 2002). Agricultural land has increased steadily in developing regions but not in developed ones (Figure 2.27a, 2.27b). The decrease in agricultural land in developed regions seems to be driven less by land resources availability and more by economic forces.

Figures 2.27a and 2.27b show that agricultural land use distribution in many parts of the world is quite different. Agricultural land area in Europe and North America declined slightly between 1970 and the late 1990s; Africa, Oceania, and the Americas seem to be stable. Agricultural land area in Europe has seen a dramatic decrease between 1990 and 2000 before levelling out in the later years. While, agricultural land in Asia and the Pacific rises significantly from 1980s to 2000 contributing to the increase in agricultural land area of the whole world.

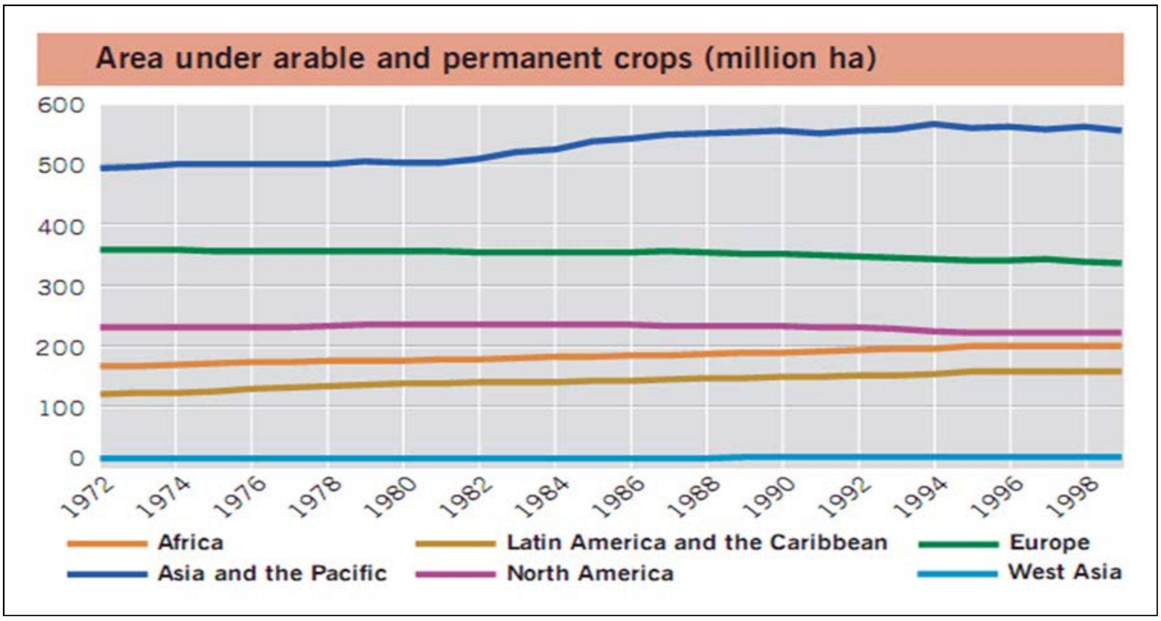

Figure 2.27a: Area under arable and permanent crops in specific regions[11] **(million ha)**

Source: UNEP (2002)

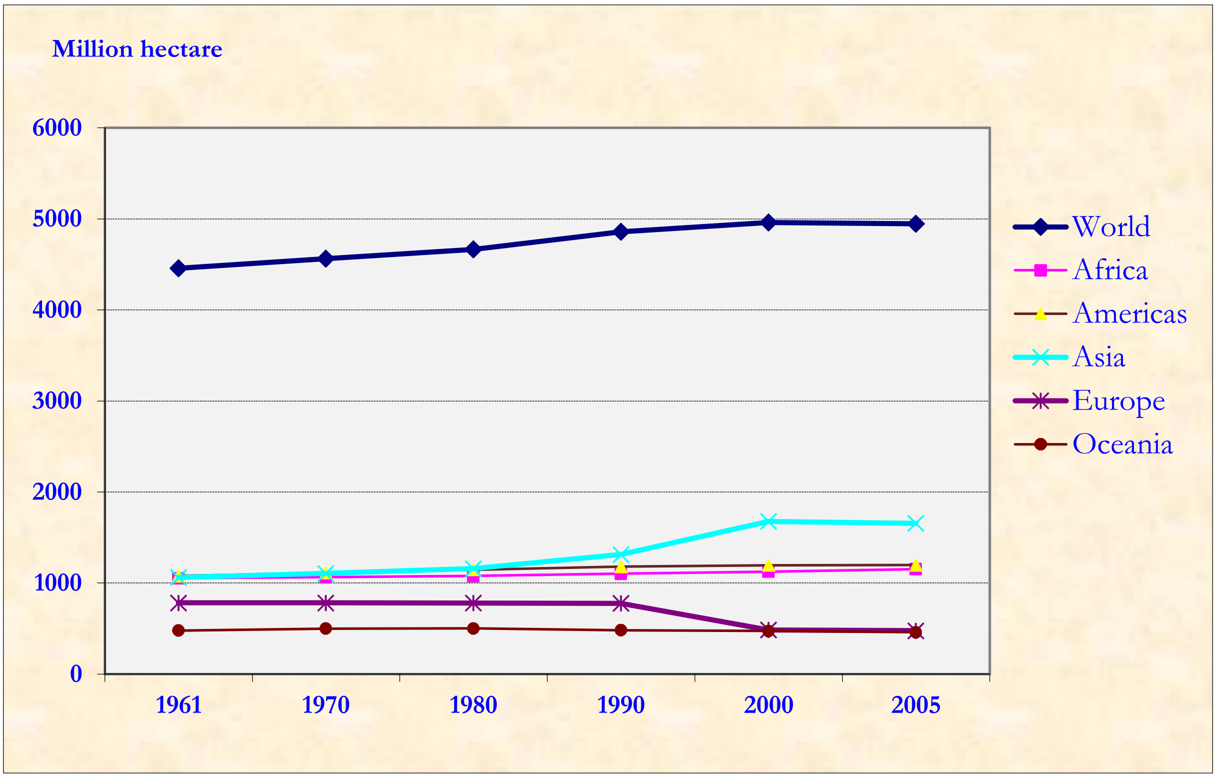

Figure 2.27b: The world agricultural land area distribution. *Source: FAO (2009a)*

[11] *(Country groups are those specified in the United Nations classification, refer to http://faostat.fao.org/)*

Today, agricultural land use distribution depends on macro land policies and general land use planning where bio-physical, technical, and socio-economic factors are integrated and balanced to achieve the goals of economic growth and environmental protection. At different periods of societal development, policies on land use in general, and on agricultural land use in particular, are improved and upgraded with the aim being to maximise the potential of land.

At the national level, agricultural land use is distributed or allocated depending on a strategic land use policy based on socio-economic development goals. Land managers and policy makers will weigh carefully the total natural land area available, land demands for industry, construction and urban development (housing, infrastructure, factory building), land demands for grazing, forestry, wildlife, ecological tourism, and land for food security as part of the key objective for land use planning (FAO, 1993).

There are many research projects and arguments relating to land policies worldwide, on topics such as land redistribution, land reallocation, and land reforms; as well as their impacts (Lerman, 2009; Swinnen, 2002; May and Lahiff, 2007; Bradstock, 2006; Bryden and Geisler, 2007; Ding, 2003; Gorton, 2001; Kinsey, 2004; Valente, 2009). Hard policy has been the topic of a large body of descriptive and analytical literature (Lipton, 2009). This literature contends that there is a growing consensus among rural specialists and economists on the importance of land reforms.

The modern era of land reform began in Prussia with the French Revolution. Slowly, associated with many fits and starts, these reforms have led to the redistribution of land to the actual tillers. The EU completed this agenda after World War I with land redistribution undertaken in southern Italy, Mexico, Russia and during the Chinese revolution, leading to the first countryside redistribution outside of the EU (Lipton, 2009).

These land reform policies have resulted in both positive and negative impacts. They helped many countries eliminate a hunger situation that has existed for a long time and has allowed them to become exporters of agricultural products (e.g. Viet Nam) (Son *et al.*, 2006). These countries are now prosperous, and have increased average incomes and improved income contribution. They have reduced poverty (e.g. in Zimbabwe)

(Chitiga and Mabugu, 2008), and they have seen significant positive effects on the long-term accumulation of human capital (Klaus *et al*, 2008).

However, in some cases, the inappropriate land reform policies have led to significantly lower productivity (Klaus *et al*, 2008), and the negative and significant impact of land reform on rural poverty remained intact (Besley and Burgess 1998). During the execution of the land reforms and the establishment of new patterns for land use types, agricultural land use has been relocated and redistributed.

Figures 2.28a and 2.28b reveal that Asia globally has the dominant agricultural area (34%) followed by the Americas (24%) and Africa (23%), while Europe (10%) and Oceania (9%) have the smallest area of agricultural land. This explains why most agricultural products in the world import-export markets come from Asia and the Americas. In Asia, the agricultural area has been divided into five typical regions (FAO, 2009a), the widest is Western Asia and the narrowest is South-Eastern Asia. Despite owning the smallest agricultural area, countries in South-Eastern Asia have been generating and contributing significantly to the global agricultural product market, particularly rice exports from Thailand and Viet Nam.

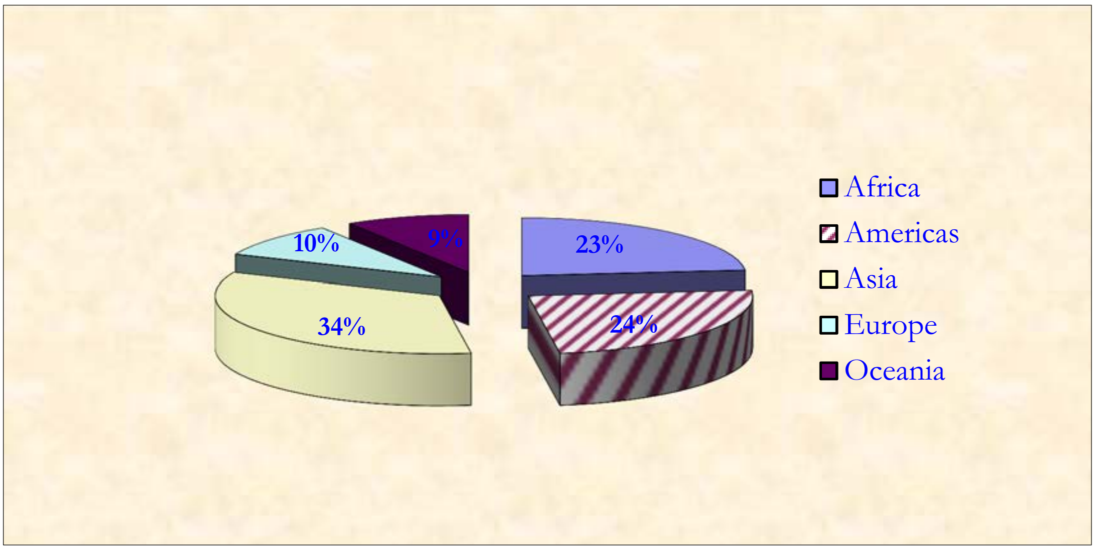

Figure 2.28a: World agricultural land use distribution in 2009. *Source: FAO (2009a)*

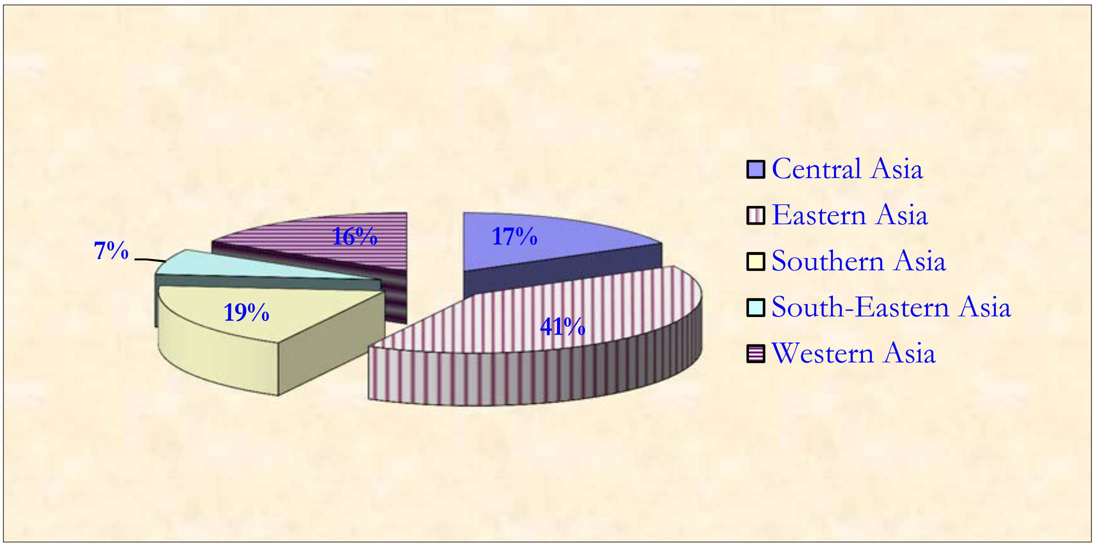

Figure 2.28b: Asian agricultural land use distribution in 2009. *Source: FAO (2009a)*

To sum up, the world's agricultural land is distributed in different ways, depending on climatic and soil factors (bio-physical) and technical factors, but also according to cultural and socio-economic considerations. The majority of croplands, where rice, wheat, legumes and corn are grown, are in the Northern Hemisphere, in the temperate zone, and in South and Eastern Asia. Areas primarily for livestock are in Africa, South America and Australia (UNEP/GRID-Arendal. 2007).

The UNEP/GRID-Arendal (2007) classifies world agricultural land into six categories, (1). agriculture <20% of land area or no growing season, (2). cropland/ grazing land mosaic, (3). cropland >50%, (4). cropland>85%, (5). grazing land >50%, and (6). grazing land >85% (Figure 2.28c). Cropland is distributed mainly in India, China, the Russian Federation, Eastern Europe, and the North Americas. While, grazing land covers mostly China, the Russian Federation, Mongolia, Kazakhstan, Australia, and the North Americas.

2.8.3 Viet Nam Mekong Delta agricultural land distribution

The Mekong Delta (MD) includes 12 Provinces and one city (*see Chapter 5*). Agricultural land area in the MD is approximately 2,560,000ha; it has up to 27% of the agricultural land area of the nation (GSO, 2008). Kien Giang, Long An, An Giang, Dong Thap, and Soc Trang are the top four Provinces with the largest area of agricultural land. Data in Table 2.5 show that agricultural land area in the Mekong Delta is positively correlated with total natural land area. Provinces with large total natural land areas e.g. Kien Giang and Long An have large agricultural land areas.

Meanwhile, some provinces having a smaller total natural land area e.g. Can Tho and Bac Lieu, and often have less area for agricultural production. However, the dominance of agricultural land over total natural land differs between provinces. For example, the total natural land area of Ca Mau Province is 533,200ha and its allocated area for agriculture is 142,000ha (26.6%). Can Tho Province has a much smaller total land area compared to Ca Mau Province, with 140,200ha, but Can Tho uses 114,000ha (81.3%) for agricultural production.

The Mekong Delta agricultural land distribution is fragmented, and the topography is diverse. The MD covers six agro-ecological zones, from the fresh water alluvial zone to the Ca Mau Peninsula with diversified farming systems (*for further information on agricultural land use and farming systems in the Mekong Delta, see Chapter 5*).

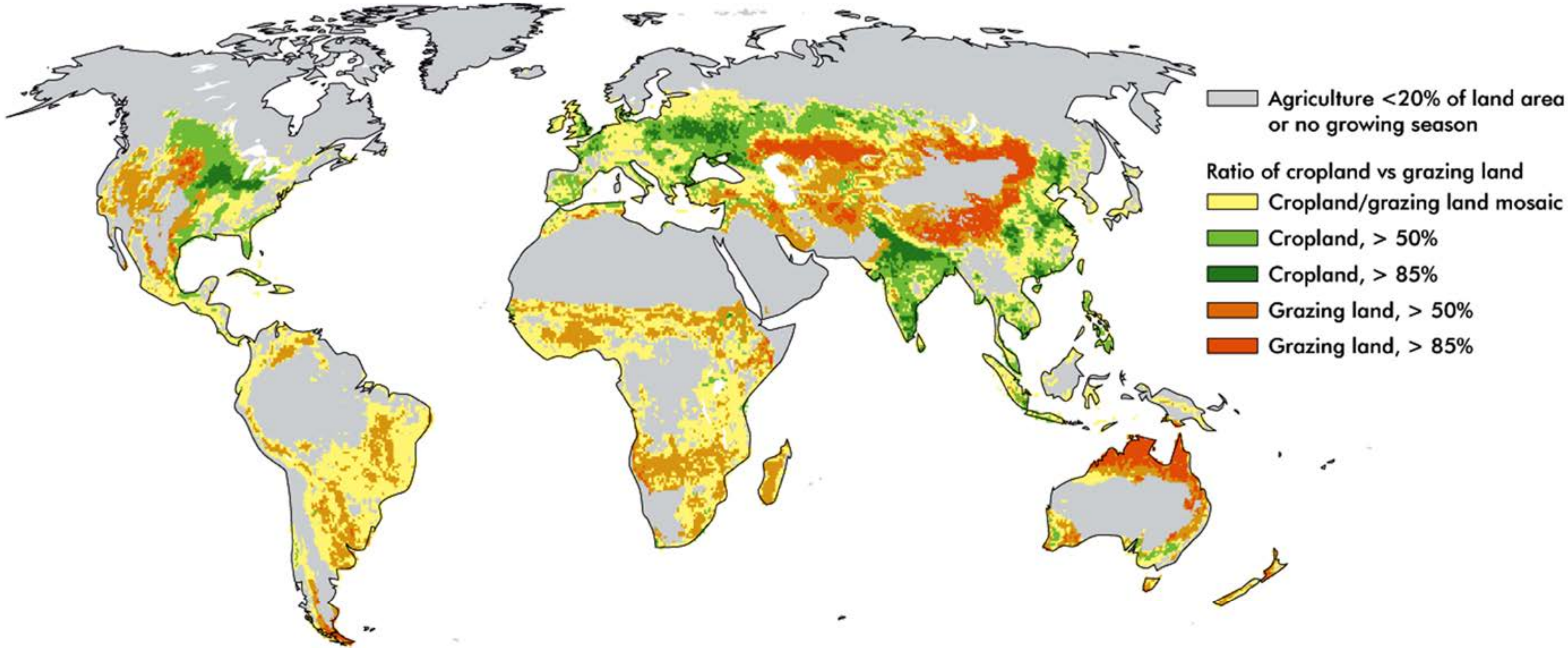

Figure 2.28c: World agricultural land distribution by cropland and grazing land

Source: UNEP/GRID-Arendal (2007)

Table 2.5: Agricultural land distribution in the Mekong Delta, Viet Nam

Provinces	Total areas *(1,000ha)*	Agricultural production land *(1,000ha)*	Share (%)
Kien Giang	634.6	439.1	69.2
Long An	449.4	303.3	67.5
An Giang	353.7	280.5	79.3
Đong Thap	337.5	259.5	76.9
Soc Trang	331.2	214.4	64.7
Tien Giang	248.4	176.1	70.9
Tra Vinh	229.5	149.8	65.3
Ca Mau	533.2	142.0	26.6
Ben Tre	236.0	136.2	57.7
Hau Giang	160.1	132.4	82.7
Vinh Long	147.9	115.4	78.0
Can Tho	140.2	114.0	81.3
Bac Lieu	258.5	97.9	37.9
Mekong River Delta	**4060.2**	**2560.6**	**63.1**
Whole country	**33115.0**	**9420.3**	**28.4**

Source: GOS (2008)

Commonly, the agricultural land use distribution varies from place to place. It depends on the total natural land area available, native characteristics of the land resources, and the land policies of localities. Evaluating the land resource to determine its capability, and to introduce a suitable land use type to effectively utilize the land resources, is the ultimate goal of sustainable development. Later sections in the next chapter discuss how to evaluate the suitability of land for agriculture.

2.9 Summary

In this chapter, common contributions of the agricultural sector to socio-economic development and the negative impacts of the agricultural practices in different contexts, from the global to local scale, have been presented. Further, the concepts relating to land and more specifically agricultural land, as well as agricultural land use distribution have been discussed. The author also reviewed and summarized information in relation to the agriculture sector and agricultural land use.

The review revealed that the agriculture sector has accelerated socio-economic development and human well-being. It contributes to economic growth, job creation, income improvement, food security, and poverty reduction, particularly in the rural areas in developing and agriculture-based countries in Asia and Africa. For Viet Nam, agriculture still contributes positively to the GDP and the export value and is a main sector in the national economic structure. Agriculture will continue to play a key role in Viet Nam economic development.

The review also revealed that agricultural practices, however, also generated negative impacts on the environment, including conversion of natural ecological systems, forest land to farmland; aquatic nutrient pollution (generated by aquaculture), terrestrial habitats and groundwater, abundance and residue of agro-chemicals, especially bio-antis accumulation or persistent organic agricultural pollutants.

An agricultural management system, designed to determine the capability of lands in order to balance economic profit and environmental goals, is the ultimate purpose of this research. Therefore, following this discussion on agricultural land use distribution, a framework and approaches, as well as support tools for land evaluation, will be discussed in the next chapter.

CHAPTER 3: APPROACHES AND SUPPORT TOOLS FOR LAND EVALUATION (Literature Review continued)

3.1 Introduction

This study aims to develop a theoretical model (AMS) for farmland capability assessment. Reviewing the principle knowledge and previous studies relating to methods, techniques, as well as support tools for land evaluation is essential. It assists with the creation of the model and makes sure the model is well designed. This chapter presents approaches and methods used for land evaluation and their adoption. Particular focus will be on two original fundamental systems designed by the FAO and the USDA. The theoretical framework for land evaluation and current land capability assessment trends, are then outlined. Common principles, implementation procedures, and land capability classification systems are included in the chapter. Finally, support tools for land capability evaluation encompassing GIS and MCDA[12] (e.g. AHP technique) are discussed.

3.2 Approaches to land evaluation

3.2.1 Land capability and suitability

The concept "land suitability" has been in use for a long time. It was formally used in a framework for land evaluation developed by the FAO (1976), and then used worldwide by many land assessment experts (Rowe, 1981; FAO, 1993; Delli *et al.* 1996; Rossiter, 1996; Mongkolsawat *et al.*, 1997; Laborte *et al.* 1999; Prakash, 2003; Malczewski, 2004; Boonyanuphap *et al.*, 2004; Ritung, 2007; Liu *et al.*, 2007; Reshmidevi *et al.*, 2009; Mauricio *et al.*, 2009; De la Rosa, 2004; 2008; 2009; Lingjun *et al.*, 2008) in land evaluation for a range of purposes, such as land use planning and land improvement.

Land suitability is an assessment of the fitness and the degree of appropriateness of a given type of land for a specified kind of land use (e.g. one rice-cropping cultivation, intensive catfish raising) (FAO, 1976; 1993; Rowe *et al.*, 1981; The ACT Parliamentary Counsel, 1999; Verheye, 1996; Choudhury & Jansen, 1998). In some instances, it is

[12] *Refer to item 3.7 in this chapter*

recommended that land suitability could include Actual Land Suitability (present conditions) and Potential Land Suitability (after improvement) (Ritung *et al.*, 2007). In the collection of land resource information, land suitability requires a much more detailed collection, pertinent to a particular land use e.g. soil nutrient status, water availability.

There is a close relationship between suitability, sustainability, adaptability, stability, land degradation, and land use. Land suitability is a function of soil properties and land characteristics in terms of whether the land quality meets crop requirements on a sustainable basis when the diverse fields of technical, biophysical, ecological and socio-economics are considered (FAO, 1993). This indicates that the hazards of soil erosion, degradation, and other limiting factors should be taken into account for land suitability evaluation (FAO, 1983; 2007b).

Land suitability is an extremely important component for sustainable use of the land resource. Sustainable land use involves a critical balance between production and conservation (FAO, 1993). The utilisation of land resources is considered in relation to present human needs while simultaneously conserving resources for future generations (Bruntland, 1987). Land suitability considers the comparative advantage of developing the land against retaining the land as a natural resource.

The FAO (1976) states that the term "land capability" is used in a range of land classification systems, such as that used by the Soil Conservation Service of the U.S. Department of Agriculture (USDA) (Klingebiel and Montgomery, 1961). In the USDA system, land capability expresses the effect on the land in relation to physical land conditions, including climate, on the total suitability for use, without damage, for crops, grazing, woodland, and wildlife. It considers the risks of land damage from erosion and other causes, and the difficulties in land use owing to the physical land characteristics e.g. climate (FAO, 1976; USDA, 2010a).

In land capability assessment, land mapping units are grouped primarily on their basic capability to produce common cultivated crops and pasture plants without deterioration of the land over a long time period (FAO, 1976; 1993; Grose, 1999; USDA, 2010a). Some land evaluators view capability as the inherent capacity of the land to perform at a given level for a general use, rather than the adaptability of a given land area for a particular land use type; others state capability as a classification of land primarily in relation to degradation hazards, whilst some regard the terms "suitability" and "capability" as interchangeable (FAO, 1976; 1993; Rowe, 1981; Grose, 1999).

The ACT Parliamentary Counsel (1999) and Grose (1999) advise that, land capability and land suitability should not be confused. Because land suitability considers how suitable a particular site is for a specific use, and this depends on land capability and a range of other factors such as proximity to centres of population, land tenure, and consumer demand. Grose (1999) notes that land suitability adds the biophysical features and does take into account economic, social and/or political factors in evaluating the 'best' use of a particular land area. Land capability classification gives a grading of land for broad scale agricultural uses; whereas land suitability is applied to more specific, clearly defined land uses, such as land 'suitable' for intensive rice cultivation.

As a result of these interpretations of "land suitability" and "land capability", the term "land capability" is used in this research. Therefore, land evaluation actually is to determine the land capability, which is defined concisely as the ability of land to sustain a specified land use without resulting in significant onsite or offsite degradation or damage to the land resources (FAO, 1976, 1993; Rowe *et al.*, 1981; The State Planning Commission, 1989; The ACT Parliamentary Counsel, 1999; USDA, 2010a). Hence, the capability of farmland is the land capability for agricultural purposes, including the capability for farming systems involving animals and plants, forestry and aquaculture, and cultivation of other organically derived products (pharmaceuticals) as well (ALC, 2009; ODTGAUS, 2009).

3.2.2 The importance and purpose of land capability assessment

Land in general, and farmland in particular, is a fragile and limited non-renewable resource. Decisions on land use alternatives are complex because they require the land users and land managers to know the land capability and the necessary investments to fulfil land use objectives. This includes assessing both the land productivity under specified management conditions and associated risks, as well as deciding the action to take to reduce risks (Rowe *et al.*, 1981).

Understanding the bio-physical, technical and socio-economic constraints identified by a land capability assessment, becomes a major consideration in a land use planning exercise. It is generally effective to build solutions, to deal with these constraints or potential problems, into the planning phase of land use (The ACT Parliamentary Counsel, 1999).

Land (soil) capability, in the past, has been represented by soil quality, and the soil quality was evaluated on how well the soil performed all of its functions for the present and it could be conserved for future use. This cannot be determined by only measuring crop yield, water quality, or any other single variable. Soil quality cannot be measured directly, so soil scientists evaluate indicators. Indicators are measurable properties of soil or plants that provide clues about how well the soil can function (USDA, 2010b).

Indicators can be physical (soil structure, depth of soil, infiltration and bulk density; water holding capacity), chemical (pH; electrical conductivity; extractable N-P-K), and biological properties (microbial biomass C and N; potentially mineralisable N; soil respiration), processes, or characteristics of soils (De la Rosa and Sobral, 2008, p. 174) They can also be morphological or visual features of plants. Indicators can be assessed by qualitative or quantitative techniques. After measurements are collected, they can be evaluated by looking for patterns and by comparing results with measurements taken at a different time or field (USDA, 2010b, wp).

According to the Soil Quality Institute (USDA, 2010c, wp), the ultimate purpose of assessing soil quality is not to achieve high aggregate stability, biological activity, or some other soil property. The purpose is to protect and improve long-term agricultural productivity, water quality, and habitats of all organisms including people. By assessing soil quality, land users and managers can develop a sustainable management practice system (De la Rosa and Sobral, 2008).

Land capability assessment is driven by human values, goals and objectives and is mostly based on land quality (indicators). It is formed to provide information for particular purposes and needs at various scales and the assessment varies from the determination of a simple, single capability parameter to complex, multiple-capability parameters. It, also determines variations in the productivity of land with respect to the growth and management of plants. Assessment can be general or crop-specific and is a necessary step in the practical consideration of complex land characteristics (Hanson *et al.* 2001, p. 9).

Rowe *et al.* (1981) argue that land capability assessment systems can be designed to predict productivity and the effects of the land use types, or to determine required management techniques to gain land use objectives. Land capability assessment offers an analysis of bio-physical, socio-economic, and technical characteristics of land, and therefore it provides basic information for land use planning. Land assessment explores and provides related important information such as (FAO, 1993, wp; 2007b): (1) the current management mechanism of the land, and future perspectives if present practices remain unchanged; (2) possible improvements in management practices, within the present use; (3) other feasible uses of land that can possibly be relevant to the physical and socio-economic features; (4) land uses offering possibilities of sustained production; (5) existence of adverse effects, including physical, socio-economic problems, created from each use; (6) recurrent necessary inputs to achieve the desired production and minimize the adverse effects, as well as identifying the benefits of each form of use;

In the case of a new land use where significant change is undertaken on the land itself, for examples in irrigation schemes, farming systems, or flooding control regimes, land capability assessment also reviews the following additional issues: (7) feasible and necessary changes in the condition of the land, trends of change; (8) non-recurrent necessary inputs to implement these changes.

The result of land capability assessment does not in itself determine the land use types, but provides data on the basis of which such decisions can be made through assessing alternative potential forms of use generated for each area of land, including the consequences, beneficial and adverse.

Land capability assessment supports many different disciplines and purposes. It can be used for land use planning, exploring the potential for specific land uses and assessing the need for improved land management or land degradation control. The primary objective is the improvement and sustainable management of land for the benefit of land users. According to FAO (2007b), land evaluation, as given in the original framework (FAO, 1976) mainly refers to the identification of adverse effects and benefits of land uses.

To sum up, land or farmland capability assessment has a very significant role to play in planning and utilisation of the land resource. By this means, data related to the land including its soils, climate, vegetation, farming systems will be integrated and analysed to offer realistic alternatives for improving the use of the land. Land capability identifies vital elements, which help decision makers to avoid the costly mistakes that have resulted from investment in forms of land development unsuited to local environmental conditions.

Obviously, the determination of the capability of farmland is a tool which can be useful for agricultural land planners, land developers, and Government Authorities to assist in evaluating alternative practices or general designs that will overcome unfavourable soil or terrain characteristics and minimise off-site effects, such as sedimentation and pollution of waterways (The ACT Parliamentary Counsel, 1999).

This determination is based on the analysis and integration of technical, bio-physical, policies and institutions, and socio-economic factors by the interactions and relations between these factors, as well as analysis and careful consideration of factors limiting the capability of farmland. This provides a fundamental guidance for land resource managers, land policy makers, agricultural development planners, and land users in planning, managing, and sustaining the land resource.

3.2.3 The USDA Land Capability Classification-LCC technique

Land evaluation can be defined as the process of evaluating land performance when used for specified purposes (FAO, 1985), it is a method used to explain or predict the utilised potential of land (Van Diepen *et al*., 1991). Once the land potential is determined; land use planning can proceed rationally, at least with respect to what the land resource is capable of (FAO, 1993). Thus, land evaluation is a tool for strategic land-use planning. It predicts land performance, both in terms of the expected benefits, constraints, as well as the expected environmental degradation when the land is used (Rossiter, 1996).

Rossiter (1996, p. 166) advises that the logic that makes land evaluation possible and useful includes: (1) land varies in its physical, social, economic, and geographic characteristics ("land is not created equal"); (2) this variation affects land uses: there are areas more or less suited to each use type in physical or economic terms; (3) the variation is at least in part systematic, with definite and knowable causes; (4) the variation (physical, political, economic and social) can be mapped by surveys, for example the total area can be divided into smaller regions with less variability than the entire area; (5) the behaviour of the land when subjected to a given use can be predicted with some degree of certainty, depending on data quality on the land resource and sufficient understanding about the relation between land and land use; (6) land suitability for the various actual and proposed land uses can be systematically described and mapped; (7) decision makers such as land users, land-use planners, and agricultural support services can use these predictions.

Land evaluation originated from the need for a comprehensive assessment on land performance when used for different purposes. Many countries had developed their own systems for land evaluation by 1970 (FAO, 2007b). Land assessment techniques and approaches evolved midway through the 20th century in response to devastating land degradation throughout Australia, Africa, India and the United States (Burrough, 1978).

Before the generation of the Framework for Land Evaluation formed by the FAO (1976), the land capability technique developed by the U. S. Department of Agriculture

(USDA), (Klingebiel and Montgomery, 1961) pioneered land evaluation endeavours and this is still the principal method used worldwide, either directly or in modified forms (Hanson *et al.* 2001; FAO, 2007b). The latest version of the National Soil Survey Handbook (NSSH) was updated on the 18/10/2009 by the USDA (USDA, 2010a). In the NSSH, land potential is assessed based on soil properties using soil potential ratings associated with other resource information, as a guide to making land use decisions.

The soil potential ratings help decision makers to determine the relative suitability of soils (relative quality) for a particular use as compared with the suitability of other soils in a given area. They often concentrate on yield or performance level; the relative cost of applying modern technology to minimize the effects of any soil restrictions, and the adverse effects of continuing limitations, on social, economic, or environmental values (USDA, 2010a).

Definition of soil potential rating (USDA, 2010a, wp), includes five classes: (1) very high potential: production/ performance is at least at local standards or above because soil conditions are exceptionally favourable, installation or management costs are low, and soil limitations are insufficient; (2) high potential: production/ performance is at or above the level of locally established standards, the cost of measures to overcome soil limitations are judged locally to be favourable in relation to the expected performance or yields, and soil limitations that continue after corrective measures are installed do not detract appreciably from environmental quality or economic returns; (3) medium potential: production/ performance is somewhat below locally established standards, the costs of measures to overcome soil limitations are high, or soil limitations that continue after corrective measures are installed detract from environmental quality or economic returns; (4) low potential: production/ performance is significantly below local standards, measures that are required to overcome soil limitations are very costly, or soil limitations that continue after corrective measures are installed, detract appreciably from environmental quality or economic returns, and (5) very low potential: production/ performance is much below locally established standards, severe soil limitations exist for which economically feasible measures are unavailable, or soil limitations that continue after corrective measures are installed seriously detract from environmental quality or economic returns.

Soil interpretation can be used to determine the potential of soil which in turn can be used for land potential evaluation. The USDA method reveals that primary land potential was assessed based on physical parameters such as soil depth, soil structure, soil texture, landform, altitude, rainfall, temperature and growing season. The technique utilises the parametric approach to land classification, which gathers specific physical parameters independently and then combines them to form land capability classes (Land Capability Classification-LCC) (Hanson *et al.*, 2001).

The LCC purpose was to offer recommendations for land users on the most appropriate use of their farms. Land mapping units were classified into eight classes driven by the basic ability to support general kinds of land use (e.g. produce common cultivated crops and pasture plants) without degradation or significant off-site effects (USDA, 2010a). Every class is determined by limitations to land use such as erosion hazard, flood risk, slope gradient, stoniness, low fertility, rooting zone restriction and climate. Thus, as limitations increase, land-use options decrease (Hanson *et al.*, 2001).

The first four classes relate to arable land, in which the limitations to the use and need for conservation measures and required careful management, increase with class number (Helms, 1992; FAO, 2007b, p. 5; USDA, 2010a, wp). The remaining four classes are unsuitable for cropland, but may have uses for pasture, woodland, grazing, wildlife, recreation and other purposes (FAO, 2007b, p. 5; USDA, 2010a, wp).

In the broad classes, subclasses indicate special limitations such as erosion, excess wetness, problems in the rooting zone, and climatic limitations. Within the subclasses, capability units present some indication of expected yields and management needs. The capability units are soil groups that have common responses to pasture and crop plants under similar systems of farming but requiring different management. Units are locally defined for each survey and are described in detail, which make the system applicable to local situations. The first category listed in the LCC system, is a grouping of one or more individual soil mapping units having similar potentials and continuing limitations or hazards (FAO, 2007b; USDA, 2010a, wp).

Despite identification for local land use and management, the LCC only considers relatively permanent, static land characteristics and does not take into account socio-economic components. The system provides a general appraisal, and does not assess capability separately for each kind of land use. It relies on a ranking of kinds of use in an implied order of desirability, with agriculture preferred over forestry, and both over wildlife conservation (FAO, 2007b). The USDA LCC system will be revisited in the coming sections of this Chapter.

Adoptions of the USDA LCC technique

The LCC developed by the USDA technique was disseminated, modified and applied in many parts of the world.

Rowe *et al.* (1981) built specific guidelines for land capability assessment in Victoria, Australia. In the guidelines, land capability is grouped into only five classes from very high capability to very low capability corresponding to an increase in limitations. The authors also formed a set of land capability rating tables for engineering uses, septic waste disposal, earth resources, land-based recreation, grazing, cropping, and forestry.

The British Land Capability Classification, adapted from the USDA technique, is an assessment of the land capability from known relationships between crop production and management and the soil physical factors, topography and climate. It is essentially a negative approach in which land is graded according to mixed qualitative and quantitative measures of limitations to land capability. Land capability is rated into seven classes. Class 1 land has a wide range of uses with few (if any) limitations, the remaining six classes suffer from increasingly severe limitations and are progressively less flexible in the range of their potential land uses. Land capability subclasses are defined on the basis of one of more permanent or semi-permanent physical factors that limit production. (http://www.geog.leeds.ac.uk).

In recent years, the LCC has gained international recognition as a tool for land resource assessment. Many studies have reported on the use of the LCC. Land capability classification for agriculture in British Columbia, Canada (MAF and ME, 1983), Land Capability Assessment for the Wellington-Blackwood Survey (Peter, 1996), Agricultural Land Classification of England and Wales (MAFF, 1998), Pre-and

Post-mining land capability assessment at Quintette Operating Corporation (Smyth and Bittman, 1998), Mapping Land Resource Potential and Agricultural Pressure in Papua New Guinea (Hanson *et al.* 2001), Land Capability Assessment for Onsite Domestic Wastewater Management (EPA, 2003), Soil-landform units, land capability analyses and lands hazards (Robinson *et al.*, 2004), Developing a land capability system for the Western Plains of New South Wales (Smith *et al.*, 2004), a revised land and soil capability classification for New South Wales, Australia (Murphy *et al.*, 2004).

Several other studies concentrated on methods, techniques, or procedures for execution of the LCC. Guidelines for Land Capability Assessment for Local Rural Strategies, Western Australia (The State Planning Commission, 1989), Land Capability Handbook-Guidelines for the Classification of Agricultural Land in Tasmania, Australia (Grose, 1999), Land Capability Assessment Guidelines (The ACT Parliamentary Counsel, 1999), Guidelines for Soil Quality Assessment in Conservation Planning (USDA, 2001), Land Capability Classification System for Forest Ecosystems in the Oil Sands in Canada: Field Manual for Land Capability Determination (CEMA, 2006), as well as National Soil Survey Handbook updated on 18/10/2009 by the USDA (2010a).

As a part of the USDA-ARS Soil Resource Management National Program, Andrews *et al.* (2004) designed the Soil Management Assessment Framework (SMAF). The framework has flexibility to accommodate site-specific differences due to soil, crop, climate and other factors within the scoring curves. It can help select appropriate soil quality indicators, interpret their measurement outcomes, and integrate the interpretations to accurately assess the effects of management practices on overall soil function. However, the authors also recognized that, the framework needed to be referenced with each of the biological, chemical and physical indicators under a variety of management practices and ecosystems to improve selection rules and interpretation algorithms relative to management goals and site-specific factors.

The SMAF is specified by a study on Soil Quality Assessment in the Iowa South Fork Watershed (Karlen *et al.*, 2007). The study describes soil quality assessment samplings conducted between 2003 and 2006 to evaluate land management effects and to help determine what conservation practices are needed to protect soil and water resources within the South Fork Watershed of the Iowa River, as well as revealing indicators to further improve the SMAF assessment tool.

A majority of the approaches and techniques in the studies above have been modified from the original USDA method; the USDA technique has been improved and developed flexibly to suit a wide range of different specific conditions in the field of land capability assessment. This provides a critical opportunity for the LCC to be become an international standard for land capability determination.

3.2.4 The FAO method for land evaluation

According to Hanson *et al.* (2001), limitations to techniques based on the USDA method are well founded and identified by authors such as Moss (1978, 1985), Rowe (1980, 1981)[13], and Bouma *et al.* (1993). The authors identify common criticisms which include: biased assumptions about suitable land utilisation strategies, such as undertaking permanent annual cropping on high potential land; the inadequate identification of permanent and temporary land-use constraints; and the qualitative and often unverifiable nature of data processing methods.

Fortunately, these limitations have been addressed and supplemented by the Framework for Land Evaluation-FLE (FAO 1976, 2007b). The FAO method utilises ecological parameters directly relevant to crop growth through verifiable and repeatable data-processing methods. This technique is focused on providing levels of suitability for predefined land-use types based on complex land characteristics in terms of land qualities, such as water availability, nutrient availability, oxygen availability, rooting conditions and erosion hazard (FAO 1976, 1993, 2007b).

Similar to the USDA LCC, the FAO method has been widely adopted and in some cases improved, adjusted, modified, and developed for worldwide application.

Laffan (1994) utilises the FAO (FAO, 1976) land qualities to determine the suitability for crop growth supported by additional factors, such as traffic-ability, workability,

[13] Rowe, J. S.

flood hazard, erosion hazard and landslide hazard, to determine suitability for practical land management. The Automated Land Evaluation System (ALES) designed by Rossiter and Van Wambeke (1997) has further improved the FAO technique through automation of the evaluation process, using decision trees for the classification, and the ability to query outcomes. In addition, ALES can determine economic suitability through techniques such as gross margin analysis, predicted net present value, cost/benefit ratios and internal rates of return.

Messing *et al.* (2003) basically started from the concepts of the FAO FLE (FAO, 1976) to develop criteria for land suitability evaluation in a small catchment on the Loess Plateau in China. The authors integrated participatory (land users) planning, land evaluation and soil erosion modelling into a united system to identify an approach for land use planning. The results enable biophysical land characteristics to be linked with socio-economic land characteristics using a participatory approach and soil erosion modelling to construct scenarios for a more sustainable use of the land.

An interesting approach is a combination of the FAO (1976) technique (a physical land suitability index computed using a fuzzy set approach in a Geographic Information System, GIS) and Economic Suitability assessment (EconSuit). The product supports dynamic assessment of economic land suitability for major economic crops in Thailand (Samranpong *et al.*, 2009). The procedure bypasses crop modelling and permits suitability to be defined on a continuous scale with a graphic interface. Economic land evaluation is accomplished by assigning field survey data to land mapping units using spatial interpolation. The results show that the EconSuit system is helpful for planners and decision makers in finding alternative land use options to cope with rapid market and policy changes. Further refinement is necessary to improve the spatial interpolation and the integration of socio-economic and bio-physical data.

Rahimi Lake *et al.* (2009) also based their technique on the FAO principles when integrating qualitative and quantitative land characteristics to evaluate the suitability for Olive (*Olea europaea* L.) groves in the Roodbar Region, Iran. The research implies that associated with the quantitative approach, the qualitative land suitability evaluation assists decision makers in ensuring that lands are used according to their capabilities to satisfy land users' needs for present and further generations, and thus sustaining the ecological and economic productivity of land as a natural resource.

Other countries such as China evaluate and classify the land based on the basic of research by the FAO FLE, the Australian CSIRO Division of Land Research, and the U.S. Soil Conservation Service (Fu, 1998). In the early 1980s, India also adopted the FAO approach to conduct land suitability analysis (Murthy *et al.*, 1983). In Italy, Corona *et al.* (2008) assessed land suitability for short rotation coppices (groves) by combining Multi-Criteria Evaluation methods and Fuzzy Membership Functions based upon the basic concept of land suitability/land capability developed by the FAO (1976).

Over more than a quarter of a century, the FAO method has been adopted and implemented in many countries of the developing world (FAO, 2007b), including Kenya (FAO, 1980; Kassam *et al.*, 1991), Indonesia (FAO, 1980; Hashim *et al.*, 2002; Ritung *et al.*, 2007), Mauritania, Ethiopia, Philippines (FAO, 1980), Viet Nam (Trung, 2006; Son, 2005; Giap *et al.*, 2005), Bangladesh (Hossain *et al.*, 2007, 2009, 2010), Jamaica (Batjes, 1986), Malaysia (Biot *et al.,* 1984), Nigeria (Hill, 1979), Algeria (Delli *et al*, 1996), Thailand (Samranpong *et al.*, 2009), and Sri Lanka (Ekanayake, & Dayawansa, 2003).

The present trend is that, land evaluators prefer to combine advanced aspects of the USDA LCC and the FAO FLE, and introduce modifications (if applicable) associated with support tools to create a flexible technique for land evaluation and assessment suitable for different specific sites worldwide (FAO, 2007b; Hossain *et al.*, 2007; Corona *et al.*, 2008; Hossain *et al.*, 2010). An example of this flexible combination is the assessment of the land suitability for different crops associated with the generation of cropping patterns in a watershed using quantitative land evaluation procedures. This study combines the USDA LCC and FAO Land Evaluation Procedure for Soil Site Suitability and is applied to various land utilisation types as studied by Matin and Saha (2009).

The principles set out in the FAO FLE have been amplified in guidelines for rain-fed agriculture, forestry, irrigated agriculture, extensive grazing (FAO 1983, 1984, 1985, 1991a), for the special conditions encountered in sloping areas (Siderius 1986). Further, the FLE and the USDA LCC seem to be the control framework for land suitability/capability evaluation on a range of land utilisation types, such as crab culture (Salam *et al.*, 2002), rice, maize and soybean cultivation in Viet Nam (Hao, 2008; Ni, 1993; Ha *et al.*, 2006), shrimp farming (Giap *et al.*, 2005), Robusta coffee production (D'haeze *et al.*, 2005), giant prawn (*Macrobrachium rosenbergii*) farming in Bangladesh (Hossain *et al.*, 2010), vegetable crops cultivation in Nepal (Baniya, 2008), and Musa (ABB group) plantation (Boonyanuphap *et al.*, 2004).

3.2.5 Land evaluation systems originating from the FAO method

The FAO FLE has been used widely as a methodology for land capability/suitability identification. The FAO (2007b) has a concise record of land evaluation systems that have originated since the FAO framework. These are presented below:

Soil survey and crop yield interpretations

The Fertility Capability Classification (FCC) is a technical soil classification system, focusing quantitatively on the physical and chemical characteristics of the land that are important to fertility management (Sanchez *et al.*, 1982). Land information is obtained from the soil profile descriptions and associated field data, laboratory analysis data, and soil classification (Soil Taxonomy). The FCC presents the land characteristics important to management decisions, rather than ranking. Its application is to upland and wetland rice crops, pasture, forestry, and agro-forestry needs in high or low input systems. The system provides management statements for the classified soil and lists the general adaptability of various crops. Recently, Sanchez *et al.* (2003) has a report on the use of the FCC for soil quality assessment in tropical regions.

Another approach is to use productivity indices. Productivity indices are mostly multiplicative indices tied to land characteristics, and are used to give a relative ranking of land with respect to the yield. Rooting depth and available water capacity are the prime land characteristics. Some productivity indices also rely on a few critical land characteristics, such as pH and bulk density, to rate soils (Pierce *et al.*, 1983).

Soil potential ratings (Beatty *et al.*, 1979) are classes that indicate the relative quality of a soil for a particular use compared with other soils in a given area. Yield or performance level, the relative cost for modern technology to minimize the effects of soil limitations, and the adverse effects of continuing limitations on social, economic, or environmental values are used in assigning ratings.

The Land Evaluation and Site Assessment (LESA) system was developed by the US Soil Conservation Service, in 1981. Before the LESA was adopted, land evaluation involved the rating of the quality of soil for agriculture based on a land capability classification, important farmland classes, soil productivity, and soil potential (Steiner, 1987). Site assessment then involved the weighting of a number of attributes including: agricultural land use, agricultural viability factors, land-use regulations and tax concessions, options for the proposed new use, the impact of the proposed use on agriculture, compatibility with local plans, and existing urban infrastructure (Steiner, 1987).

Agro-Ecological zoning

Agro-Ecological Zoning (AEZ) is a quantitative adaptability assessment of crops to a certain land region. It is an expanded and quantified method based on the FAO framework concepts. Agro-ecological zones refer to a division of the earth's surface into homogeneous areas with respect to the physical factors that are most important to plant production. The FAO (2007b) discusses that the continental-scale efforts are preferred to obtain a first approximation of the production potential of the world's land resources; while the physical data base necessary for planning future agricultural development and zoning for rural development policies are provided by the national-scale AEZ maps and reports. The FAO (1981) has reported on continental assessment that was carried out for Africa, Southeast and Southwest Asia and Central and South America, and a study on a national scale, executed in Kenya (Kassam *et al.,* 1991).

Combination of land evaluation and farming systems analysis

Land evaluation (LE) and farming systems analysis (FSA) approaches are probably the most elaborate of several methods that have evolved to analyse and assess the productivity of lands and farms. The LE started as a physical land assessment method developed by soil scientists prior to the incorporation of socio-economic aspects; the main disciplines involved are soil science and agricultural economics. The FSA was built by agronomists and agro-socio-economists (Luning, 1991).

The integration of the LE and the FSA as a sequential procedure (LEFSA) is intended as a tool for land use planning in relation to cropping and livestock systems to geo-reference land use types, and farming systems at different levels (national, regional, farm, farm components) (Luning, 1991; Fresco, 1991). Both the LE and the FSA aim to improve agricultural land use. The FSA concentrates on farm level constraints with a view to developing improved farm management for different typologies of farmers, whereas the LE focuses on land suitability for certain land use types. In most cases, there is a close correlation between the land use type and the farming system (either cropping or livestock) such that land use types are components of farms (FAO, 2007b).

The LEFSA sequence as applied in the Zona Atlantica of Costa Rica aims to develop a method for determining alternative scenarios for sustainable land use as a regional system, land use system, and farm system (Fresco, 1991). It is also used for subregional level planning in the Mekong Delta, Viet Nam (Tri and Tri, 2005).

The Sustainable Land Management (SLM) approach is defined (World Bank, 2006a) as a knowledge-based procedure that helps integrate land, water, biodiversity, and environmental management (including input and output externalities) to meet rising food and fiber demands while sustaining ecosystem services and livelihoods. The SLM has five principle objectives embracing productivity, security, protection, viability, and acceptability.

An international framework for evaluating sustainable land management **(**FESLM**)** is designed to guide land suitability analysis, through a series of scientifically sound, logical steps (Smyth *et al.*, 1993). It comprises three main stages: 1) identify the purpose of the evaluation, specifically land use systems and management practices; 2) define the process of analysis, consisting of the evaluation factors, diagnostic criteria, indicators and thresholds to be utilized; and 3) identify the sustainability status of the land use system under evaluation. The FESLM is based upon indicators of performance, rather than land suitability such as in the FAO Framework (Smyth *et al*., 1993; Smyth and Dumanski, 1995).

Computerized land evaluation systems and GIS

Several computerized land evaluation systems use statistically derived, and analytically applied, land use models, while others use qualitative impact assessment approaches based on expert opinion and rules (FAO, 2007b). Geo-information technology provides the scientific means to satisfy the demand for quantifiable spatial information about land resources, for example pedometrics is used to meet the requirements for quantitative spatial soil information, for predicting soil properties at remote sites, for creating and analysing classifications, and for exploring multivariate relations (Webster, 1994). A GIS can provide essential management information or be used to develop a better understanding of environmental spatial relationships, and can be used for land suitability mapping and modelling (Corona, 2008), and for planning and management as a component of land use suitability mapping and analysis (Collins *et al*., 2001). These points will be discussed in detail, in the next sections of this chapter.

Land evaluation using earth observation

Campbell (2002) states that advanced technologies in Earth observation have provided new environmental data sources and techniques to upgrade spatial information on land cover, and to monitor changes due to human activity from a biophysical perspective (Turner, 1997). Remote sensing defined as the collection of data about an object from a distance (Pidwirny, 2006b), including aerial photography and satellite imagery, has great advantages in regions lacking qualitative and quantitative information on land cover (FAO, 2007b). Remote sensing imagery has been applied in mapping land-use and land cover, agriculture, soils mapping, forestry, city planning, archaeological investigations, military observation, and geomorphologic surveying (Pidwirny, 2006a; 2006b). Moreover, earth observation can helps land evaluators and land users to predict scenarios of land use changes over time.

In summary, despite its widespread and long-term application, the process of the FAO FLE (FAO, 1976) has been criticised by the scientific community for its qualitative and empirical base, which is not effective in addressing many new agro-environmental challenges where the dynamic characterisation of the interrelated physical and chemical processes are taking place in the soil landscape (Manna *et al.*, 2009).

An important requirement is that universal methods for land evaluation should not be recommended because each particular site requires a different set of land indicators, but several general principles can apply in most situations. The FAO and USDA approaches for land evaluation are concerned with developing common principles for land evaluation. Depending on specific circumstances, adapted versions of these approaches are generated and many adaptations outlined above go some way to address the FLE's short coming but more research is needed.

3.2.6 A theoretical framework for land evaluation

Land evaluation is an evolving issue that has been debated over the last decades, but up to the 1990s, Rossiter (1996) claims that "there has not been an explicit statement of the theoretical basis of land evaluation". To propose a unified theoretical framework that describes land evaluation models, the author has undertaken a critical literature review of existing models, ranging from models where each land unit is assessed separately, without regard to its actual position on the earth's surface, to models where a land unit's location must be considered, and further models where a set of land areas must be evaluated together.

Rossiter (1996, p. 185) presented a classification of land evaluation models according to eight more-or-less independent axes include spatial versus non-spatial analysis, static versus dynamic concept of the resource base, static versus dynamic concept of land suitability/capability, evaluation based on land qualities or not, suitability/capability expressed by physical constraints to land use, yields, or economic value, homogeneous versus compound land utilisation type, spatial scale and minimum decision area, single-area versus multi-area suitability/capability. The results can be cross-referenced with the classification of models developed by Hoosbeek and Bryant (1992) according to the degree of computation, descriptive complexity, and level in the organization hierarchy.

A fundamental challenge land evaluation faces is meeting pressing problems of sustainable land use. Predictions of land performance should be based on what land information is available (a data-driven approach), who the decision makers are, who actually needs the land evaluation (a demand-driven approach), professional land use planner input, and soil scientists and agronomists' knowledge (Rossiter, 1996), because in some cases there are insufficient dimensions to present the capability of the land resource effectively.

In today's environment, a land evaluation methodology is needed that considers the costs, the complexity of the evaluation procedure and the benefits in handling a specific land evaluation (FAO, 2007b; Manna, *et al.*, 2009). Unfortunately very little scientific literature supports this approach especially in terms of the corporative analysis of different land evaluation approaches (Trung, 2006; Manna, *et al.*, 2009).

Following the arguments above, it is clear that there is no single best land evaluation method that is suited to multiple regions of the world. The desired precision of land assessment results, by any land evaluation method, are obviously affected by the land evaluators' understanding and knowledge about the land characteristics, land-land use relationships, land data availability and analysis techniques, available support tools, the temporal and spatial dynamics of the land utilisation types, financial capital, and especially cultural, biophysical, socio-economic, and environmental issues in specific localities. The challenge for most land resource assessment methods is satisfying the goal of integrating human-centred requirements while maintaining a balance between the maximisation of production and the attainment of environmental goals, as well as the conservation of land resources for future use.

Stakeholders' participation receives increasingly more attention in the assessment and the planning of land resource management. Recent developments in spatial analysis and landscape ecology have much to offer in the understanding of the underlying linkages between land resources and local management, and in monitoring whether the management is sustainable (FAO, 2007b).

The common objectives of land assessment are to determine accurately the capability of the land resources; to identify the limiting factors; and to develop a reasonable management system for planning and the sustainable use of the lands. Hence, a method of combining multi-perspectives such as the biophysical, technical, management, policy, institutional consideration, socio-economic surveying and spatial modelling with participatory approaches (FAO, 1999a); as well as the application of support tools, needs to be developed, in order to incorporate local knowledge and environmental concerns into land evaluation and land resource models.

3.3 Land capability assessment trends

3.3.1 Combined qualitative and quantitative evaluation

Land capability is an integrated analysis determined from considering various contributing factors. It relates not only to technical and bio-physical aspects, but also to the socio-economic. There is insufficient evidence to conclude that the land capability is high or low if the analysis is based only on a single qualitative or quantitative assessment technique. Expert interpretation by soil scientists, agronomists, and environmentalists, in terms of such characteristics as soil properties and crop requirements, need to be linked and cross-checked with the quantitative economic simulation and prediction models of economists. Studies mixing qualitative and quantitative land evaluation, include the economic land evaluation for agricultural resource management in Northern Thailand (Samranpong *et al.*, 2009), qualitative and quantitative land suitability evaluation for olive groves (*Olea europaea* L.) in Iran (Rahimi Lake *et al.*, 2009), land evaluation for rice, maize and soybean in the Bac Can Province, Viet Nam (Ha *et al.*, 2006).

3.3.2 Combined experts and local community knowledge

The ultimate goal of land evaluation is to determine the land capability. Such assessment, however, will be moderated in reality by land users' practices. For many years, land evaluation and land use planning were viewed as top-down processes. Local community knowledge was ignored, and the assessment focused only on the expert and the land planners' knowledge. In some instances, this resulted in unfeasible or even failed implementation, such as in Viet Nam (Trung, 2006). The advantage of using the knowledge of local growers and farmers is that they understand clearly the characteristics of the land resources at the micro-level, whereas land experts have advanced knowledge and experience on land resources at the macro-level. Decision making should be based on the views and information from both the micro and macro-levels.

A study in the Mekong Delta, Viet Nam applies local farmers' knowledge for land use planning through a participatory approach conducted by Trung (2006). The results showed that farmers became involved with enthusiasm; they offered valuable information on the land, and contributed suggestions about the strategic use of the land. In another study, farmers proved to be experts in soil suitability classification (Habarurema and Steiner, 1997). Interestingly, an integration of conventional land evaluation methods and farmers' soil suitability assessment (Cools *et al* 2003) demonstrated that local farmers' knowledge was very useful in terms of the biophysical environment. This reduced significantly the costs compared with when that information is collected by experts. In other words, scientific knowledge is complimented by local knowledge.

3.3.3 Multi-disciplinary land evaluation

Land resources can be deemed to support sustainable land use when the capability assessment has been considered from the point of view of economic, societal, and environmental goals. The relevant issues and impact indicators of the sustainability of land use systems need to be identified and assessed (Walter and Stutzel, 2009a; 2009b). A careful balance of those issues is a required principle in land capability assessment. The FAO (2007b, p. 3) suggests that there are two trends that land evaluation experts need to concern themselves with to integrate the best methods for land evaluation.

These trends are summarized as "First there is recognition of the wider functions and services of land. Land performs a multitude of key environmental, economic, social and cultural functions, vital for life. These functions are generally interdependent and the extent to which land performs them is strongly related to sustainability. When land is used for one function, its ability to perform other functions may be reduced or modified, leading to competition between the different functions. The land also provides services that are useful to humans and others. An example of an environmental service is carbon sequestration. Secondly there is the growing recognition given to stakeholders, ranging from international and regional organizations, national governments, non-governmental organizations and commercial organizations to-most importantly-villages, rural communities and individual farmers and other land users. An important aspect is the participatory approach, in which surveys take account of the knowledge and views of land users, at the start as well as in later stages." (FAO, 2007b, p. 3).

3.4 The common principles of land capability assessment

Land capability evaluation in general, and farmland capability assessment in particular, are complex, with many stakeholders and disciplines involved. The main goals relate to classifying the capability of land resources for sustainable land use. To achieve these goals, principles in land evaluation should be developed and considered. Normally, each technique or method of land capability evaluation is associated with different specific principles, which depend on local objectives and specific conditions. There are however general principles that have been integrated and refined by the FAO (1976, 1985, 1993, 2007b), as well as by Rowe (1981), Rossiter (1996), Ritung *et al.* (2007), and The State Planning Commission of Western Australia (1989). These principles are noted below:

i. Land capability assessment must consider all relevant land characteristics including soils, climate, topography, water resources, vegetation, farming systems, technical, management, socio-economic conditions, and infrastructure;

ii. The main objective of land assessment is to predict the benefits to and prosperity of farms, the local area, and the region where the benefits and prosperity will be sustained without damage to the environment. Classification of land potential is required based on the interactions between, and within, components in a system of diverse perspectives, including the bio-physical, technical and management, land development and improvement, conservation and environment, policies/institutions, and socio-economic factors;

iii. The land capability is determined and classified with respect to specified types of use. Different land utilisation types may have different requirements. Therefore the determination of farmland capability, and the prosperity of farms, for any specific use of the land is the result of the accumulated evaluation of factors contributing to the capability of farmland;

iv. Assessment requires a comparison between the calculated benefits associated with particular land use and the level of inputs needed to utilise the land. This is done in order to assess the land's productive potential. Land resources will be maximised for their capability when inputs such as labour, nutrients, and seeds are judiciously invested because land in itself, without inputs and investment, rarely has productive potential;

v. The assessment process requires a multi-disciplinary approach. A range of specialists, stakeholders in the fields of soil science, agronomy, farming system, economics and sociology need to be involved. To reach the goal of the sustainable development of farmland resources, an integrated approach to qualitative and quantitative assessment is required;

vi. Assessments should be undertaken in terms of the biophysical, technical, economic, social and political context of the area concerned**.** The political context is a macro-issue; it sometimes is changeable and suitable at a regional scale only, and policies influence the use of the land, rather than the land capability;

vii. Capability refers to the sustainable use of the land resources. The environmental goals and negative impacts such as degradation and pollution should be identified when assessing the land capability. Certain land use may generate high profits in the short term but may cause physical degradation or hazards in the long term and are therefore classed as very low capability. For any proposed land use, the probable consequences to the environment should be assessed as accurately as possible and taken into consideration in determining capability;

viii. Assessment involves the analysis of more than a single land use. Assessment has significance if the land capability for any given use can be compared with at least one, and usually several different, alternative uses. If only one land use is considered then there is the danger that, while the land may indeed be capable or non-capable for that use, some other more beneficial use may be ignored;

ix. The circumstances of different land use projects are highly varied, land evaluation therefore should not be executed rigidly. Flexibility to allow for adaptation to make the most of the local situation is required.

x. Land assessment must consider the needs, preferences and views of all stakeholders. Especially, the Participatory Rural Appraisal (PRA) approach (FAO, 1999a) and the sustainable livelihood framework (SLF) for land users developed by DFID (1999-2005) need to be involved during assessing the capability of farmland;

xi. The scale and level of decision-making needs to be clearly defined prior to the land evaluation process. This principle has just been added by the FAO (2007b). It is important not only for selecting the techniques and tools for data gathering and analysis, but also for reporting which stakeholders and sectors have been explicitly considered and primarily addressed in the analysis. Despite the principles and general procedure of land evaluation being scale-independent, the specific tools and methods should take into consideration the goals, the decision-making level and the envisaged scale. A land evaluation designed to respond to the needs of regional farmland planners might not provide results directly relevant for individual farmers, because farmers often have different views, requirements, concerns, and interests to planners. The timeframe of a land evaluation exercise will also depend on the scale and detail required.

3.5 The procedure of land capability assessment

Land capability assessment forms the central part of land evaluation in general. A procedure has been developed which presents two critical approaches. These are, that for any given land what kinds of land use are possible, and for any specific kind of land use, which areas of the land are suitable.

The procedure consists of five basic steps adopted by the FAO (1976, 1985, and 1993), The State Planning Commission (1989), Hashim *et al.* (2002), Ritung, *et al.* (2007), Rahimi Lake *et al.* (2009), Fu (1998), Giap *et al.* (2005), Son (2005), Thapa and

Murayama (2008), and De la Rosa (2008) focusing mainly on farmland as outlined below:

3.5.1 Defining the alternative land uses: land use types or farming systems

The FAO (1985) recognizes two levels of detail at which land use is defined. A major kind of land use is that which represents a major subdivision of rural land use such as extensive agriculture, intensive agriculture, forestry. This is called a land utilisation type and is a kind of land use defined in more detail as a farming system. Land use types (LUTs), or farming systems, comprise (1) single LUT: only one kind of use undertaken on an area of land (e.g. irrigated rice, upland rice cultivation); (2) multiple LUT: more than one kind of use simultaneously undertaken on the same area of land, each use having its own inputs, requirements and produce (e.g. modern rice grown under young coconut in the Mekong Delta, Viet Nam); and compound LUT: more than one kind of use sequentially undertaken on the same area of land (e.g. Winter-Spring Rice and in Summer-Autumn Corn in the Mekong Delta, Viet Nam).

In some instances, alternative land uses are unclear and LUTs are first identified in a tentative and general way at the start of the study. The LUTs are progressively defined in detail when the survey proceeds and as new quantitative data are acquired. The cropping, irrigation and management aspects of the LUT are modified with inputs and land improvements to obtain a satisfactory match between the requirements or limitations of the LUT, and the actual on-ground conditions of the land (FAO, 1985; 1993).

Therefore, the required output from this step is the identification of promising LUTs and their levels of detail. This depends on the specific purposes and objectives of the land evaluation in various localities, as well as the objectives of a project or study.

3.5.2 Defining land use requirements

Land use requirements are described by the land qualities needed for sustained production. A land quality is a complex attribute of land that has a direct effect on land use. Most land qualities are determined by the interaction of several land characteristics, measurable attributes of the land (FAO, 1993).

In this step, the land characteristics required in terms of land quality such as water availability, nutrients, pH, pesticides, seeds, and labour for each LUT are determined. Then, they are classified as a range of capabilities with relevant indices corresponding to the performance of each LUT.

Land capability classes (very high, high, moderate, low, and very low) which express the capability of land for a specified use, are evaluated in terms of a land productivity index based on physical production (e.g. ton/ha) or in terms of economic returns.

3.5.3 Describing land mapping units

Land units are identified and form the basis for the diagnosis of problems. In this step, a survey is conducted to map land units and to describe their characteristics e.g. climate, slope, soils relevant to requirements of each land use type.

3.5.4 Matching land use requirements and land conditions

At this step, the requirements of each land-use type and the land qualities of each land unit are compared by checking the measured values of each land quality or characteristic against the class limits, and allocating each land unit to its land capability class according to the most severe limitation.

3.5.5 Presenting the results of land capability assessment

The results of land capability assessment are displayed, and computerised support tools are often used to generate the display. The main outcomes from this step are land capability maps, showing the capability of each land unit for each land-use type, and descriptions of these land-use types, including required techniques or management for land improvement.

3.5.6 The notable points in land capability assessment

In a worldwide context, land cannot be moved; different areas present different opportunities and different management options. However, capital, labour, management skills and technology can be moved to where they are needed to improve the land capability (FAO, 1993).

The land conditions that are suited for the production of crops and LUTs vary from place to place. Different farming systems, irrigation methods and management systems have differing requirements and therefore the specification of land capability classes in terms of a few universally applicable land characteristics is not a sound approach (FAO, 1985).

Hence, the following key points in land assessment exist in most studies:

- Land uses and LUTs (farming systems) vary from place to place. Their definitions and levels of detail cannot have a uniform framework. The adoption of an appropriate framework depends on the goals, development policies, and locally specific conditions, and therefore

- Land use requirements or limitations for each LUT (LUTs) differ between locations and regions and in some cases they conflict. To illustrate, the limitation to agricultural production in the Mekong Delta, Viet Nam is inundation (Thao, 2008), while the limitation to agricultural industry in Australia is water available for irrigation (Hamblin, 2009). This leads to inconsistency in determining land use requirements for the same use in different regions.

- Indices for each land use requirement or LUT capability are often different for different places. Literature on the topic indicates that values (the value range) of indices based on knowledge from agronomists, economists, environmentalists and land users in a local area may vary from another area. An example is the optimum temperature (very high capability) for rice cultivation in Himachal Pradesh, India has a value in the range of 18-30^{0}C (Bhagat *et al.*, 2009), whereas it is 26-28^{0}C in the Mekong Delta, Viet Nam (De, 2008).

- When developing class specifications it is more appropriate to specify the land capability classes in terms of land use requirements and limitations (e.g. Table 3.1) rather than directly in terms of land characteristics (FAO, 1985).

- Matching land use requirements with land qualities is a vital task in land evaluation. In the matching process, relationships, interactions and the importance of these land qualities, significantly influence the development of class-determining criteria (FAO, 1985). In cases where one limitation is enough to render the land incapable for the use, the most severe limitation method is valid. For less severe limitations, alternative methods of combining ratings can be used.

Table 3.1: Land capability matrix

Land feature listing	Rating category (Class)				
	Very high (1)	High (2)	Moderate (3)	Low (4)	Very low (5)
A	Feature range	➔			
B		Increasing	➔		
C			Limitation	➔	
D				Risk	➔
Limitations	Very significant	Significant	Moderate	Less significant	No significant
Source: adopted from the EPA, 2003					

- Matching land use to land capability involves a wider process than the simple comparison of land use requirements with the land qualities. If the initial comparison shows certain land units are incapable of being used for a given land use, the specification of the land-use type can be reconsidered and the capability of those land units can be raised. Land cannot be graded from "best" to "worst" independently of the kind of use and management practice, as each kind of use has special requirements (FAO, 1993).

- Land qualities can render land incapable for a certain LUT but capable for another. A new LUT could be introduced, or solutions for land improvement introduced, in order to achieve a higher overall land capability (FAO, 1993).

- Over a long time period, land capability ratings for a range of specific land utilisation types can be developed, such as in the following cases: for evaluating and classifying land for irrigated agriculture (FAO, 1985), developing a land capability system for the Western Plains of New South Wales (Paul Smith *et al.*, 2004), land suitability evaluation for several crops in Indonesia (Ritung *et al.*, 2007), assessment of land suitability potential for agriculture (Bandyopadhyay *et al.*, 2009), land suitability evaluation for Olive groves (Rahimi Lake *et al.*, 2009), land suitability modelling for giant prawn farming (Hossain *et al.*, 2010), rather than developing a united theoretical framework for land capability ratings in general.

3.6 Land capability classification systems

The expected result of land evaluation is the generation of classes indicating land potential. Land use planners and land managers use these outputs to develop reasonable strategies for the improvement, use, and management of the land. In a worldwide context, there have been a range of classification systems to determine land potential, which depend on different specific situations. However, the most commonly used and most standardised are two systems, one generated by the FAO (1976, 1983, 1984, 1985, 1991a, 1993) and one by the USDA (Klingebiel and Montgomery, 1961; USDA, 2001a; 2001b; 2005; 2010a).

3.6.1 The USDA land capability system

In the USDA system (Klingebiel and Montgomery, 1961; USDA, 2010a), the land potential is classified by land capability. Land capability classification is a system that groups soils, primarily based on their capability to produce common cultivated crops and pasture plants without deterioration over a long time. The land capability classification comprises three major categories: capability classes, capability sub-classes, and capability unit (USDA, 2010a).

Capability classes: are groups of land capability into areas having the same relative degree of hazard or limitation. The risks of soil damage or limitation in use become progressively greater from class I (1) to class VIII (8). The capability classes are presented with more detailed information on a soil map. The classes show the location, area, and general land suitability for agricultural use. Land in classes 1-4 are suited to cultivation and other uses, whereas classes 5-8 are limited in use, generally not suited to cultivation.

Capability subclasses: are groups of capability units which have the same major conservation (such as e: erosion and run-off, w: excess water, s: root-zone limitations, and c: climatic limitations). The capability subclass provides information on the kind of conservation problem or limitations involved. The integration of class with subclass provide information about both the degree of limitation and kind of problem involved for broad program planning, conservation need studies, and similar purposes.

Capability units: are groups of individual soil mapping units having similar potential and continuing limitations or hazards. In a capability unit, soils are sufficiently uniform to (1) produce similar planted crops and pasture plants using similar management practices; (2) require similar conservation treatment and management in the same kind and condition of vegetative cover, (3) have comparable potential productivity.

Below is a brief description of classes and sub-classes in the USDA system (USDA, 2010a, wp):

"***Class 1***: have few limitations that restrict the use. Soils in this class are suited to a wide range of plants and may be used safely for cultivated crops, pasture, range, woodland, and wildlife.

Class 2: have some limitations that reduce the choice of plants or require moderate conservation practices. Require careful management, including conservation practices, to prevent deterioration or to improve air and water relations when the soils are cultivated. The limitations are few and the practices are easy to apply. The soils may be used for cultivated crops, pasture, range, woodland, or wildlife food and cover.

Class 3: have severe limitations that reduce the choice of plants or require special conservation practices, or both. Soils in class 3 have more restrictions than those in class 2 and, when used for cultivated crops, the conservation practices are usually more difficult to apply and to maintain. They may be used for cultivated crops, pasture, woodland, range, or wildlife food and cover.

Class 4: have very severe limitations that restrict the choice of plants, require very careful management, or both. The restrictions in use for soils in class 4 are greater than those in class 3 and the choice of plants is more limited. When these soils are cultivated, more careful management is required and conservation practices are more difficult to apply and maintain. Soils in class 4 may be used for crops, pasture, woodland, range, or wildlife food and cover.

Class 5: have little or no erosion hazard but have other limitations impractical to remove that limit their use largely to pasture, range, woodland, or wildlife food and cover. Soils in class 5 have limitations that restrict the kind of plants that can be grown and that prevent normal tillage of cultivated crops. They are nearly level but some are wet, are frequently overflowed by streams, are stony, have climatic limitations, or have some combination of these limitations.

Classes 6: have severe limitations that make them generally unsuited to cultivation and limit their use largely to pasture or range, woodland, or wildlife food and cover. Physical conditions of soils placed in class 6 are such that it is practical to apply range or pasture improvements, if needed, such as seeding, liming, fertilizing, and water control with contour furrows, drainage ditches, diversions, or water spreaders.

Class 7: have very severe limitations that make them unsuited to cultivation and that restrict their use largely to grazing, woodland, or wildlife. Physical conditions of soils in class 7 are such that it is impractical to apply such pasture or range improvements as seeding, liming, fertilizing, and water control with contour furrows, ditches, diversions, or water spreaders.

Class 8: have limitations that preclude their use for commercial plant production and restrict their use to recreation, wildlife, or water supply or to aesthetic purposes. Soils and landforms in class 8 cannot be expected to return significant on-site benefits from management for crops, grasses, or trees, although benefits from wildlife use, watershed protection, or recreation may be possible.

Subclass (e) erosion: is made up of soils where the susceptibility to erosion is the dominant problem or hazard in their use. Erosion susceptibility and past erosion damage are the major soil factors for placing soils in this subclass.

Subclass (w) excess water: is made up of soils where excess water is the dominant hazard or limitation in their use. Poor soil drainage, wetness, high water table, and overflow are the criteria for determining which soils belong in this subclass.

Subclass (s) soil limitations: within the rooting zone includes, as the name implies, soils that have such limitations as shallowness of rooting zones, stones, low moisture-holding capacity, low fertility difficult to correct, and salinity or sodium.

Subclass (c) climatic limitation: is made up of soils where the climate (temperature or lack of moisture) is the only major hazard or limitation in their use".

Concisely, the USDA land potential classification is presented in Figure 3.1

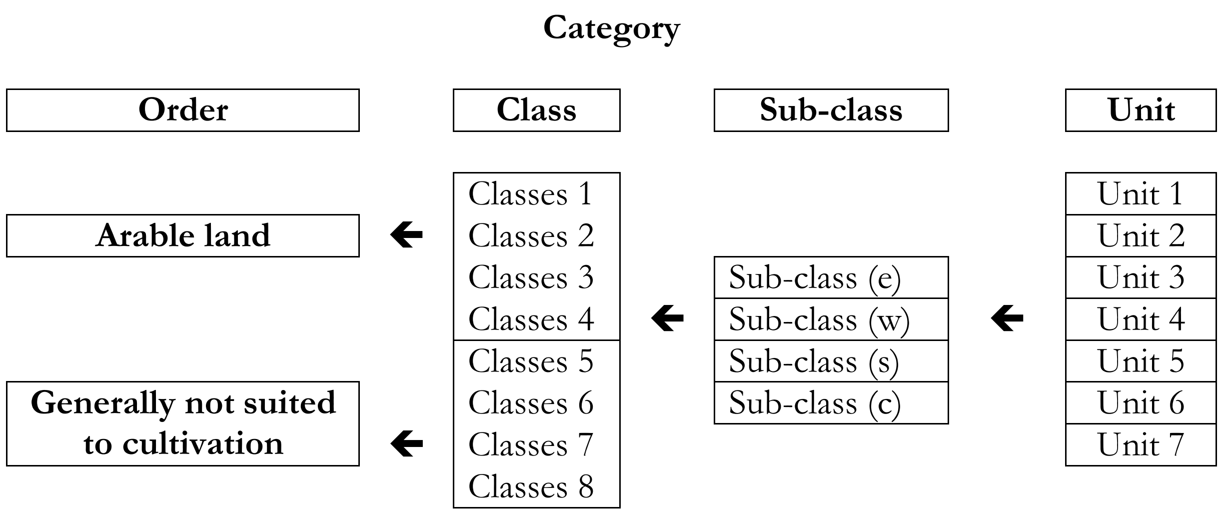

Figure 3.1: The USDA land potential classification systems

Figure 3.1 shows that capability classification in the USDA system includes two major groups. Class 1 to class 4 are suited to agricultural production, and class 5 to class 8 are not suited to cultivation with respect to the decline in the capability from class 1 to class 8. This description reveals that the land capability in the USDA system is based on the purpose of the agricultural use.

In summary, the USDA land potential classification system includes three main levels: classes, sub-classes, and units. The level of classes has 8 ratings, ranging from few limitations (class 1) to very many limitations (class 8) that restrict the use for arable purposes. The level of sub-classes has 4 key limitations being erosion, excess water, soil limitations, and climate limitations. The capability of each class is impacted by subclasses, and as a hierarchy, the capability of sub-classes is influenced by units.

3.6.2 The FAO land suitability classification system

In the FAO (1976, p. 22; 1983; 1984; 1985; 1991a; and 1993) system, the land potential is classified by land suitability. Land suitability classification includes four categories of decreasing generalization: land suitability orders (kinds of suitability), land suitability classes (degrees of suitability within orders), land suitability sub-classes (kinds of limitation or main kinds of improvement measures required, within classes), land suitability unit (minor differences in required management within subclasses).

Land suitability orders indicate whether land is assessed as suitable or not suitable for the use under consideration. There are two orders represented: S and N.

S (suitable): Land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources.

S1 (highly suitable): Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.

S2 (moderately suitable): Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land.

S3 (marginally suitable): Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.

N (not suitable): Land which has qualities that appear to preclude sustained use of the kind under consideration.

N1 (currently not suitable): Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner.

N2 (permanently not suitable): Land having limitations which appear as severe as to preclude any possibilities of successful sustained use of the land in the given manner.

Land suitability sub-classes reflect kinds of limitations, e.g. moisture deficiency (m), erosion hazard (e)

Land suitability units are subdivisions of a subclass. All the units within a subclass have the same degree of suitability at the class level and similar kinds of limitations at the subclass level. Suitability units are distinguished by Arabic numbers following a hyphen, e.g. S2e-1, S2e-2".

Examples of land suitability sub-classes:
S2e: land assessed as S2 on account of limitation of erosion hazard
S2w: land assessed as S2 on account of inadequate availability of water
N2e: land assessed as N2 on account of limitation of erosion hazard
Shortly, the FAO land potential classification is shown as Figure 3.2

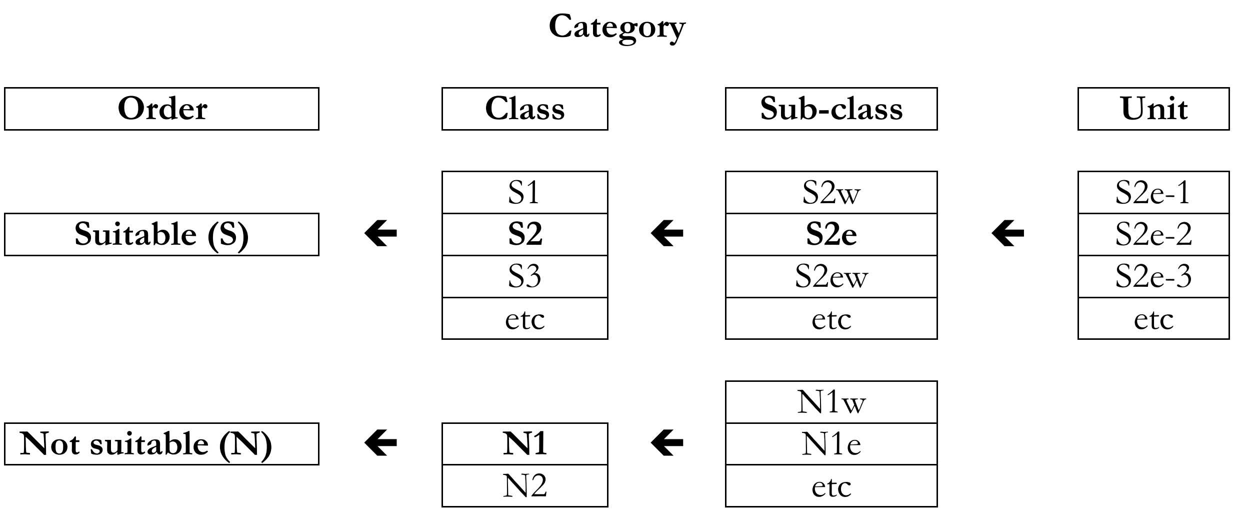

Figure 3.2: The FAO land potential classification system

Associated with the two main FAO and USDA land potential classification systems, many researchers also modify or develop new ones, to be suitable to particular circumstances, such as those by Rowe *et al.* (1981), The State Planning Commission (1989), Grose (1999), The ACT Parliamentary Counsel (1999), CEMA (2006). In general, most are based on these key principles:

(1) Land potential is indicated by the three major categories, including units, sub-classes, and potential classes to arrive at a higher level of order (arable land or not suitable to cultivation)

(2) Land potential classes decrease gradually corresponding to a gradual increase in physical, socio-economic, and management limitations, these constitute constraints for the use of the land resources
(3) The number of land potential classes is flexibly modified to suit different situations.

To summarize, the FAO land potential classification system also includes three key categories (class, sub-class, and unit) likes the USDA system. However, at the class level the FAO system distinguishes separate suitable (S) and non-suitable classes (N). Particularly, the non-suitable class is divided into two more sub-classes, currently and permanently not suitable.

3.7 Support tools for land capability assessment

Land capability assessment is designed to determine the capability of specific land for specific land uses. It enables environmental managers, agricultural planners, farmers, and others to analyse the interactions between three factors: location, proposed land development, and environmental elements (Collins *et al.*, 2001) in order to achieve the goal of sustainable land use. Useful capability assessments cannot be solely based upon biophysical resource information because the farmland capability is influenced by other considerations, including technology, management, and socio-economic (FAO, 1976, 1993; Baniya, 2008).

Today's rural land managers are becoming increasingly aware of the technological advancements in land-use planning and capability modelling. Emerging technology, used in data and knowledge engineering, provide excellent possibilities for the land evaluation, development and execution processes (De la Rosa *et al.*, 2004). These new methods and techniques of spatial analysis are now commonly integrated and applied in land assessment and the development of land-use plans (Collins *et al.*, 2001), comprising the development and linkage of integrated databases, computer programs, spatial analysis tools, and decision support systems. Decision support systems are computer technology that can be used to support complex decision making and problem-solving (Shim *et al.*, 2002).

3.7.1 Computerised land evaluation systems

The Automated Land Evaluation System-ALES (Rossiter and Van Wambeke, 1997) is a computer program that allows land evaluators to build their own expert systems to evaluate land according to the FAO framework for land evaluation (FAO, 1976). ALES is a framework within which evaluators can input their own knowledge for use in local projects or regional scale land evaluation, taking into account local conditions and objectives. The administrative entities evaluated by ALES are map units, which may be defined either broadly, such as in reconnaissance surveys and general feasibility studies, or narrowly, such as in detailed resource surveys and farm-scale planning. Since each expert system is built by a different evaluator to satisfy local needs, there is no fixed list of land use requirements by which land uses are evaluated, and no fixed list of land characteristics from which land qualities are inferred. Instead, these lists are determined by the evaluator to suit local conditions and objectives (http://www.css.cornell.edu/landeval/ales/alesprog.htm; FAO, 2007b, p. 10).

Basically, the ALES has seven components:

1. "a framework for a knowledge base describing proposed land uses, in both physical and economic terms;
2. a framework for a database describing the land areas to be evaluated;
3. an inference mechanism to relate these two, thereby computing the physical and economic suitability of a set of map units for a set of proposed land uses;
4. an explanation facility that allows model builders to understand and fine-tune their models;
5. a consultation mode that allows a casual user to query the system about one land use at a time;
6. a report generator (on-screen, to a printer, or to disk files); and
7. an import/export module that allows data to be exchanged with external databases, geographic information systems, and spread sheets. This includes the ALIDRIS interface to the IDRISI geographic information system as well as an interface to xBase (dBase III+) - format database files, including Attribute Tables in PC-Arc/Info" (http://www.css.cornell.edu/landeval/ales/alesprog.htm).

ALES is not a GIS tool and does not display maps. It, however, can analyse geographic land characteristics if map units are appropriately defined, and it can directly reclassify IDRISI maps or Arc/Info Attribute Tables with the same mapping unit legend as the ALES database.

Another computerised land evaluation system is called MicroLEIS. The MicroLEIS system (De la Rosa *et al.*, 2004) was developed to assist specific types of decision-makers faced with specific agro-ecological problems. It was designed using a knowledge-based approach which incorporates a set of information tools, as presented in Figure 3.3. Each of these tools is directly linked to another, and custom applications can be carried out on a wide range of problems related to land productivity and land degradation. They are grouped into the following main modules: i) basic data warehousing, ii) land evaluation modelling, and iii) model application software. The land attributes used in MicroLEIS DSS correspond to the following three main groups: soil/site, climate, and crop/management (De la Rosa *et al.*, 2004).

Recently, the MicroLEIS system was used to assess soil quality in Argentina (De la Rosa *et al.*, 2008), and to design soil-specific agro-ecological strategies for sustainable land use in Spain (De la Rosa *et al.*, 2009).

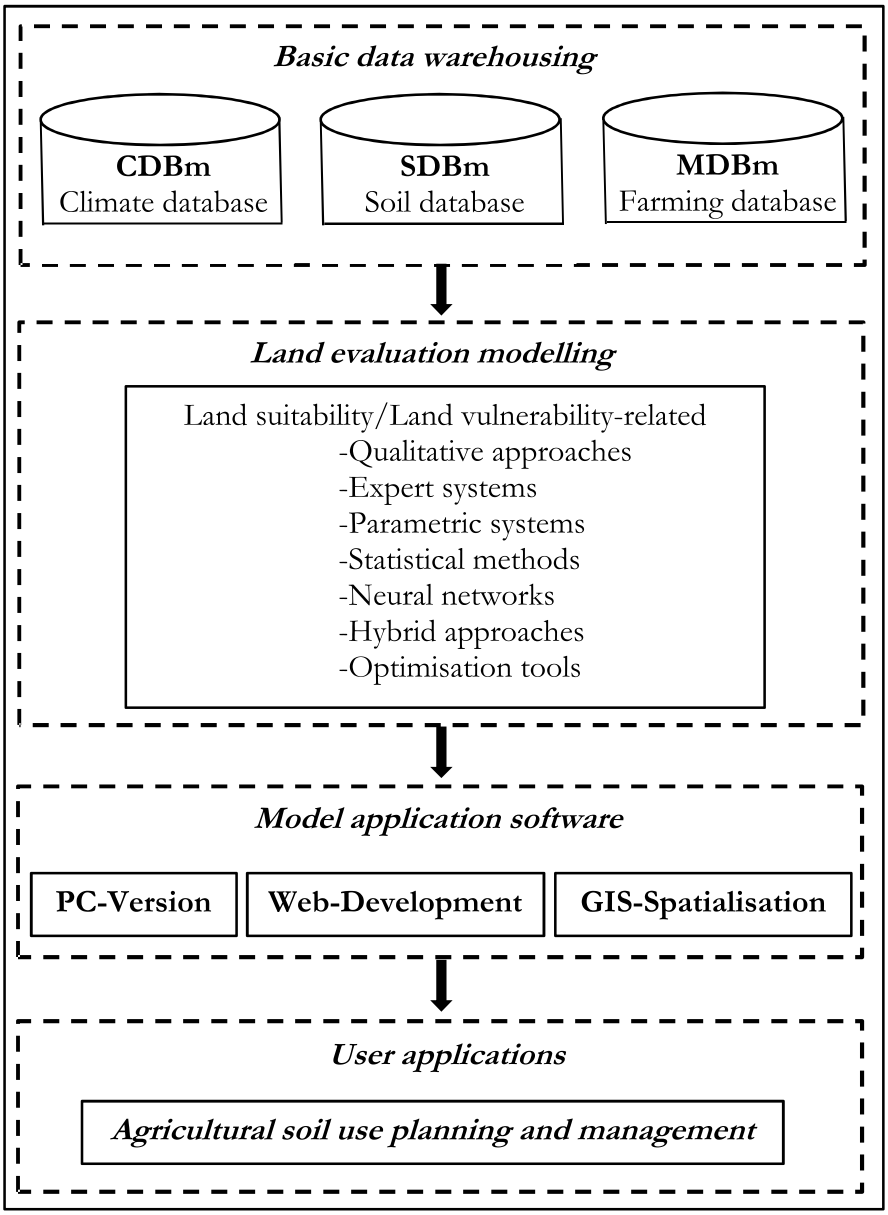

Figure 3.3: Conceptual design and component integration of the MicroLEIS DSS system

Source: De la Rosa et al. (2004)

A system called sustainable options for land use (SOLUS) provides a framework for sub-regional land use analysis by quantifying biophysical and economic sustainability characteristics. The SOLUS framework was developed for land use analysis at the field to regional scales (Bouman *et al.*, 1998). Bouman *et al.* (1999, p. 57) describe SOLUS as consisting of technical coefficient generators which are used to quantify inputs and outputs of production systems, a linear programming model that selects production systems by optimizing regional economic surplus, and a geographic information system. Biophysical and economic factors are integrated and various types of knowledge, ranging from empirical expert judgment to deterministic process models are synthesized in a systems-analytical manner. Economic sustainability indicators include economic surplus and labour employment, and biophysical ones include soil nutrient balances (N, P and K), biocide use and its environmental impact, greenhouse gas emission and nitrogen leaching loss and volatilization. Land use scenarios can be implemented by varying properties of production inputs (e.g., prices), imposing sustainability restrictions in the optimization, and incorporating alternative production systems based on different technologies.

Another system called the Intelligent System for Land Evaluation (ISLE) automates the land evaluation process and graphically illustrates the results on digital maps (Tsoumakas and Vlahavas, 2001). ISLE is designed as a framework for integrating the functionality of a geographical information system with an expert system and consists of the following main features:

1. The front end, that provides the interface to the expert system, encapsulates the mapping objects, and provides the user interface;
2. The digital map and the geographical database of the land subject to evaluation;
3. The expert system, which is responsible for land evaluation.

Land evaluation and site investigation (LESI), are also systems for land evaluation. They are undertaken to determine the most suitable use of land in terms of planning or development (Bell, 2004). In the LESI process, the environmental impacts may have to be assessed, including geological hazards, mineral resources and the impacts of mining, water supply and hydro-geological conditions, soil resources and the ground condition of the disposal of waste. An investigation in relation to land use planning and development obviously can take place at various scales, from specific site to regional investigation. A site investigation may form part of a feasibility study or be carried out to assess the suitability of a site and surroundings for a proposed engineering structure.

The Crop Yield Simulation and Land Assessment Model for Botswana (CYSLAMB), was designed to improve the crop production systems in different biophysical and socio-economic settings (Birch-Thomsen and Kristensen, 2005). It is a dynamic model which is based on historical climatic data which is used to calculate potential crop production estimations. Using a statistical analysis of the results it is possible to identify the different potential yield levels which could be achieved by different crop production systems. The 75% quartile yield represents the annual potential yield level which can be expected to be exceeded 75% of the time. This yield level corresponds to the dependable yield, satisfying the yield requirements of farmers in the majority of years.

CYSLAMB is a tool for land use planning, which integrates knowledge about the heterogeneous livelihood strategies and the biophysical conditions at various spatial scales. Although the CYSLAMB model primarily reflects a farmer/farm-oriented approach, other levels within the stakeholder hierarchy are also considered indirectly through the management component of the model. By analysing the farmer's access to resources (land, labour and capital) and the availability of technologies within the local setting, aspects influenced by other land management levels are considered. They include factors such as land tenure, marketing conditions and government support systems (Birch-Thomsen and Kristensen, 2005).

Further, information regards physical parameters or land characteristics, and a number of management-related variables reflecting the socio-economic conditions of the farmer are also included. Such as, date of ploughing and planting, number of planting opportunities used, date of weeding and percentage weed cover. The management variables can be adjusted to reflect differences in the farmers' socio-economic conditions, such as the availability of household labour, sources of power, tools and fertilizer, income levels, non-agricultural incomes, and livestock-crop interactions. This facility makes CYSLAMB a flexible tool that can model crop production based on physical and socio-economic conditions at several levels, village to district and the national scale (FAO, 2007b). The application of CYSLAMB for determining the rain-fed arable production potential of climatically marginal land has been conducted by Mbatani (2000).

Thanks to the development of computer science, many computerised land evaluation systems have been generated. These systems effectively support land evaluation, giving land evaluators opportunities to select and apply models in different situations. Using these computerised systems can lead to decreased costs, and more importantly, help time saving for the land evaluation procedure. Today, many computer programs are used widely as support tools for land evaluation. They can help to store, import, export, and analyse data during land evaluation, as well as to present the results of land evaluation. A Geographic Information System is a tool which can satisfy the above functions and it will now be described.

3.7.2 GIS for land capability assessment

A Geographic Information System (GIS) is used widely by many disciplines and for many purposes. In land assessment, the main GIS functions are inputting, storing, managing, manipulating, analysing, and outputting geographically referenced data. To assist in understanding these functions of a GIS for land assessment, its definitions and characteristics are described below.

GIS definitions

The development of GIS technology has undergone three major milestone periods. (i) 1950-1970s: the GIS research frontier, called innovation; (ii) 1980s: the development of the general goal GIS, called the integration stage; and recently, the proliferation stage which is identified by the development of the user-oriented GIS technology (Malczewski, 2004). Associated with the evolutionary history, functions, roles and applications for GIS in many disciplines have been developed. This has led to a significant change in the experience, perception and understanding of GIS. The definition of GIS has changed along with the human experience with GIS (Chan and Williamson, 1997).

GIS was an emerging technology in 1989 (Cowen, 1998) and it generated massive interest worldwide (Maguire, 1991). Today, there is a range of textbooks, newsletters, journal articles, workshops, and conferences relating to the GIS field. The definition of a GIS has created debate among academic. Maguire (1991) confirms that the different ways of defining and classifying objects and subjects causes difficulties in defining GIS. This stimulates researchers to explore and study GIS as well as its applications and therefore the definitions of GIS are diverse, with typical examples being:

- "GIS as an integrated collection of hardware, software, data and liveware which operates in an institutional context" (Maguire, 1991, p. 15),
- GIS is "a system for capturing, storing, checking, integrating, manipulating, analysing and displaying data which is spatially referenced to the earth" (FAO, 1996b, wp),
- GIS indicates two main perspectives, the technological and organisational/ institutional (Maguire, 1991; Chan and Williamson, 1997),
- GIS as a management tool and decision support system (Cowen, 1998),
- GIS is a toolbox, an information system, an approach to science, a multibillion-dollar business that, comprise the three main components of the database, the spatial or map information, and ways to link the two (Clarke, 1998),
- GIS is "a computer-based tool for mapping and analysing things that exist and events that happen on Earth. GIS technology integrates common database operations, such as query and statistical analysis, with the unique visualization and geographic analysis benefits offered by maps" (ESRI, 1999, p. 3),
- GIS includes: "the measurement of natural and human made phenomena and processes from a spatial perspective, the storage of measurements in digital form in a computer database, the analysis of collected measurements to produce more data and to discover new relationships by numerically manipulating and modelling different pieces of data, the depiction of the measured or analysed data in some type of display - maps, graphs, lists, or summary statistics" (Pidwirny, 2006a, wp),
- "In the strictest sense, a GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information (that is data identified according to their locations). Practitioners also regard the total GIS as including operating personnel and the data that go into the system"

(United States Geological Survey, 2007 *at 22/01/2007, http://egsc.usgs.gov/isb/pubs/gis_poster/*),

- "GIS is an integrated system of computer hardware, software, and trained personnel linking topographic, demographic, utility, facility, image and other resource data that is geographically referenced (NASA, undated, http://gislounge.com/what-is-gis/),
- and some others like Scholten and Lepper (1995), and Malczewski (2004) also have definitions of GIS. But, the most refined definition is that of a GIS as a system of hardware and software used for the storage, retrieval, mapping, manipulation and analysis, and output of spatial data (http://www.nwgis.com/gisdefn.htm).

With these definitions, GIS presents as an integrated multidisciplinary science embracing interrelated fields of geography, information technology, statistics, computer science, cartography, photogrammetry, mathematics, surveying, civil engineering, and remote sensing. Graphical features and tabular data are incorporated into a GIS in order to assess real-world problems (http://gis.nic.in/gisprimer/introduction.html).

GIS components

A GIS refers to "a system", rather than "software". The system comprises many interrelated components, each having a different role and function, including interrelationships and functional interactions. Basically, GIS encompasses five main functional components: hardware, software, data, procedures, and people (expertise, users) (Rossiter, 1994; ESRI, 1999; Pidwirny, 2006a) for relevant missions of data input, data storage and management, data manipulation and analysis, and data output (Malczewski, 2004; ESRI, 1999; Pidwirny, 2006a; Maguire, 1991). To be successful for any GIS project, all of these components need to be in balance under the system, no one part can work effectively without the other. The GIS components are shown in Figure 3.4 and can be concisely summarized as:

*+ **Hardware:*** is the computer and related devices on which GIS is located and operated. Software works on a wide range of hardware types, from desktop computers used in stand-alone or networked configurations to centralised computer servers. Popular examples of hardware technical equipment include scanners, digitizers, GPS data loggers, media disks, printers, keyboards, and satellites.

*+ **Software:*** is a central part of the system. Many different GIS software packages are available, and can be classified according to their intended use within the three categories: GIS data viewers, desktop GIS, and high-end GIS (Malczewski, 2004). GIS packages must have data input, storage, management, transformation, analysis, and output functions. However, the appearance, methods, resources, and ways of operation may be different between these systems.

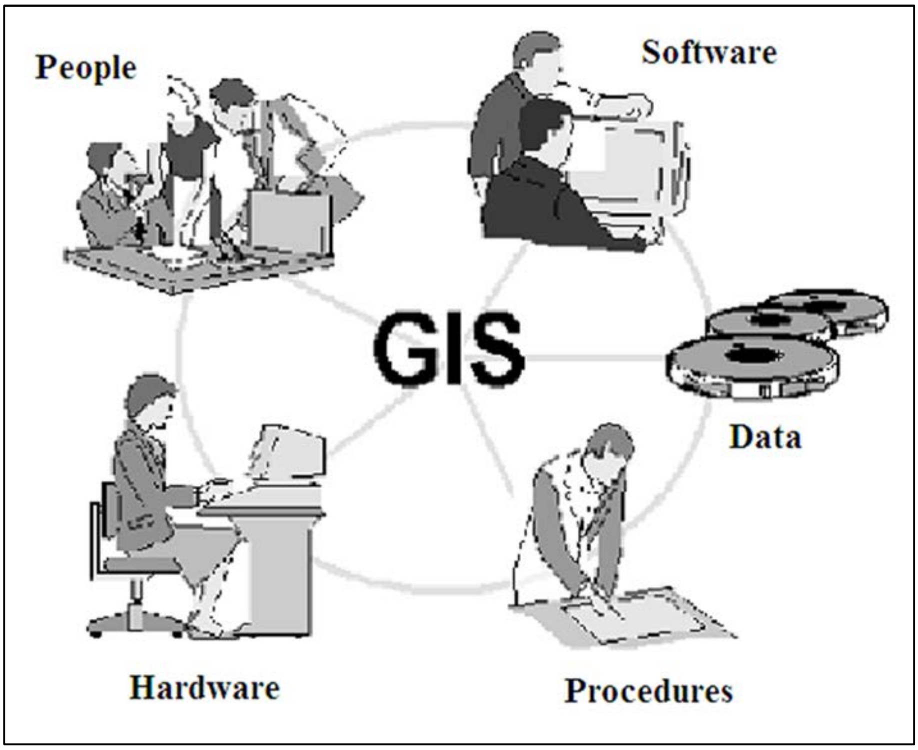

Figure 3.4: Main functional components of a GIS

*+ **Data:*** are the core, and often most expensive component of a GIS. Data in GIS is of two types, spatial and attribute data; spatial data represents locations of phenomenon and events, attribute data describes the nature and characteristics of the spatial data. Fortunately, a huge amount of spatial data available on the Internet can be downloaded for free or purchased from data providers. Malczewski (2004) lists a wide variety of spatial data providers for the USA, the UK, Canada, and Europe, such as

GoeCommunity-GIS Data Depot (www.data.geocomm.com), Geography network clearinghouse (www.geographynetwork.com), Committee on Earth Observation Satellites (NASA) (www.Gcmd.gsfc.nasa.gov/ceosidn), and the USGS Geospatial Data Clearinghouse (www.nsdi.usgs.gov).

+ Procedures: documented methods on how the data will be retrieved, input into the system, stored, managed, transformed, analysed, and finally presented in an ultimate output. These steps guide the users so they can achieve the objective of a GIS project.

+ People: the component that is required to make the GIS work. People occupy the positions of GIS manager, database administrator, application specialist, systems analyst, and programmer. People associated with a GIS can be divided into three groups: viewers, general users, and GIS specialists. Viewers are the public class of users, who use a geographic database to recover reference material. General users who use GIS to conduct business, perform professional services, and make decisions. This group includes facility managers, resource managers, planners, scientists, engineers, lawyers, business entrepreneurs. GIS specialists are the people who plan the project and operate; they consist of GIS managers, database administrators, application specialists, systems analysts, and programmers (http://maic.jmu.edu/sic/gis/components.htm).

The above statements describe GIS components that help GIS to play a role and a function in land assessment. The next section outlines the basic function of a GIS for land assessment.

Basic GIS functions

The functions of a GIS are mostly performed by functional components. Maguire (1991) states that a GIS can be synthesized and presented through three distinct views. They are the map, database, and spatial analysis views. The map view concentrates on cartographic aspects of a GIS, the database view expresses the importance of a well designed and implemented database (Frank, 1989), and the third view highlights the importance of spatial analysis in a GIS. A GIS can play a major role in spatial decision-making (Prakash, 2003) as a decision supporting tool used for land capability evaluation. To be systematically understood, the GIS functions are presented step by step below:

- ***Data input***

Data input refers to data identification and collection to the specific requirements of the system. The process includes acquisition, reformatting, geo-referencing, compiling, and documenting the data. This function, data input, transfers raw or existing data into a GIS data system using alternative ways such as keyboard entry (attribute data), manual digitizing and scanning, or importing existing data files (Malczewski, 2004).

- ***Data storage and management***

The essential requirement in this task is developing database sets that are capable of being stored, retrieved, and shared effectively and efficiently (Baniya, 2008). The data analysis and processing of the data will be impacted upon by the methods used to execute the data storage and management. The database can be defined as an ordered collection of data organised so that it can be expanded, updated, retrieved and shared by different users for different purposes (Malczewski, 2004). In land evaluation, the database often consists of detailed information obtained during field surveys, describing the site and characteristics of specific land units.

- ***Data manipulation and analysis***

The heart of a GIS is its analytical capabilities used to distinguish between objects and perform an integrated analysis of the spatial and attribute data. The data manipulation and analysis is used to sort and analyse useful information that is required for a particular application that can be utilised by the GIS. A wide range of analytical operations are available to users. The operations have been classified (Burrough, 1992) and presented in a manner making them easily available for a particular application.

- Data output

This function provides clear, visual results from the GIS data processing and analysis. The resulting information can be presented in the form of maps, tables, reports and diagrams in hard copy, soft copy, or electronic copy (Malczewski, 2004).

An expert multidisciplinary team of natural resource managers are essential if a GIS is to be used as an effective tool for the support of land evaluation and land use planning. The expert team may include physical geographers, agronomists, climate-soil-crop modellers, geo-statisticians, computer programmers, economists, social scientists, and also data extension workers. The system and its products should also be transparent to the occasional users such as policy-makers and stakeholders at every level (FAO, 1995).

In summary, a spatial database is set up and converted to thematic layers and maps. The content of individual maps consists of spatial and non-spatial attributes relating to the land evaluation objective. Evaluation criteria are established according to the land use requirements of each specific land use type. The evaluation is independently implemented using the GIS approach. The evaluation criteria are imbedded in GIS context. A land units map and land use requirements for each land use type are also established and the evaluation criteria are standardised to make each criterion comparable with each other. Finally, the land capability maps are formed for the land use types (Baniya, 2008).

GIS application in land capability assessment

With the rapid development of GIS technology, has come an expansion in the number of applications. In general, GIS is used in five major areas: facilities management (planning facility maintenance, telecommunication network service); environmental and natural resources management (agricultural lands, crops suitability, water resources, wetlands, environmental impact assessment, disaster management); street network (car navigation, locating houses and streets); planning and engineering (urban planning, regional planning); and land information system (cadastre administration, taxation, land use zoning).

Many GIS practical applications have been studied and documented, such as the Enterprise GIS in Health and Social Service Agencies (ESRI, 1999), GIS for transportation (Miller and Shaw, 2001), GIS and Internet/Intranet Technology (Reinhardt, 2000), Wetland and environmental applications of GIS (Lyon and McCarthy, 1995), Urban planning and development applications of GIS (Easa and

Chan, 2000), and practical applications of GIS for archaeologists: a predictive modelling toolkit (Wescott and Brandon, 2000), GIS applications for water, wastewater, and stormwater systems (Shamsi, 2005), as well as the potential application of GIS in agriculture (Pierce and Clay, 2007).

One of the most efficient and useful applications of GIS for planning and management is for the land evaluation (Collins *et al.*, 2001, Malczewski, 2004; 2006), because in land evaluation, GIS is used as a computer-assisted system for the acquisition, storage, analysis and presentation of geographic data (Eastman, 2006). In fact, a GIS can provide essential management information or be used for understanding of environmental impacts and relationships (Corona *et al.*, 2008).

In recent years, GIS has expanded to include a powerful set of tools for spatial data management and analysis. It can be used to generate, in a flexible, versatile and integrated manner, maps, tables and textual reports that are needed to support land-use planning (FAO, 1999b). It has become popular to apply GIS for land evaluation, by mapping and modelling spatial data (Corona *et al.*, 2008), and for two vital branches of GIS based land evaluation called, overlay mapping and multi-criteria evaluation (Collins *et al.*, 2001).

MacDougall (1975) and Steinitz *et al.* (1976) state that the development of computer-assisted overlay techniques is a response to the limitations of manual methods of mapping and of combining large datasets in paper format. Overlay mapping work is not complex, thematic layers are acquired and transformed into input factors, these are assigned with relative ranking values, based on matching between land use requirements and land conditions[14] (Corona *et al.*, 2008; FAO, 1993). Application of a GIS for land suitability can be illustrated in Figure 3.5 below. Chuong and Boehme (2005) evaluated physical land suitability for "Thanh Tra" pomelo in Hue, Viet Nam using a multi-criteria evaluation approach within a GIS context, and the study results reveal that GIS is very useful for multi-criteria land evaluation in the local conditions.

[14] *Comparison between land characteristics with land use requirements. Please refer to the case study chapter*

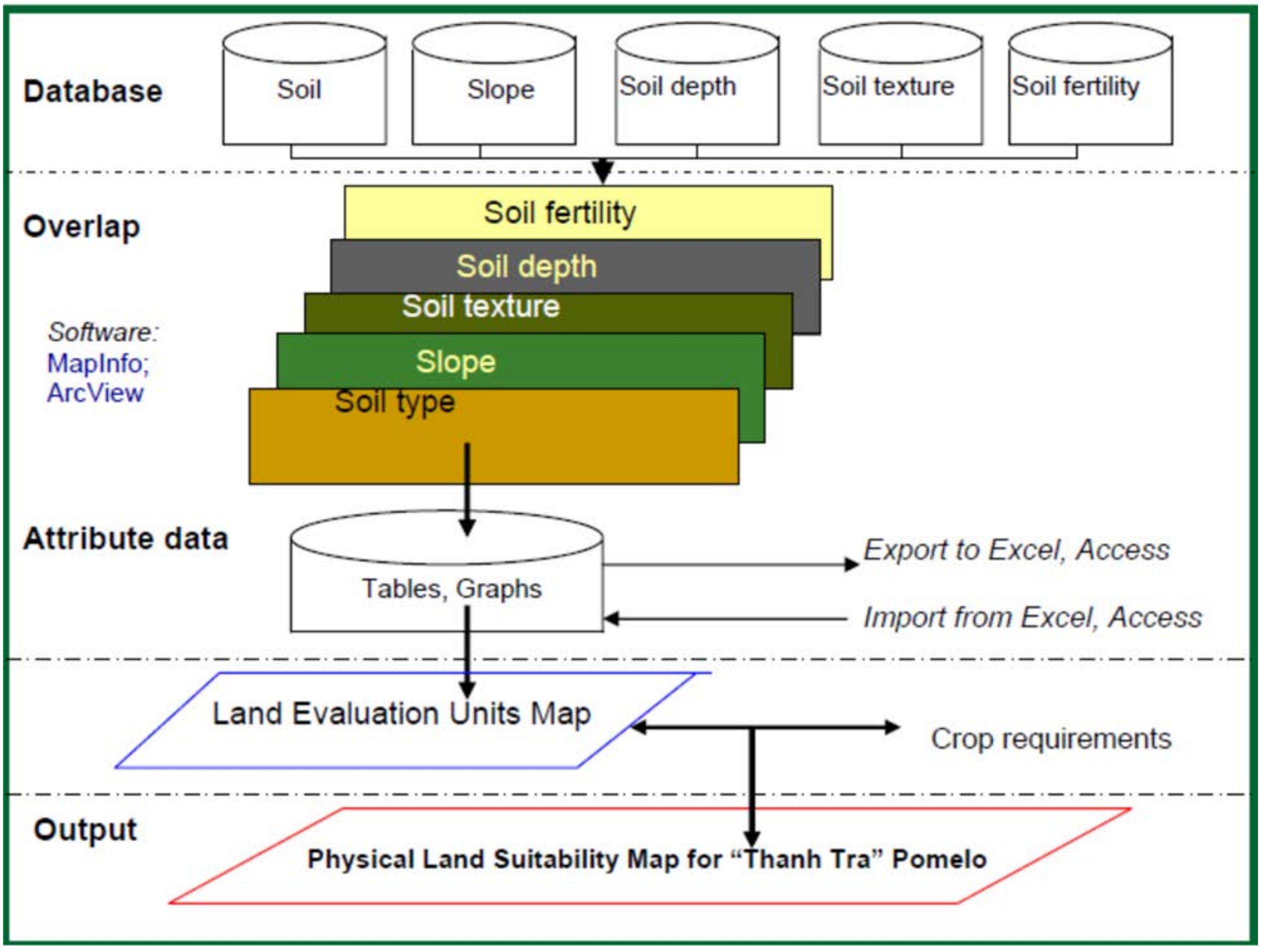

Figure 3.5: Flowchart of GIS application to physical land suitability

Source: Chuong and Boehme (2005)

The overall land suitability/capability is generated from analysis and combination of the individual suitability/capability maps of class-determining factors (FAO, 1993; Malczewski, 2004) using logic or algebraic functions (Lyle and Stutz 1983). The inappropriate use of methods for standardising potential maps and untested or unverified assumptions of independence among suitability/capability criteria have been the major criticisms of computer associated methods over the conventional map overlay approach (Hopkins, 1977; Pereira and Duckstein, 1993). Fortunately, this limitation can be resolved by integrating the GIS and multi-criteria decision analysis (MCDA) method (Corona *et al.*, 2008) which is explained in section 3.8.

Some limitations to the use of GIS

Despite the benefits of GIS applications in land evaluation being recognised widely, there are still existing limitations as the FAO (1995, wp) has identified below:

(i) "the inadequate analysis of real-life problems as they occur in complex land management and sustainability issues at the household level, and as they involve the integration of biophysical, socio-economic and political considerations in a truly holistic manner;

(ii) the limitation in data availability and data quality at all scales, especially those that require substantial ground truthing;

(iii) the lack of common data exchange formats and protocol; and

(iv) the inadequate communication means between computer systems, data suppliers and users due, for instance, to poor local telephone networks".

To conclude, GIS is a useful support tool for land evaluation. It plays an important role in managing and analysing spatial and non-spatial data during land evaluation. Particularly, GIS is very effective for land suitability analysis and presentation of land suitability maps. However, land evaluation involves a consideration and analysis of many criteria, and therefore along with GIS, multi-criteria decision analysis (MCDA) needs to be involved in land assessment. The next section describes multi-criteria decision analysis as used for land capability assessment. The combination between GIS and MCDA for land capability determination is presented in the case study chapter (Chapter 6).

3.8 Multi-Criteria Decision Analysis for land capability assessment

The main goal of the MCDA techniques is to consider a range of alternative solutions in the investigation of multi-criteria and conflicting objectives (Voogd, 1983). The MCDA procedures/decision rules define a relationship between the input thematic information and the output potential map that is more complex than logical or algebraic relationships (Malczewski, 2004; Corona *et al.*, 2008). The procedures and decision rules help to overcome issues covering concepts, perceptions, approaches, models, and methods. They can be used for exploiting the references of decision makers, stakeholders, as well as other experts (Diakoulaki and Grafakos, 2004). In the literature, Diakoulaki and Grafakos (2004, p. 3) synthesise several advantages of the MCDA:

+ "MCDA directly involves the stakeholders facing a particular decision problem in order to detect their preferences and values regarding the decision criteria,

+ MCDA acts as an interactive learning procedure,

+ MCDA is a multi-disciplinary approach,

+ MCDA applications can consider a large variety of criteria, whether quantitative or qualitative, independent of the measurement scale,

+ MCDA is less prone to biases and distributional problems".

Land capability assessment for agricultural land use involves an interdisciplinary approach that requires the combination of various criteria belonging to different sciences. Both quantitative and qualitative analyses are involved in the assessment process, and the criteria are considered for different alternatives. Decision making on land use types, priority crops, capability factors, and the standards of capability classes are very important and complex and must be researched before the finalisation of the land capability assessment. Thus, land capability evaluation is a multiple criteria decision making process (Prakash, 2003; Baniya, 2008).

The MCDA, itself, does not offer "the best capability area" for a particular land use type. The ultimate result of land capability classification is formed by integrating, organising, considering, analysing, and weighting factors that contribute to the feasibility and success of land use types. There has long been a desire to link MCDA and GIS in making land allocation decisions by the integration of sophisticated decision theory and advanced spatial analysis (Hill *et al*, 2005).

In recent years, many multi-criteria evaluation methods have been utilised for GIS based land potential analysis. For examples, a GIS-integrated fuzzy rule-based inference system for land suitability (Reshmidevi *et al.*, 2009), GIS-based multi-criteria evaluation for land-use suitability analysis (Malczewski, 2006), an integration of GIS and multi-criteria decision analysis for urban aquaculture development (Hossain *et al.*, 2009), GIS-based fuzzy membership model for crop-land suitability analysis (Ahamed *et al*, 2000), and a GIS-based multi-criteria evaluation for land suitability modelling for giant prawn (Hossain and Das, 2010).

Integrating the MCDA and GIS has significantly advanced the conventional map overlay approaches to the land potential analysis (Malczewski, 1999; Banai, 1993; Carver, 1991). GIS-based MCDA can be understood as a process that combines and transforms spatial and a-spatial data (input) into a resultant decision (output) in order to obtain appropriate and useful information for decision-making (Boroushaki and Malczewski, 2010). The MCDA procedures comprise the utilisation of geographical data, the decision maker's preferences and the manipulation of the data and preferences according to specified decision rules (Malczewski, 2004).

Malczewski (2004) offers two critical important considerations for spatial MCDA: (i) the GIS capabilities of data acquisition, storage, retrieval, manipulation and analysis, and (ii) the MCDM capabilities for combining the geographical data and the decision maker's preferences into uni-dimensional values of alternative decisions. The capability model can include decision maker's preferences, which are turned into decision rules. The input thematic layers are transformed into constraint or factor criteria (Corona *et al.*, 2008). A *constraint* limits the capability of land use alternatives under consideration (Eastman 2006, FAO, 1985); a *factor* is a criterion that has a significant contribution to the land capability for a particular use. Many multi-criteria decision rules have been implemented in the GIS environment for tackling land-use suitability problems. The decision rules can be classified into multi-objective and multi-attribute decision making methods (Malczewski, 1999). In relation to advantages of GIS and MCDA for land evaluation, Carver (1991, p. 338) has interesting conclusions:

(i) "GIS is an ideal means of performing deterministic analyses on all types of geographical data,

(ii) GIS provides a suitable framework for the application of spatial analysis methods, such as MCDA, which do not have their own data management facilities for the capture, storage, retrieval, editing, transformation and display of spatial data,

(iii) MCDA procedures provide the GIS with the means of performing complex trade-offs on multiple and often conflicting objectives while taking multiple criteria and the expert knowledge of the decision-maker into account,

(iv) GIS and MCDA based systems have the potential to provide a more rational, objective and non-biased approach to making decisions on sitting than used hitherto".

To summarise, along with GIS, the MCDA is an effective support tool in selecting and deciding criteria for land capability assessment. In land suitability analysis, the MCDA helps land evaluators determine the importance and priority of each criterion impacting upon land suitability. Whereby, land suitability classes for specific use are calculated and finalised. There are several methods belonging to the MCDA approach, and Analytical Hierarchy Process (AHP) is one of the most effective techniques, which links with GIS to be used for land suitability evaluation. The next discussion is about the AHP.

3.8.1 Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) is a decision-making theory developed by Saaty (the University of Pennsylvania), while directing his research project in the U.S Arms Control and Disarmament Agency (Bhushan and Rai, 2004). It is widely applied in MCDA as a comprehensive framework designed to deal with the intuitive, the rational, and the irrational when decision makers make multi-objective, multi-criterion and multi-factor decisions with or without certainty about any number of alternatives (Harker and Vargas, 1987, p. 1383). AHP offers a methodology to rank alternative courses of action based on the decision makers' judgments concerning the importance of the criteria and the extent to which they are met by individual alternatives (Nydick and Hill, 1992).

Decision makers can incorporate qualitative (intangible) and quantitative (tangible) aspects of a complex problem using the AHP approach. The complex problems can be systematically solved by decomposing the structure of a problem into hierarchies and the users then make pair-wise comparison judgments as to the importance or preference to develop priorities in each hierarchy (Gerdsri and Kocaoglu, 2007, p. 1073).

First introduced in 1976, AHP has gradually evolved through a wide variety of applications as diverse as energy allocation, marketing decisions, project selection and evaluation, technology selection, new product screening, and conflict resolution (Gerdsri and Kocaoglu, 2007). Recently, AHP has been applied in various disciplines, such as using the AHP in SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis to a forest-certification (Kurttila, 2000), AHP for engineering process selection (Hotman, 2005), applying the AHP in a firm's overall performance evaluation in China (Yang and Shi, 2002), and applying the AHP to build a strategic framework for technology road-mapping (Gerdsri and Kocaoglu, 2007). The AHP can integrate with a GIS to become a useful and effective tool for land capability evaluation. This has been done to compare land use planning approaches in the Mekong Delta, Viet Nam (Trung, 2006), and for land suitability evaluation using GIS for vegetable crops in Nepal (Baniya, 2008).

Malczewski (2004) outlined that the AHP can be incorporated into GIS-based analysis in two distinctive ways for land evaluation. First, AHP can be employed to derive the weights associated with attribute map layers. Accordingly, the weights can be combined with the attribute map layers in a way similar to the linear additive combination methods. Second, the AHP principle can be used to aggregate the priority for all levels of the hierarchy structure including the level representing alternatives. In this case, a relatively small number of alternatives can be evaluated (Banai, 1993).

3.8.2 Steps of the AHP technique

Fundamentally, the AHP provides the objective mathematics to process the inescapably subjective and personal references of an individual or a group (such as land evaluators) in making a decision (Garuti & Sandoval, 2006, p. 189). It works by developing priorities for alternatives and the criteria used to judge the alternatives, and the criteria are often measured at various scales as presented in the Table 3.2 (Saaty and Vargas, 2001, p. 6; Saaty, 2008a, p. 257; Saaty, 2008b, p. 86). In the AHP, "a decision hierarchy is structured with a goal, criteria, and alternatives. The criteria are pair-wise compared for their importance according to the goal to derive a scale of relative importance and the alternatives are pair-wise compared with respect to each criterion to derive the relative scales. The relative scales are synthesized using a weighting and adding process to show which is the best alternative" (Saaty, 2002, p. 216). All those processes can be summarised by the following main steps of the AHP technique (Bhushan and Rai, 2004, p. 15; Saaty, 2008b, p. 85; Lee *et al.*, 2007, p. 824):

(i) "Define the problem and determine the kind of knowledge sought. The problem is decomposed into a hierarchy of goal, criteria, sub-criteria, and alternatives. This is the most creative and important part of decision making,

(ii) Structure the decision hierarchy from the top with the goal of the decision, then the objectives from a broad perspective, through the intermediate levels (criteria on which subsequent elements depend) to the lowest level (which usually is a set of the alternatives),

(iii) Construct a set of pair-wise comparison matrices (square matrices, *see Chapter 6*). Each element in an upper level is used to compare the elements in the level immediately below with respect to it. The diagonal elements of the matrix are 1. The value of element (***i, j***) is more than 1 when the criterion in the ***i***th row is better than criterion in the ***j***th column, otherwise the criterion in the ***j***th column is better than the criterion in the ***i***th row. The (***j, i***) element of the matrix is the reciprocal of the (***i, j***) element, (i=1/j), and ***i, j*** = 1, 2, 3, n.

(iv) Use the priorities obtained from the comparisons to weigh the priorities in the level immediately below. Do this for every element. Then for each element in the level below add its weighed values and obtain its overall or global priority. Continue this process of weighing and adding until the final priorities of the alternatives in the bottom most level are obtained".

To make comparisons, a scale of numbers that indicates how many times one element is more important or dominant over another element with respect to the criterion, needs to be set up (Table 3.2).

In farmland capability assessment, the significance and priority of sub-criteria and criteria in the final goal for a specific farmland use are identified by the AHP technique. Based on this, strategies and solutions for farmland improvement and development will be proposed, in order to increase the capability of farmland.

Table 3.2: The fundamental scale of absolute numbers

Intensity of importance	*Definition*	*Explanation*
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8		Intermediate values to reflect fuzzy inputs
Reciprocals of above	If activity ***i*** has one of the above non-zero numbers assigned to it when compared with activity ***j***, then ***j*** has the reciprocal value when compared with ***i***	A reasonable assumption
1.1-1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

Source: Saaty and Vargas (2001, p. 6); Saaty (2008a, p. 257); Saaty (2008b, p. 86); Bhushan and Rai (2004)

3.9 Examples of GIS and MCDA-based land evaluation

As mentioned previously, GIS and MCDA are two useful support tools that are used in many parts of the world for land evaluation. However, procedures and ways of application, as well as their effectiveness vary from place to place, depending on specific conditions. This section provides an overview list of applications developed so far, concentrating on agricultural land evaluation (Corona *et al.*, 2008).

Table 3.3 shows that GIS and MCDA tools are applied widely for land assessment and have been for a long time in many parts of the world. They can be used for specific studies in certain regions such as evaluating land suitability for a selected crop (single land use type), and used for complicated studies like classifying or evaluating land suitability for multi-farming systems (multi-land use types) and compound land use types[15], as well as studies that predict the agricultural capability. Applying GIS and MCDA together allows the consideration of and integration of multi-disciplines in land evaluation. Moreover, interrelationships and interactions between bio-physical, socio-economic, and other land characteristics are weighted equally with respect to the performance of a specific land use.

Obviously, GIS and MCDA have a major function and have played a much more important role in land evaluation so far because of the development of new AHP versions and GIS software, associated with the development of other decision support systems. They help land evaluation procedures to be more effective, appropriate, and undertaken at a lower cost. However, the GIS or MCDA tool, itself, does not cover all tasks in land evaluation. They should be linked together, or with other tools, to perform the function because land evaluation requires the involvement of a range of multi-disciplines, and is dependent on different conditions in local areas.

The AHP linked with the GIS tool, as used for land capability assessment in this study, is presented and interpreted in Chapter 6 of this thesis.

---

[15] *Single, multi and compound land use/utilisation types will be defined in Chapter 4 "see item 4.4.1"*

Table 3.3: Examples of GIS-based and (or) MCDA-based land evaluation

Author (s)	Purpose	Support tools used	Data layers	Outputs
Liengsakul *et al.* (1993)	Comparing GIS + digital remote sensing with soil inventories, and the use of soil and other data to locate new sites for cropland and settlements	GIS + remote sensing	Satellite image interpretation (geological, topographic, and landform), land use/cover, soil map, terrain, accessibility	GIS and remote sensing present to planners and decision makers potentially suitable and accessible locations (based on selected criteria) for permanent cropland in highland areas that are not yet used at present.
Wandahwa and van Ranst (1996)	Assessing qualitative land suitability for pyrethrum (*Chrysanthemum cinerariaefolium)*	Computer-captured expert knowledge and GIS	Climatic, soil and landform (drainage, soil texture or structure, flooding, coarse fragments, soil depth, calcium carbonate, water pH, organic carbon, and CEC	Land suitability maps for pyrethrum cultivation
Delli *et al.* (1996)	Evaluating land suitability for rainfed winter wheat	Satellite image interpretation and attribute data analysis	Climate, geomorphology, soils, vegetation, socio-economic such as labour intensity, capital intensity, market orientation, infrastructures.	Yield potential map of wheat
Bydekerke *et al.* (1998)	Land suitability assessment for cherimoya (*Annona cherimola* Mill.) in southern Ecuador	GIS and expert method	Climate, soils, landforms	Land suitability map for cherimoya
Ahamed *et al.* (2000)	Assigning the land suitability for crops in Kalyanakere sub-watershed in Karnataka, India	Linkage of MCDA and GIS	Texture-surface, texture-subsurface, soil pH, drainage, CEC, gravel-surface, gravel-subsurface, and base saturation	Land suitability maps for paddy, ground nut, and finger millet

Table 3.3: Examples of GIS-based and (or) MCDA-based land evaluation (continued)

Author (s)	Purpose	Support tools used	Data layers	Outputs
Store and Kangas (2001)	Improving habitat suitability evaluation over large areas to produce habitat suitability maps for old-forest polypore (*Skeletocutis odora*)	Spatial MCDA and expert knowledge integrated for GIS-based	Soil fertility, slope direction, soil moisture, density of growing stock, stem volume of spruce, and age of spruce	Land suitability maps for *Skeletocutis odora*
Kalogirou (2002)	Implementing a land suitability evaluation model by combining GIS and expert-systems	GIS and expert-systems	Physical FAO (1976) land classification for crops such as soil toxicities, rooting conditions, excess of salts	Suitable areas for agriculture and a group of selected crops: wheat, barley, maize, seed cotton, sugar beet)
Prakash (2003)	Extending potential of the Fuzzy AHP into land suitability decision-making	Integration of GIS and MCDA (AHP, Ideal Vector Approach-IVA, and fuzzy AHP)	Soil, climate, topographic, socio-economic, market-infrastructure, and irrigation facilities	Suitability maps for Rice from AHP, IVA, Fuzzy AHP
Ceballos-Silva and López-Blanco (2003)	Identifying land suitability for the production of maize and potato crops in Central Mexico	Integration of the GIS and Multi-criteria evaluation techniques	Climate, relief, and soil databases are involved	Comparison of current and potential land suitability areas for maize and potato cultivation
Boonyanuphap *et al*. (2004)	Evaluating land suitability for Musa (ABB group) plantation	GIS and GPS	Soil texture, depth, drainage, pH, CEC, total C, slope, elevation, rainfall	Land suitability classification map for Musa, maps of possible area for new Musa plantation based on land use types and based on soil series characteristic
Sicat *et al*. (2005)	Classifying land suitability for crops	Fuzzy modelling of farmers' knowledge combined with GIS	Cropping season, soil colour, soil texture, soil depth and slope	Land suitability maps for optimum land-use planning.

Table 3.3: Examples of GIS-based and (or) MCDA-based land evaluation (continued)

Author (s)	Purpose	Support tools used	Data layers	Outputs
Liu *et al*. (2007)	Developing an integrated GIS-based analysis system for supporting land-use management of lake areas in urban fringes in China	Incorporation of MCDA and GIS	Geology and topography, hydrology, ecology, population, economics, environmental impacts, economic location, and transportation location	Two scenarios for potential land use changes from 2006 to 2020 are generated
Baniya (2008)	Evaluating land suitability for vegetable crops in Nepal	GIS and AHP	Temperature, soil texture, fertility, soil pH, irrigation, soil depth, slope, service	Current land suitability maps and potential land suitability maps for vegetable crops
Santé-Riveira *et al*. (2008)	Developing a planning support system for rural land-use allocation	A Multi-objective linear programming model (LINDO optimum software, hierarchical optimization, ideal point analysis, and an algorithm) GIS-based	Agronomic, management, socio-economic, and environmental impacts	A support tool for rural land-use planning is formed
Bandyopadhyay *et al*. (2009)	Assessing land suitability potentials for agriculture	GIS and remote sensing	Soil texture, erosion, slope, depth, organic carbon	Agricultural land suitability map
Reshmidevi *et al*. (2009)	Introducing a GIS-integrated fuzzy rule-based inference system for land suitability evaluation	GIS and fuzzy model	Land use, soil texture, terrain slope, drainage density, soil depth, pH, CEC, OC, salinity, rainfall, elevation	Land suitability maps for paddy, propose weighted attribute aggregation methods for land evaluation
Hossain *et al*. (2009)	Identifying suitable sites for carp farming development in urban water bodies in Bangladesh	GIS-based Multi-Criteria Evaluation	Water, soil and infrastructure database	Suitable maps for carp farming are created
Hossain and Das (2010)	Identifying appropriate site for the farming of giant prawn (*Macrobrachium rosenbergii*) in Companigonj of Noakhali, Bangladesh	GIS-based Multi-Criteria Evaluation	Twenty base layers of quality, soil characteristics and infrastructure facilities	Suitable land maps for prawn farming

3.10 Land capability assessment in Viet Nam's Mekong Delta

Up until 1954, land use in Viet Nam was impacted by the land administration system of the French. In the period 1954-1975, land policies and land use systems in the North and South were very different. The country was unified in 1975. Land use between 1975 and 1986 was guided by a unified system of land policies based on the state subsidy mechanism.

Unfortunately, there has been very little scientific literature on land capability evaluation in the Mekong Delta in particular, and Viet Nam in general. At this time, the capability of the land resource is often grouped according to land management classifications such as agriculture, forestry, rural residential, urban residential, specialist use and unused land. Studies on land evaluation in the Mekong Delta have actually started and developed since the open policies which have been implemented, and especially in the early 1990s.

In these years, the FAO (1976) framework for land evaluation was used most widely in the Mekong Delta as a standard guide for land evaluation advice. A wide variety of studies were carried out with differential levels, such as land evaluation for rain-fed lowland rice areas (Ni, 1993), using soil and agro-hydrological characteristics as dominant factors in agro-ecological analysis for rain-fed lowland areas (Minh, 1995), and present land use as a basic for land evaluation (Tri, *et al*, 1993), coarse land evaluation of the acid sulphate soil areas based on farmers' experience (van Mensvoort *et al.*, 1993).

The most important-common point in those studies is that they are all based on the FAO method for land evaluation. The land capability/suitability assessment in some studies is purely a bio-physical study of crop growth possibilities; others integrate socio-economic factors into criteria sets for land evaluation (Trung, 2006). Most of these evaluations focused on agriculture and farmland. Land suitability classification was often based on limitations and constraints such as salinity, presence and depth of sulphate layer and water source for irrigation. Land evaluation at this stage seems to be only a soil scientists' mission, rather than having stakeholders' participation regarding natural resources management. The main purpose of land evaluation was to look for farming systems that were adaptable to local land conditions.

Recently, land evaluation and land use in Viet Nam have been investigated by multi-disciplinary land evaluators, land policy makers, and land managers, particularly around the third land law enacted in 2003. Support tools like GIS, GPS, remote sensing, and MCDA are now used in land evaluation. Typical studies include GIS for land evaluation for shrimp farming in Hai Phong, Viet Nam (Giap *et al.*, 2005), land suitability assessment for Robusta coffee in the Dak Gan region (D'haeze *et al.*, 2005), combining top-down and bottom-up modelling approaches to land use/ cover change to support public policies (Castella *et al.*, 2007), land evaluation for rice, maize and soybean (Ha *et al.*, 2006), and the application of land suitability analysis and landscape ecology to urban green-space planning in Hanoi, Viet Nam (Uy and Nakagoshi, 2008).

For the Mekong Delta, land resources are presently facing the challenges of climate change, salinity, flooding (Minh, 2002), and drought. Intensive farming systems have been causing considerable soil erosion, degradation, fertility depression, and desertification since the exhaustion of the lands capability. In many areas, this warns that the land as a resource needs to be entirely reassessed in order to offer solutions and ways for sustainable land resource use. However, the assessment should not simply concentrate on soils; a broader view of land should be considered.

Minh *et al.* (2003a, 2003b) developed a method for land evaluation and land use planning to be used for the Mekong Delta context. The authors integrated socio-economic factors into criteria sets for land evaluation with a GIS tool support. The assessment procedure and activities were mostly based on the FAO (1976) methods. Relationships and interactions between criteria used to evaluate land use types were not calculated or considered. Thus, the results of the land evaluation indicate the bio-physical or socio-economic capability, but not an integration of both.

Trung *et al.* (2004) use GIS for Participatory Land Use Planning (PLUP). The results indicate that the PLUP approach is a useful tool to encourage involvement of the farmers, the most disadvantaged stakeholder, into the land use planning procedure. Farmers have the opportunity to present their knowledge of the land, their needs and to express their opinions on how to use the land. However, the study does not result in a land use plan.

The FAO method based on the MCDA (Trung, 2006) and integrated approaches (Son *et al.*, 2008) were also applied in the Mekong Delta for land-use planning. The authors combined factors such as the biophysical, socio-economic, environmental impact, and policies in the land potential assessment for the purpose of planning. Nevertheless, these approaches have several limitations: (1) the importance of class-determining factors (FAO, 1993) is appraised independently and therefore the scenario analysis forced the decision makers to consider trade-offs between different possibilities and goals. Functional interrelations and interactions between these factors are not taken into account in the final results of land evaluation; (2) the possible subjective justification on the importance of the chosen criteria, e.g. socio-economic and environmental due to the land use planners or decision makers bias, educational background and political views as well (Trung, 2006); and the standardisation of evaluation criteria because different standardisation methods may lead to different land capability patterns (Malczewski, 2004).

To sum up, land capability assessment is limited. Most conducted studies use or adopt the original FAO framework for land evaluation, associated with support tools e.g. GIS, remote sensing, MCDA. The VLAP (Viet Nam Land Administration Project, 07/2008-06/2013) has just been executed in three representative provinces: Ben Tre, Vinh Long, and Tien Giang, and this provides a good opportunity to upgrade the land database in the Mekong Delta. But, this project is only for land administration. So far, there has been no study, program, or project to develop the specific method, or a theoretical framework, for land evaluation; or for the assessment of land capability in this whole region. Therefore, a case study undertaken in the Mekong Delta to apply the theoretical model for farmland capability determination is needed. The case study implementation will be presented in Chapter 6 of this thesis.

3.11 Summary

Understanding the background knowledge on land evaluation is required to develop a theoretical model for farmland capability assessment, which is the dominant objective of the study. In this chapter, the concept "land suitability" and "land capability" and the purposes of land evaluation were clarified. The key point was introduced that two original fundamental systems for land evaluation: the FAO and USDA approaches, as well as adopted techniques, have been generated, based on those two parent approaches. A theoretical framework for land evaluation and relevant land capability assessment trends such as combining qualitative and quantitative considerations, integrating scientific and local knowledge, and multi-disciplinary evaluation, have been discussed. These are shown to be really useful in designing an agricultural management system to determine the farmland capability that will be outlined in the next chapter.

More importantly, the author described and synthesized common required principles, execution procedures, classification systems, and summarized previous studies on land evaluation in the worldwide and study area context. Finally, support tools for land evaluation such as GIS and MCDA (e.g. AHP technique) were reviewed. The review included descriptions of required principles, implementation procedure, and practical application examples.

These literature reviews are fundamental instruments for the author to develop a theoretical model to determine the capability of farmland, which is the goal of the study. The model created for this research integrates many components like the biophysical, socio-economic, and environmental factors based on the findings from these literature reviews.

CHAPTER 4: A THEORETICAL MODEL DEVELOPMENT FOR FARMLAND CAPABILITY DETERMINATION

4.1 Introduction

This chapter presents one of most important phases of the research which is the design of a theoretical model. The key steps and procedures to design an Agricultural Management System (AMS) for farmland capability assessment are presented. Components and factors that impact upon the capability of farmland are explored and built into the design of the AMS. The theoretical system, the AMS, for farmland capability classification is developed and described. The main content in this chapter includes the: (1). Theoretical framework of the research; (2). Procedure for the development of a theoretical model, the AMS, for farmland capability determination; and (3). Conceptual framework of the research. The theoretical model design is based on information and knowledge gained from the literature review chapters. The developed model is then tested by undertaking a case study that is presented in Chapter 6.

4.2 Conceptual framework

4.2.1 Agricultural management concept

The agricultural sector is defined by any agricultural business (agribusiness), including related businesses (Figure 4.1) such as the supply of farming input materials (fertilizers, pesticides, seeds, labour, equipment), the production process (planting, care taking, harvesting, transporting), and the consumption of agricultural products (marketing, selling, warehousing, processing, wholesaling, transporting and retailing) (Womach, 2005, p. 7). Agricultural management, therefore, is business management that is driven by four key functions: the planning, organizing, directing and monitoring of entire farming activities in a specific farming system (http://www2.ag.ohio-state.edu/~mgtexcel/Function.html) in order to create agricultural products and generate high benefits for producers. The management process is more described and clarified in Appendix 1.

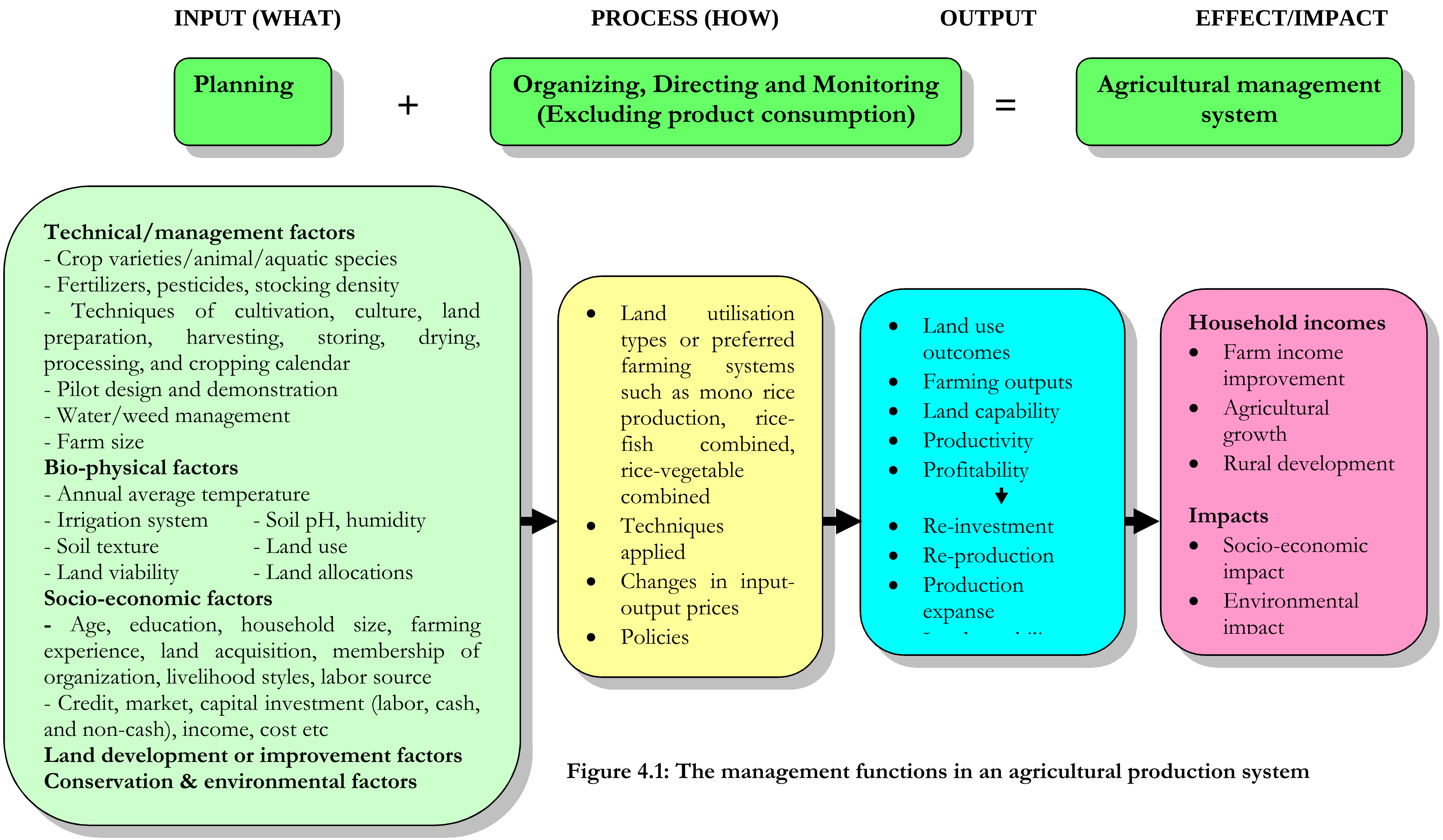

Figure 4.1: The management functions in an agricultural production system

In the agricultural management procedure, **planning** is one of the most important functions to delineate, configure and prepare a sequence of action steps to achieve a specific goal of a farming system (farmland use type). It reveals for farmers (farmland users) how much they have progressed towards their production goal and how far they are from their destination. Based on this, farmers can make reasonable decisions for their agribusiness. For example, to cultivate a hectare of rice, farmers can list and calculate what the required input materials (seeds, fertilizers, pesticides) are, and how much involvement these inputs have in the planning function.

Organizing is the act of rearranging or placing activities, in an agricultural production system, in a specific order to minimize production costs and increase the economic efficiency of a farming system.

Directing is demonstrating how to conduct and lead farming activities using logic and scientific production rules.

Monitoring represents the act of observing entire farming activities. It is the systematic information collection and analysis of individual farming activities for decision-making. Monitoring provides information about how allocated funds are being used for farming activities and whether progress towards expected outcomes for a farming system are being achieved.

4.2.2 System concept

Systems theory stresses that a system is a set of interrelated components working together to achieve a common purpose (Pidwirny, 2006a; FAO, 1993). Systems are often visualized or modelled as component blocks that have connections drawn between them. They exist at every scale and are often arranged in a hierarchical fashion. Large systems are regularly composed of one or more smaller systems each working within its various elements. Processes within these smaller systems can be connected directly or indirectly to processes found in the larger system (Pidwirny, 2006a, 2006b). A clear example of a system within a system is the hierarchy of systems found in the rice seed supply system in the Mekong Delta (Figure 4.2).

The FAO (1993), Haaf *et al.* (2002) and Pidwirny (2006a) highlighted the importance of, and characteristics of, systems theory as the following:

1. Emphasizes the need to view a situation as a whole (generalizations of reality), and not as separate parts. The boundaries of systems change with a change in focus;
2. Systems tend to function in the same way, recognizing the interaction of components, in the process of transforming inputs to outputs (the various parts of a system have functional as well as structural relationships between each other);
3. Stresses systems hierarchy, whereby every system is part of a larger system and it consists of sub-systems. Systems can be open (influenced by environmental factors) or closed (not influenced by environmental factors);
4. Systems have productivity, stability, sustainability, unification, and balance.

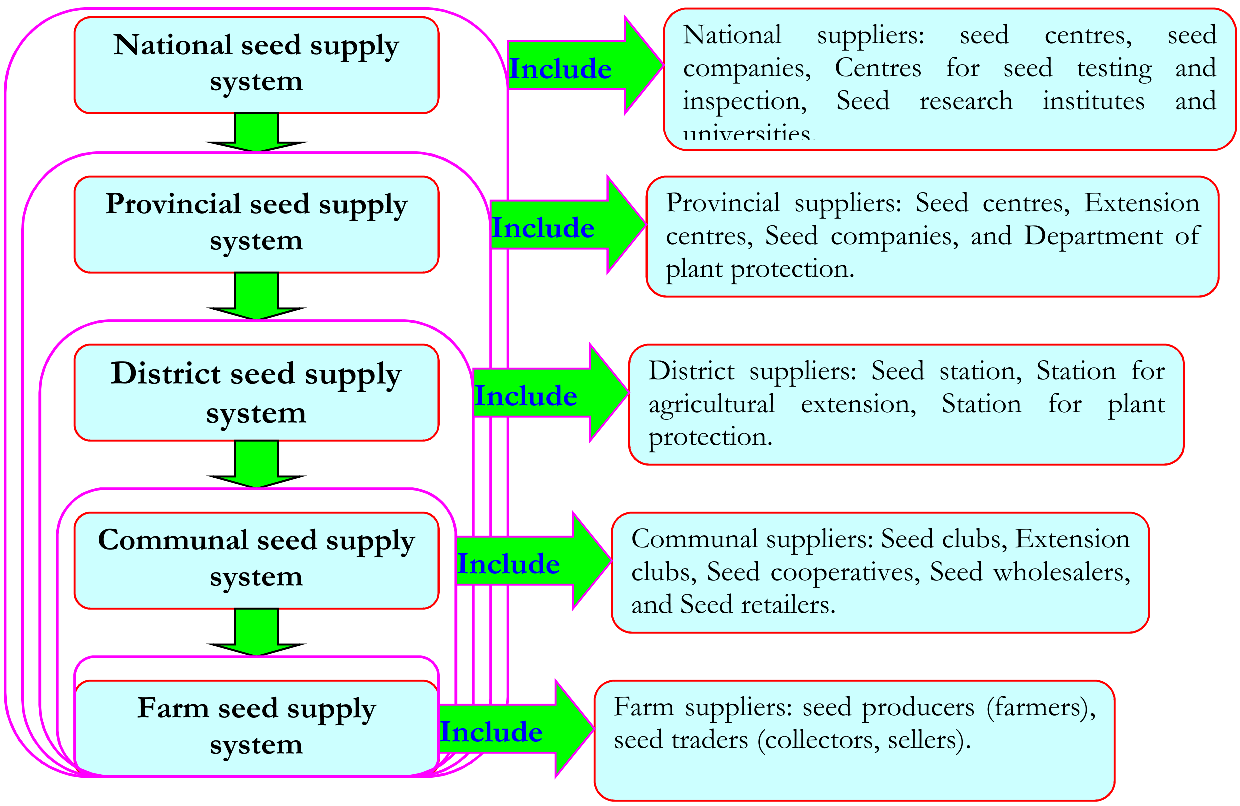

Figure 4.2: The hierarchy of systems in the rice seed supply system in the Mekong Delta, Viet Nam. *Source: Tin (2005) and Huynh et al. (2010)*

Further, a system has three kinds of properties in term of the boundary:

(1). Elements: are the kinds of parts (components or factors) that make up a system. These parts may be atoms or molecules, or larger structures like plants, animals, or a production system.

(2). Attributes: are characteristics of the elements that may be perceived and measured, for example: quantity, size, volume, and mass.

(3). Relationships: are the associations that occur between elements and attributes, these associations are based on cause and effect.

Systems theory is applied to a system comprised of interacting parts and together, these separate parts contain the inputs and outputs from the different processes.

Figure 4.2 shows that the national rice seed supply system is the largest system; it includes many smaller systems (provincial systems); provincial seed supply systems are components of the national seed supply system. The farm seed supply system is the smallest system in the hierarchy. When there is a small system in a larger/higher level system this is known as a hierarchical characteristic of the system.

4.3 Theoretical framework

There are many approaches for land use planning available, the Land Use Planning guidelines by the FAO (FAO, 1993), the Participatory Land Use Planning (PLUP) methodology (Usongo and Nagahuedi, 2008; Jones and Sysomvang, 2005; Beall and Zeoli, 2008), the Land Use Planning and Analysis System (LUPAS) (Van Ittersum *et al.*, 2004 and Rotter *et al.*, 2005), the Conversion of Land Use and its Effects (Veldkamp and Fresco, 1996; De la Rosa *et al.*, 2009) are examples. Each of the above stated techniques has been applied by several case studies in different locations, and they contain different activities in the application procedure. However, all these approaches have the same major goal which is land evaluation, including land suitability evaluation, undertaken by appraising alternatives in the context of environmental, technical, bio-physical, and socio-economic analysis.

Land capability/suitability assessment is widely described, discussed, and studied in many parts of the world. De la Rosa *et al.* (2004, 2009) have reviewed a number of case studies in England and Spain, Rowe *et al.* (1981) and Hanson *et al.* (2001) described their studies in Australia, Walter & Stützel (2009a, 2009b) introduced a new method for assessing the sustainability of land use systems in Germany. While, many other authors defined and developed a framework or guidelines for land evaluation, land capability assessment, as well as conducting case studies in land evaluation (FAO, 1976; 1985; 1991a; 1993; 2007b; Karlen *et al.*, 1997; USDA, 2001; Paul Smith *et al.*, 2004; Murphy *et al.*, 2004; The State Planning Commission, 1989; EPA, 2003; Peter, 1996; MAF and ME, 1983; The ACT Parliamentary Counsel, 1999; Ritung *et al.*, 2007; Jaruntorn Boonyanuphap *et al.*, 2004; USDA, 2009).

This current study applies a holistic approach and refers to previous studies, as well as drawing on a literature review, to develop a theoretical model that integrates land characteristics in terms of land quality to determine the capability of farmland. The study uses theoretical perspectives from systems theory by the FAO (1993), Haaf *et al.* (2002), Pidwirny (2006a; 2006b) that (1) an agricultural management system (AMS) must be structured, formed, and developed; (2) factors (in components) and components in the AMS, which impact upon the capability of farmland and the prosperity of farms must be explored and defined, including bio-physical, technical and management, land improvement or development, conservation and environmental, policy and institutional, and socio-economic aspects; (3) roles and functions of every factor in the AMS must be determined and analysed; (4) functional interactions and relationships within and between components in the AMS must be considered and evaluated; (5) modelling optimal expected scenarios of the capability of farmland and the prosperity of farms; (6) the capability of farmland and the prosperity of farms (processed outputs of the AMS) can be revealed by linking the Analytical Hierarchy Process (AHP) with GIS tools.

4.4 Developing a theoretical model

The procedure and important steps in conducting the study include three interrelated activities: land use requirement definition, land resource investigation, and land capability analysis (Figure 4.3). These activities were integrated and grouped into two main phases, developing a theoretical model of the AMS for farmland capability assessment, and testing the developed theoretical model by conducting a case study.

First, a theoretical model was structured and developed, based on the findings from a literature review with possible application in many parts of the world. This model design could also be adjusted and modified for use in different specific situations.

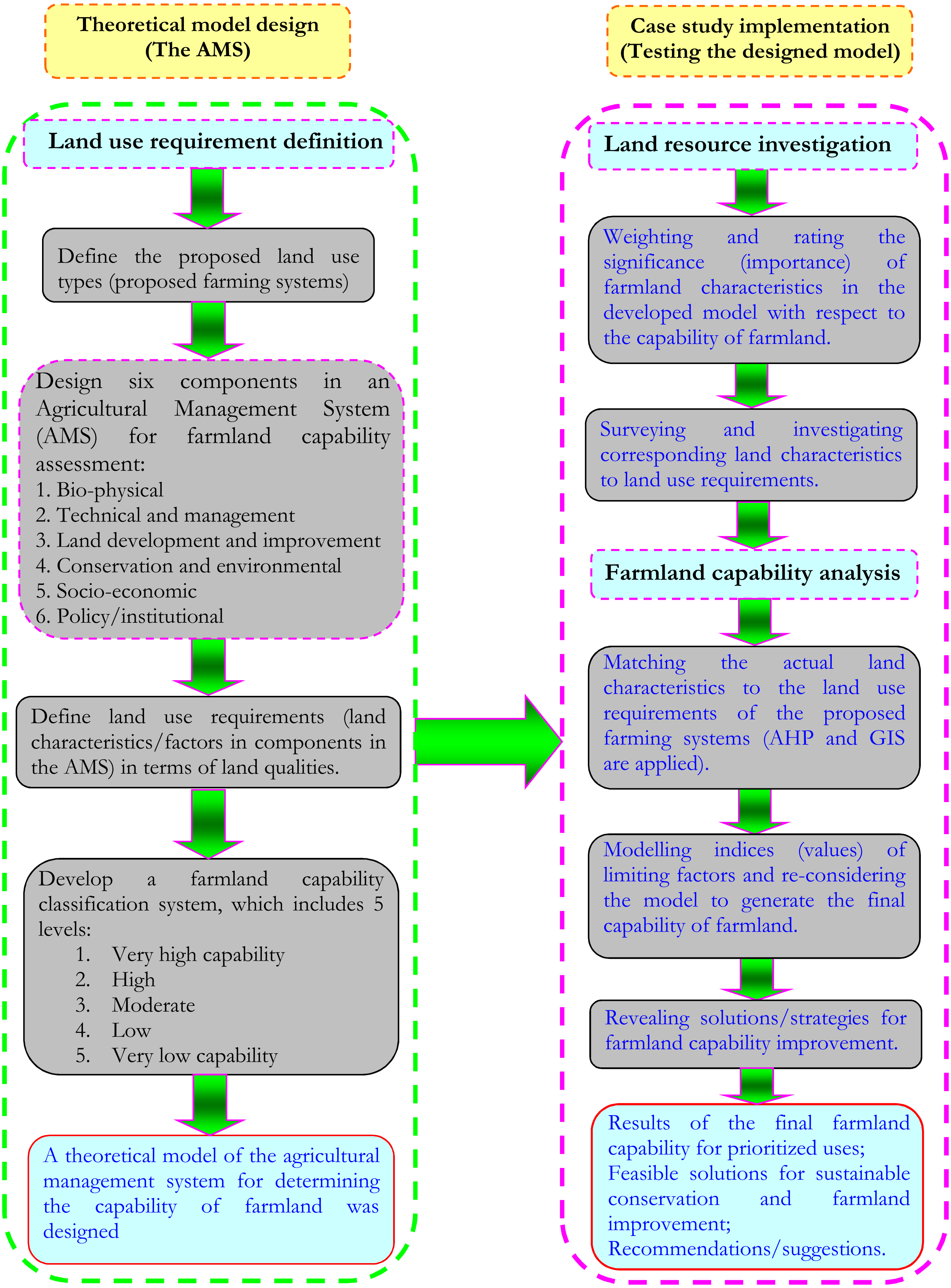

Figure 4.3: The conceptual flowchart of the research approach

The following steps are involved in the development phase of a theoretical model (theoretical model development phase):

(1). Defining the proposed farming systems for farmland capability assessment

(2). Determining key components in the AMS for farmland capability assessment

(3). Identifying class-determining factors (required land characteristics) of each component in the AMS

(4). Developing a farmland capability classification system for the proposed farming systems

(5). Determining the capability of farmland for the proposed farming systems

The model design is then tested through conducting a case study (practical testing phase), which is presented in Chapter 6.

4.4.1 Defining land utilisation types (proposed farming systems)

The FAO (1976, p. 12-14, 1985, 1993, 2007b) stated that land capability assessment involves relating land mapping units to specified types of land use. The types of use considered are limited to those which appear to be relevant under the general physical, economic and social conditions prevailing in an area. These kinds of land use serve as the subject of land evaluation. The activities in land evaluation that are specifically concerned with the choice and evaluation of cropping, irrigation and management systems (i.e. with land use) start with decisions about the alternative Land Use Types (LUTs) that will be separately evaluated (FAO, 1985).

The FAO framework (1976, p. 12-14, 1985, 1993, and 2007b) for land evaluation recognizes levels of detail at which land use is defined, and distinguishes between forms of LUTs as the following:

<u>A major kind of land use</u> is that which represents a major subdivision of rural land use such as extensive agriculture, intensive agriculture, forestry, or recreation;

<u>A land utilisation type</u> is a kind of land use defined in more detail (farming systems) according to a set of technical descriptors in a given bio-physical, economic and social setting;

Single LUT specifies only one kind of use undertaken on an area of land (e.g. irrigated rice, upland rice cultivation);

A multiple LUT specifies more than one kind of use simultaneously undertaken on the same area of land, each use having its own inputs, requirements and produce;

A compound LUT specifies more than one kind of use sequentially undertaken on the same area of land.

This current study is concerned with land use types, rather than a major kind of land use. Therefore, the required output in this step is to identify promising agricultural LUTs (proposed farming systems) and their levels of detail, which can be used for farmland capability assessment. In determining the farming systems, which have high priority for cultivation, in the model, the product should focus on a range of aspects, such as profitability, and the sustainability factors, including the bio-physical, agro-ecological, and socio-economic adjustment. Further, availability and type of input materials, local culture and habit, demography, potential local market, institution and government and accessibility are also taken into account (Baniya, 2008, p. 53). LUTs in the theoretical model of this study were based on three combined components given below:

(1). Attributes of land utilisation types include data or assumptions based on (adopted from FAO, 1976, p. 12-13):

+ Produce (scale and area for production; amount and value of production), including goods (e.g. crops, livestock, fishery), services (e.g. recreational facilities) or other benefits (e.g. economic growth, job opportunities, export value),

+ Market orientation, including whether towards subsistence or commercial production,

+ Capital intensity,

+ Labour intensity,

+ Power sources (e.g. man's labour, draught animals, machinery using fuels),

+ Technical knowledge and attitudes of agricultural land users,

+ Technology employed (e.g. implements and machinery, fertilizers, livestock breeds, farm transport, methods of harvesting, land preparation),

+ Infrastructure requirements (e.g. irrigation systems, dykes, dams, agricultural processing factories, agricultural advisory services),

+ Size and configuration of land holdings, including whether consolidated or fragmented,

+ Land tenure, the legal or customary manner in which rights to land are held, by individuals or groups,

+ Income levels, expressed per capita, per unit of production (e.g. farm) or per unit area.

(2). Current agricultural land utilisation types in the localities.

(3). Proposed or planned agricultural land utilisation types for future agricultural land use planning in the localities.

These components and attributes of the agricultural LUTs would be inspected carefully by a multi-disciplinary team of experts specialising in the natural resources (FAO, 1995), based on specific conditions at the different local contexts for the proposed farming systems. When farming systems are defined, they become the fundamental instrument for the next step which is identifying the land characteristics.

4.4.2 Determining key components in the AMS

According to the definition of land resources described by the FAO/UNEP (1997), Sombroek (1996) and FAO (1995) (*see item 2.8.1, Chapter 2*), land refers to a range of interrelated disciplines, such as farming systems (plants, animals), landforms, climate, hydrology, geology, topography, together with the socio-economic attributes (labour, population, revenue and other human activities), and land improvements such as terraces and drainage works (FAO, 1976; FAO, 1985; FAO, 1993; Rowe *et al.*, 1981, Rossiter. 1996; The State Planning Commission, 1989).

The definition of land stated above shows that land capability is determined and formed by many different land characteristics, which have related and interacted together to determine the capability of land for a certain utilisation. In setting up the land capability class specifications prior to an evaluation of land areas for a LUT, class-determining factors[16] must be decided (FAO, 1976; 1985).

Class-determining factors affect the performance of the LUT on the land units under a certain area, such as yields, benefits and costs. During land evaluation, the number of factors that are class-determining will be short-listed, and later their influence will be aggregated in a yield or economic index (FAO, 1976; 1985). Single factors that, may or may not be selected as 'class-determining' in any given land assessment, can be grouped according to how they affect the performance of land for a specific use (FAO, 1985).

Using the definition of land resources, six fundamental components in the AMS (broad groups of class-determining factors), representing major aggregated disciplines of land characteristics were proposed for farmland capability determination. They were designed and developed based on the analysis and integration of previous studies, and guidelines developed by the FAO (1976, 1985, and 1993), Rowe *et al.* (1981), Ritung *et al.* (2007), Peter (1996), Wright *et al.* (2006), and Paul Smith *et al.* (2004).

- Bio-physical,
- Technical and management,
- Land improvement/development,
- Conservation/environmental,
- Socio-economic,
- Policy/institutional.

Each component in the AMS (theoretical model) encompasses a number of individual factors, and these components are flexibly adjusted (by removing or adding) to suit specific conditions at the different localities. The degree of importance of every component in the AMS to the capability of farmland is considered without bias, with the testing conducted by a team of multi-disciplinary land resources experts. Depending on how the individual factors affect the performance of farmland for a

[16] *Refer to Appendix 1*

specific use, as well as at which level (province, district, commune, hamlet, and farm) the capability of the farmland is determined.

4.4.3 Identifying land characteristics of each component in the AMS

Based on the determined-LUTs (*item 4.4.1*), associated with the six designed components in the AMS (*item 4.4.2*), relevant land characteristics (factors) of every component in the AMS for farmland capability assessment were explored and developed. The FAO Guidelines for Land Evaluation (FAO 1976, 1985, and 1993) formed the basis of the study and was further used for analysing agricultural structure in order to lay the foundation for collecting, evaluating and analysing information (Baniya, 2008, p. 47). Further integration into the global context, on the basis of farmland characteristics, was made according to the FAO (1976, 1985, and 1993) instructions. Table 4.1s (4.1.1 to 4.1.6) presents a large number of factors (headings) used in the AMS design, which can be refined (added or removed) by a team of multi-disciplinary land resources experts to shortlist the most suitable set of factors for determining the capability of farmland at different locations (modelling for the local context).

The measurement and criterion of each factor in the AMS used for farmland capability assessment is dependent on specific farming systems (LUTs) (*in item 4.4.1*), and the specific local conditions, where the model will be applied. Moreover, the relationships and interactions between factors (within and between components in the AMS) would also be analysed and considered as contributing to the capability of farmland. The importance and significance of factors to the capability of farmland would be determined by the FAO (1976, 1985, 1993) approach of weighting, and supported by the multi-criteria decision analysis tool of AHP[17] (Saaty and Vargas, 2001; Saaty , 2002).

[17] *The AHP (Analytical Hierarchy Process) will be re-described in the case study-Chapter 6*

The following are factors (for the six components) that were designed for determining the capability of farmland at five different administrative scales e.g. provincial, district, communal, hamlet, and farm.

Table 4.1.1: Bio-physical factors in the AMS

(I)	(II)	(I)	(II)
	Temperature		**Toxicity**
1	Annual average temperature (^{0}C)	20	Salinity(ds/m)
2	Solar radiation	21	Alkalinity/ESP (%)
	Hydrology and humidity	22	Depth of sulphuric acid (cm)
3	Annual average rainfall (mm)	23	Hoarfrost (salt fog)
4	Dry/drought (month)		**Erosion, flood and other hazards**
5	Water quality	24	Slope (%)
6	Irrigation systems	25	Erosion hazards (eh)
7	Annual average humidity (%)	26	Duration of floods
	Oxygen availability	27	Depth of floods
8	Drainage system	28	Annual inundation period (month)
	Rooting conditions	29	Storm
9	Soil texture (surface)	30	Wind
10	Coarse material (%)		**Other bio-physical factors**
11	Soil depth (cm)	31	Growing period of crops
12	Aeration condition	32	Insect (common pest)
	Nutrient retention and pH	33	Disease (common pest)
13	CEC-clay (cmol/kg)	34	Weed (common pest)
14	Base saturation (%)	35	Distance from the house to farms
15	C-organic (%)	36	Road transport system
16	Macro-nutrients availability (NPK)	37	Waterway transport system
17	Micro-nutrients availability	38	Availability of transport facilities
18	Soil pH	39	Communication media systems
19	Water pH		

Table 4.1.2: Technical and management factors in the AMS

(I)	(II)	(I)	(II)
	Technique	48	Applied ability of mechanisation
40	Land preparation technique	49	Cropping index
41	Planting technique		**Farm management**
42	Seed sector (supply systems)	50	Pilot/field design
43	Seed quality for cultivation	51	Cropping calendar distribution
44	Yield potential of variety	52	Stocking/sowing density
45	Pre-processing technique	53	Fertilizer/insecticide use management
46	Storing technique	54	Water and pest management
47	Drying technique	55	Farm size (hectare)

Table 4.1.3: Technical and management factors in the AMS (continued)

(I)	(II)	(I)	(II)
56	Land clearing	60	Leaching
57	Flood controls	61	Reclamation period
58	Land grading	62	Irrigation engineering (construction)
59	Physical, chemical, organic aids and amendments		

Table 4.1.4: Conservation and environmental factors in the AMS

(I)	(II)	(I)	(II)
63	Long-term salinity, landslip	66	Environmental hazards
64	Ground or surface water hazards	67	Environmental control ability
65	Long-term erosion hazard		

Table 4.1.5: Socio-economic factors in the AMS

(I)	(II)	(I)	(II)
68	Average age of farmers (land users)	77	Labour force in the local area
69	Sex of farmers	78	Skills of labour force in the local area
70	Education standard of farmers	79	Production costs
71	Ethnic group of farmers	80	Farmers' credit sources accessibility
72	Social class of farmers	81	Credit allowance for farmers (amount)
73	Household size of farmers	82	Farmers' market accessibility (inputs and outputs)
74	Membership of organizations, if any	83	Farmers' accessibility to support agencies (e.g. extension agencies)
75	Farming experience (years)/skills of farmers	84	Farmers' accessibility to agricultural services (e.g. threshing, drying, land preparation)
76	Livelihood opportunities (job opportunities) for farmers	85	Farmers' accessibility to market information

Table 4.1.6: Policy/institutional factors in the AMS

(I)	(II)	(I)	(II)
86	Taxation applied for farmland	89	Land use planning policies
87	Farmers' rights/duties for the use of land	90	Loan policies
88	Laws for natural resource management e.g. land de-fragmentation		

Source: adopted from the FAO (1976, 1985, 1993, 2007b), Rowe et al. (1981), Ritung et al. (2007), Peter (1996), Wright et al. (2006), Paul Smith et al. (2004)

Note: In view of the theoretical and conceptual framework of the study, associated with components and factors in the theoretical model of an agricultural management system, the terms used in this study (e.g. Table 4.1s) were defined and in some cases, modified or supplemented to suit the context of this research (*see Appendix 1*).

4.4.4 Developing a farmland capability classification system

There are many systems for land capability/suitability classification that, have been developed and applied worldwide. Most popular systems can be listed are the USDA (Klingebiel and Montgomery, 1961; USDA, 2001a, 2001b, 2005, 2010a, 2010b) and the FAO (1976, 1983, 1984, 1985, 1991a, 1993), as well as their later adopted versions (*see items 3.2.3 and 3.2.5, Chapter 3*). In the above systems, capability of the land in general, and farmland in particular, is an individual capability aggregation of class-determining factors in the AMS and their importance/significance (weightings) to the capability of farmland for a specific use.

The farmland capability classification in the theoretical model of this research is based on a literature review and is designed and developed for five levels, ranging from very high, high, moderate, low, and very low capability for a specific use (Table 4.2). Similarly, each factor in the AMS has been categorised into five capability levels with respect to the farmland: very good, good, fair, poor, and very poor (Table 4.3). The single capability of components and their corresponding factors in the AMS, to the final integrated capability of farmland will decrease when increase the degree of limitation, hazard, special technology (management) needed for those components, and factors.

Table 4.2: Farmland capability rating classes for a specific land use

No	Capability	Degree of limitation	General Description
1	Very high	None to Very Slight	Farmland areas with a very high capability for the proposed farming system (PFS) (land use type). None or very few limitations to factors/components in the AMS to the specified use are present, or they are easily overcome. Risk of land degradation, erosion, loss of harvesting and farmland users' income, under the proposed use is negligible. Special technology/management, investment, land improvement and conservation are not needed. Very high net economic benefits for farmland users.
2	High	Slight	Areas capable of supporting the PFS. Slight limitations to components in the AMS are present in the form of engineering difficulties and/or a special technology/management, investment, land improvement and conservation limits. Careful planning and the use of standard specifications for a certain area will result in minimal environmental impacts on the land. High net economic benefits for farmland users.
3	Moderate	Moderate	Areas with fair capability for the PFS. Moderate engineering difficulties and/or special technology/management, investment, land improvement and conservation issues. Specialized designs and techniques are required to minimize developmental impact on the environment. Moderate net economic benefits for farmland users.
4	Low	Severe	Areas with poor capability for the PFS. There are considerable engineering difficulties; special technology/management, investment, land improvement and conservation issues during cultivation, and/or a high erosion hazard exists, during and after cultivation. Regionally modified design and installation techniques, and very high management are necessary to minimize the impact on the environment. Minimal economic benefits for farmland users.
5	Very low	Very severe	Areas with very poor capability for the PFS. Limitations to cultivation, either long term instability hazards, erosion or engineering difficulties cannot be practically overcome with current technology. Severe deterioration of the environment may occur if development is attempted in these areas. Negligible economic benefits for farmland users.
This general description is designed and driven by the six key components in the AMS. The description must be adjusted and clarified based on a specific farming system (land use type), specific conditions, and local farmland utilisation criteria, when the model is applied.			

Table 4.3: Factor capability rating classes with respect to the farmland

<table>
<tr><th>Class</th><th>Capability</th><th>Degree of limitation</th><th>General Description</th></tr>
<tr><td>1</td><td>Very good</td><td>None to Very Slight</td><td>The critical limits indicate that in terms of the given factor, the land is highly capable for the specified land use.</td></tr>
<tr><td>2</td><td>Good</td><td>Slight</td><td>The critical limits indicate that in terms of the given factor, the land conditions are slightly adverse for the specified land use.</td></tr>
<tr><td>3</td><td>Fair</td><td>Moderate</td><td>The critical limits indicate that in terms of the given factor, the land is marginally capable for the specified land use.</td></tr>
<tr><td>4</td><td>Poor</td><td>Severe</td><td>The critical limits indicate that in terms of the given factor, the land is marginally not capable for the specified land use (usually for adverse benefit/cost reasons).</td></tr>
<tr><td>5</td><td>Very poor</td><td>Very severe</td><td>The critical limits indicate that in terms of the given factor, the land is permanently incapable for the specified land use.</td></tr>
<tr><td colspan="4">The fundamental rules for classifying the capability of factors (to the capability of farmland in general) must be based on evaluating the contribution and importance of each factor to the general farmland capability, for a specific utilisation. The evaluation has to focus on the aspects of productivity, economic returns, and sustainability of land use types. This is done by using expert approaches, with respect to a specific land use type, specific conditions, and local land utilisation criteria, when the model is applied.</td></tr>
</table>

Source: adopted from FAO (1985)

4.4.5 Determining the farmland capability

The capability analysis using class-determining factors for decision making plays a very important role for farmland capability determination. Farmland capability assessment is carried out with the analysis of multi-disciplinary land characteristics in the AMS. Knowledge based weight assignment will be carried out for each factor in the AMS, and they are integrated and analysed using the weighted aggregation approach (ESRI, 2004).

In this technique, the total weights of the final integrated farmland capability will be derived as sums or products of the weights assigned to the different farmland characteristics (factors) according to their capability (Bandyopadhyay *et al.*, 2009, p. 884). The selecting and weighting of components and factors in the AMS for farmland capability classification is the fundamental activity to determine the farmland capability. Results of the selection and weight will be combined with their actual values (obtained by field surveys) for comparison with the requirements of the proposed farming systems, in order to determine the capability of farmland. In other words, the capability of farmland is determined based on the selected components and factors in the AMS, along with their actual values and weightings. Detail on the approach to determine the capability of farmland is presented in the case study- Chapter 6.

4.5 Summary

In brief, developing the theoretical model for an agricultural management system to determine the farmland capability is a very important phase of the study. Development includes identifying suitable farming systems, designing and describing key components and factors in the AMS for farmland capability assessment, developing a farmland capability classification system, and determining the capability of farmland for proposed farming systems. By executing the above steps, the theoretical model has been designed. This model was tested by implementing a case study.

CHAPTER 5: BACKGROUND OF THE STUDY AREA

5.1 Introduction

The main purpose of this chapter is to briefly describe the study area characteristics, including Viet Nam, the Mekong Delta, the An Giang Province, and the Cho Moi District. The study area attributes have a marked influence on the testing of the theoretical model that was developed in the previous Chapter 4. The key information in the current chapter will focus on agriculture, farming systems and issues relating to the farmland capability. The results of the data collection for testing the practical model (case study, Chapter 6) are driven by the characteristics of farmers and the biophysical, technical, and socio-economic conditions in the study area. For the aforementioned reason, the current chapter also presents the fundamental facts to be considered, for data analysis and the interpretation of the results of the case study.

5.2 General introduction to Viet Nam

Viet Nam is approximately 331,212km^2 in area, with 3,260km of seashore (not including the Hoang Sa and Truong Sa islands), and has 64 provinces and cities (GSO, 2007). It is located between the latitudes of 8^{0}10' and 23^{0}24' N and the longitudes of 102^{0}09' and 109^{0}30' E. The distance between the northern end and the southern end is approximately 1,650km (Figure 5.1). The widest east-west sections are recorded at approximately 600km in the north and 400km in the south; the narrowest section of 50km is located in the Quang Binh Province, in the middle of the country.

Three-quarters of the nation can be classified as mountainous with midlands mainly in the north and central Viet Nam. The topography mainly consists of foothills and densely forested mountains with flat land covering less than 20%. Mountains account for 40% of the area, and smaller hills account for 40%. Tropical forests cover 42% of the country. The northern part of the country consists mostly of highlands and the Red River Delta. Viet Nam's highest mountain, at 3,143m, is located in the north in the Lao Cai Province where terraced rice fields are common (e.g. Figure 5.2). The south is divided into coastal lowlands, Annamite Chain peaks, extensive forests, and poor soil. Comprising five relatively flat plateaus of basalt soil, the highlands account for 16% of the country's arable land and 22% of its total forested land (De, 2005).

Figure 5.1: Viet Nam map. *Source: http://www.worldatlas.com, accessed on 10/01/2011*

Figure 5.2: Terraced rice fields in Viet Nam's northern mountains

Source: http://www.baoyenbai.com.vn, accessed on 07/01/2011

Viet Nam has eight typical agro-ecological zones (Figure 5.3), spreading from the North to the South, they are the North East, North West, Red River Delta, North

Central Coast, South Central Coast, Central Highlands, South East, and the Mekong Delta (Table 5.1). The weather, land conditions, number of administrative units, population, natural and agricultural land areas, and method of cultivation vary between these zones.

Table 5.1: Major characteristics of the eight agro-ecological zones in Viet Nam

Agro-ecological zones	No. of provinces/cities	Population (Pers '000)	Natural land (km^2)	Agricultural land (Ha '000)
North East	11	9,544	64,025	984
North West	4	2,650	37,534	502
Red River Delta	11	18,401	14,862	756
North Central Coast	6	10,723	51,552	812
South Central Coast	6	7,185	33,166	591
Central Highlands	5	4,935	54,660	1,616
South East	8	14,193	34,808	1,608
Mekong Delta	13	17,524	40,605	2,567
Whole country	**64**	**85,155**	**331,212**	**9,436**

Source: GSO (2007), compiled by the Author. Data are subject to rounding

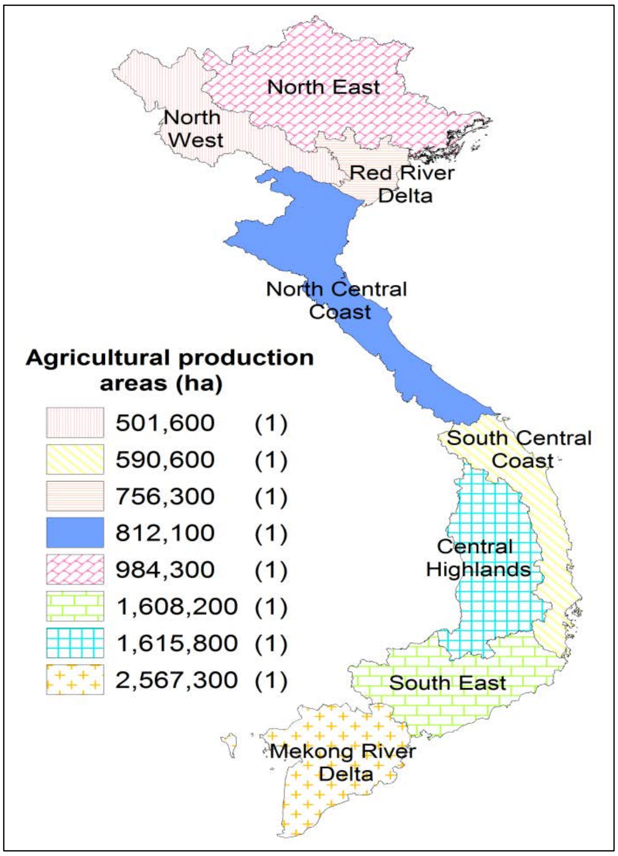

Figure 5.3: Map of the eight agro-ecological zones in Viet Nam. *Source: GSO (2007)*

Particularly, Viet Nam's agricultural land areas account for about 28% of the total natural land areas. The Northern Mountainous and Mid-land zone located in the north of the country (zones North East and North West) is the largest area having 10.1

million hectares of mountains and hills corresponding to 13% of the agricultural land. The zone is dominated by sloping and upland farming agriculture.

The Mekong Delta and the Red River Delta are the two main agricultural and aquaculture economic regions of the nation, where rice is a permanent crop (e.g. Figure 5.4). The agricultural strength of the North East and the North West is in tea cultivation. The zones of the Central Highlands and the South East have comparative advantages in terms of cultivating coffee, tea and rubber with intensive farming of vegetables in the Central Highlands.

Figure 5.4: Farmers in the Mekong Delta transplanting rice

The Red River Delta is the most populated and agriculturally intensive area of the country. The majority of the land area (more than 58%), is allocated for agriculture. The Northern and Southern Central coasts (as presented in Table 5.1), with the Truong Son mountain ranges as the backbone, are the narrowest and longest agro-ecological zones of Viet Nam. Only 14% to 16% of the natural land, consisting of sandy and degraded soils, are used for agricultural development.

The Western Highland zone is a large plateau with a cool climate and red grey basaltic, humid and sandy soils. Twenty-three percent of this land is allocated for agricultural activities. This area is suitable for perennial industrial crops such as coffee, tea, and rubber. Moreover, this region has the highest percentage of forest coverage for the country (55.2% of the natural land).

The Southeast zone is the transition area between the highlands of the middle region and the flat land of the Mekong Delta; it is where the elevation ranges from 0.5m to about 100m above sea level. This area is characterized by sandy-loam soil underlain with old alluvial soils and mixed grey podsolic and red basaltic soils. The land use pattern in this region varies with approximately 49% being for agriculture, 30% for forest and the rest for other land use types.

Recently, Viet Nam has emerged as one of the most striking economic successes (FAO in Viet Nam, 2008). From a country with quite a high rate of hunger in the 1980s, Viet Nam quickly recovered from poverty, to become the second largest rice exporter in the 1990s, based on the "Doi Moi-innovation" policies. However, its economy has relied heavily on agro-forestry and the fishery sector for rice production, aquaculture, and forestry exploitation (GSO, 2006). In general, these sectors have employed more than 55% of the labour force, distributed nearly 27% of the GDP and contributed 25% of the export value to the nation (GSO, 2007).

In general, Viet Nam is an agricultural country in Southeast Asia. Its economic growth and export values are still based on the agricultural and aquaculture sectors. Rice, fruit, and fish are typical products for exporting. However, more recently high crop intensification and rapid industrialization in aquaculture are threatening the capability of agricultural lands. So far, Viet Nam has no national program, or project, to evaluate farmland capability. Selecting Viet Nam as the study area to test the theoretical model of the agricultural management system designed to determine the capability of farmland, is very significant and appropriate. This AMS will enable local agricultural land managers in Viet Nam to plan and utilize a sustainable approach to the management of their land resource.

5.3 The Mekong Delta

The Mekong Delta starts at *Kongpong Cham* in Cambodia, covers an area of 5.9 million ha, of which about 4 million ha are in the south of Viet Nam. The Mekong Delta is a relative young land, which was formed not more than 10,000 years ago (Figure 5.5).

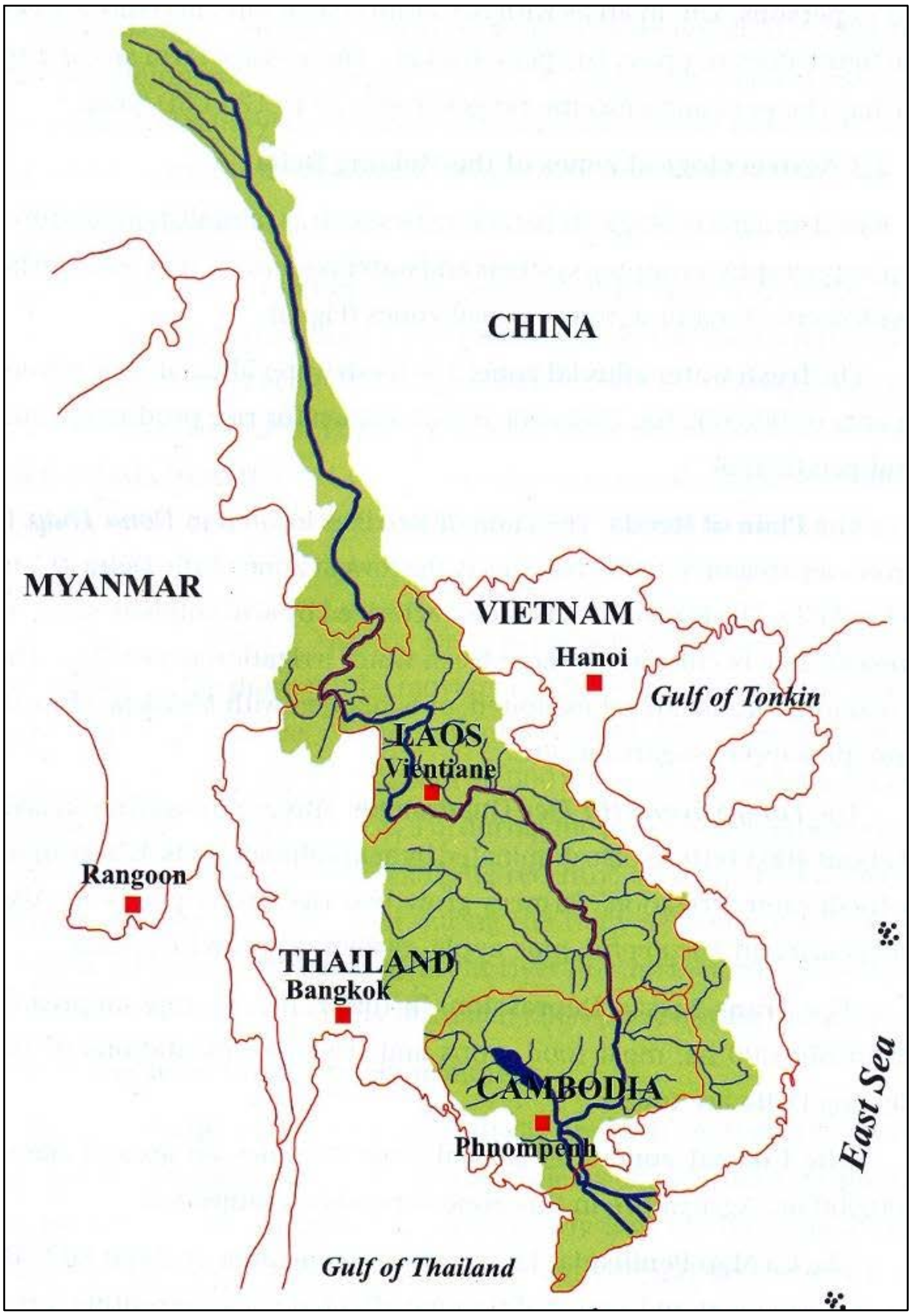

Figure 5.5: The Mekong Delta, south Viet Nam. *Source: Sanh et al. (1998)*

The Mekong Delta ranges from the latitudes of $8^{0}40'$ and $10^{0}40'$ N, and the longitudes of $104^{0}10'$ and $107^{0}10'$ E. It includes 13 provinces and cities: Long An, Tien Giang, Ben Tre, Dong Thap, Vinh Long (Vinh Long City), Tra Vinh, An Giang (Long Xuyen City), Can Tho (Can Tho City), Hau Giang, Soc Trang (Soc Trang City), Kien Giang, Bac Lieu and Ca Mau (Ca Mau City) (Figure 5.6). Hau Giang Province and Can Tho City were officially formed from the former Can Tho Province in 2003.

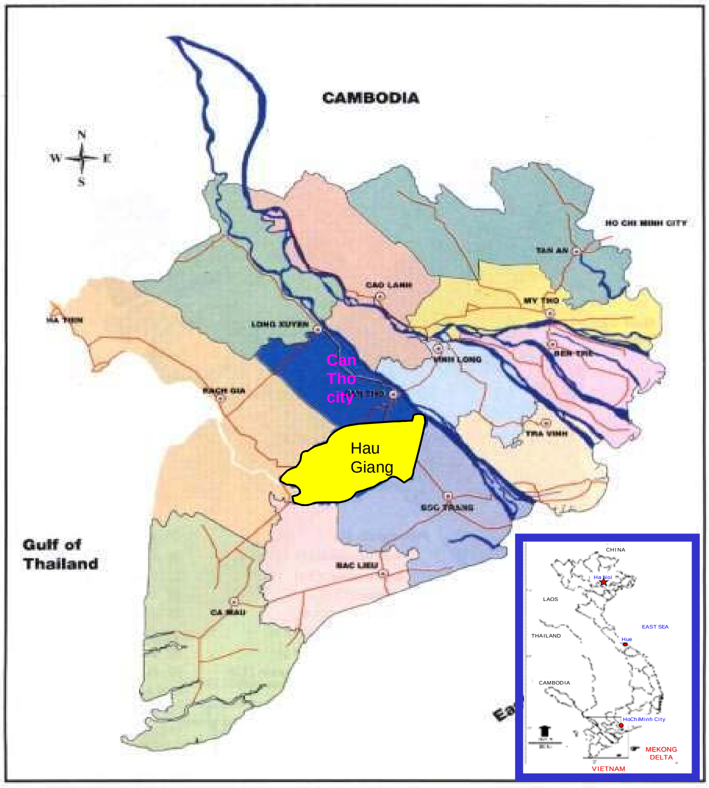

Figure 5.6: Administrative map of the Mekong Delta. *Source: Sanh et al. (1998)*

The Mekong Delta consists of fertile alluvial flat land with a monsoonal tropical semi-equatorial climate. The plain in the Mekong Delta embraces deposited alluvium carried by the Mekong River over a distance of 4,000km from Tibet along with marine accretions deposited through epochs of sea level changes. The river system in the Mekong Delta is based on two major rivers, the Mekong (Tien River) and the Bassac (Hau River). Downstream, the Tien River divides into six main flows, and the Hau River into three, to form the nine "dragons" bringing water from the Mekong River to the East Sea.

5.3.1 Soils in the Mekong Delta

The soils of the Mekong Delta are mostly young alluvial soils. The combined actions of the river and the sea have formed rich alluvial soils on elevated levees along the riverside and acid sulphate soils in depressed back swamps such as the Plain of Reeds, the Long-Xuyen-Ha Tien Quadrangle and the Trans-Bassac Depression (Xuan and Matsui, 1998).

The soil in the Mekong Delta can be categorized into four main types (Figure 5.7) as outlined below. In association with rainfall, temperature, topography, cropping system and water resources, the soils divide the Mekong Delta into six Agro-ecological zones (NEDECO, 1993; Xuan and Matsui, 1998):

+ **Alluvial soils:** found along the Tien and Hau Rivers, cover an area of approximately 1,100,000ha (28% of the Delta). The two main agro-ecological zones (first and second) which share these soils are the fresh water alluvial zone (900,000ha) that is well known for rice and fruit production, and the Trans-Bassac Depression (600,000ha) where most food crops and fruit tree plantations of the Mekong Delta are found.

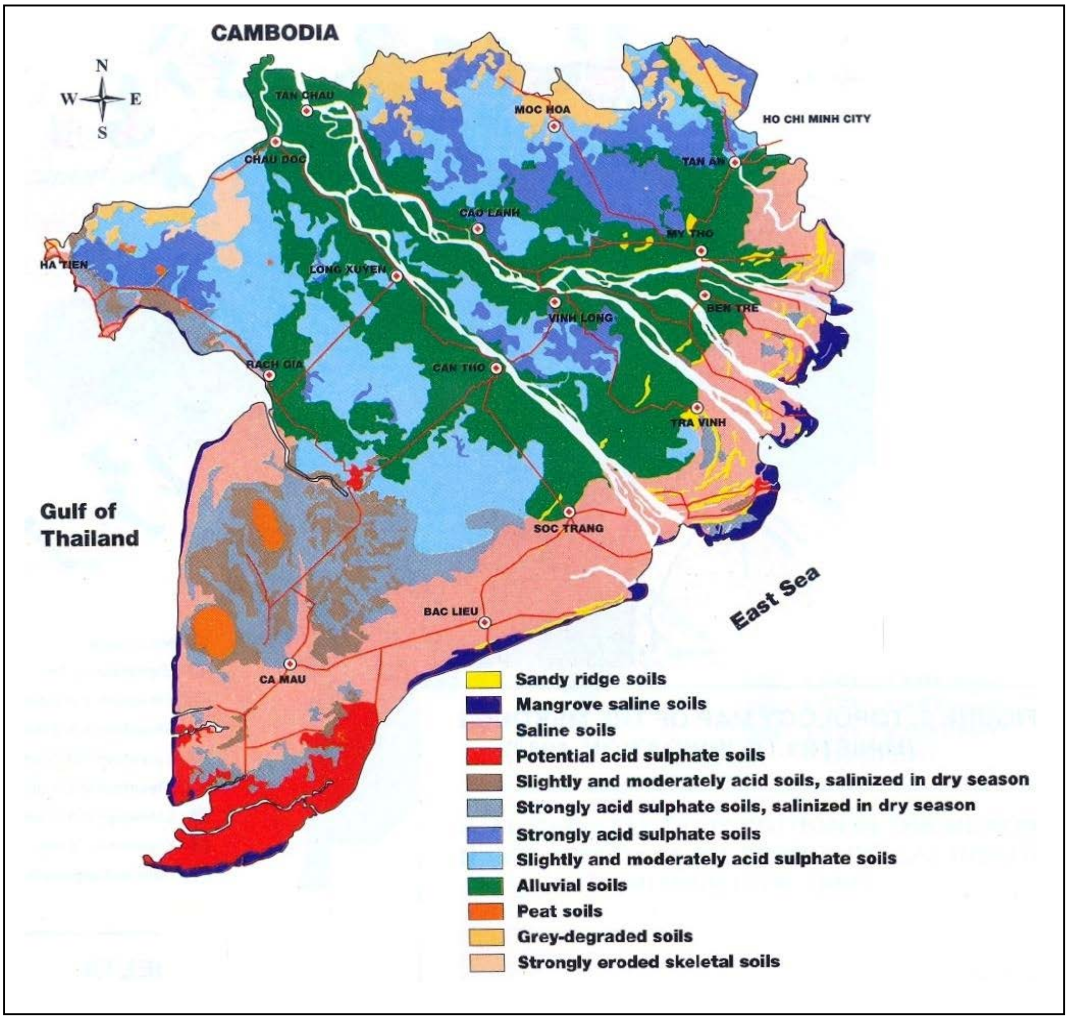

Figure 5.7: Soil map of the Mekong Delta. *Source: Sanh et al. (1998)*

+ **Acid sulphate soils:** occupy an area of 1,590,000ha mainly in the Plain of Reeds and the Long Xuyen-Ha Tien Quadrangle. Acid sulphate soils are divided into two types: (i): saline affected potential acid sulphate soils found in the south tip along the coastal line with an area of 1,080,000ha, and (ii): actual acid sulphate soils found in the Plain of Reeds and the Long Xuyen Quadrangle with an area of 510,027ha. These soils have great constraints to rice production because of the high concentrations of acid, with pH values ranging from 2.26 to 3.54 (Xuan and Matsui, 1998). In the region of these soils, two typical agro-ecological zones (third and fourth) are located and these are the Plain of Reeds (500,000ha) and the Long Xuyen-Ha Tien Quadrangle.

+ Saline soils: found along the coastal regions cover an area of 808,749ha where the agro-ecologically coastal zone (fifth) shares an area of 600,000ha and agricultural production depends on rainwater.

+ The remaining soils: are upland and mountainous peat soils.

The sixth agro-ecological zone is the Ca Mau Peninsula. It covers an area of about 800,000ha of permanent and seasonally saline-affected soils presenting a rich zone of mangrove and various rice-based farming systems under rain-fed conditions (Figure 5.8).

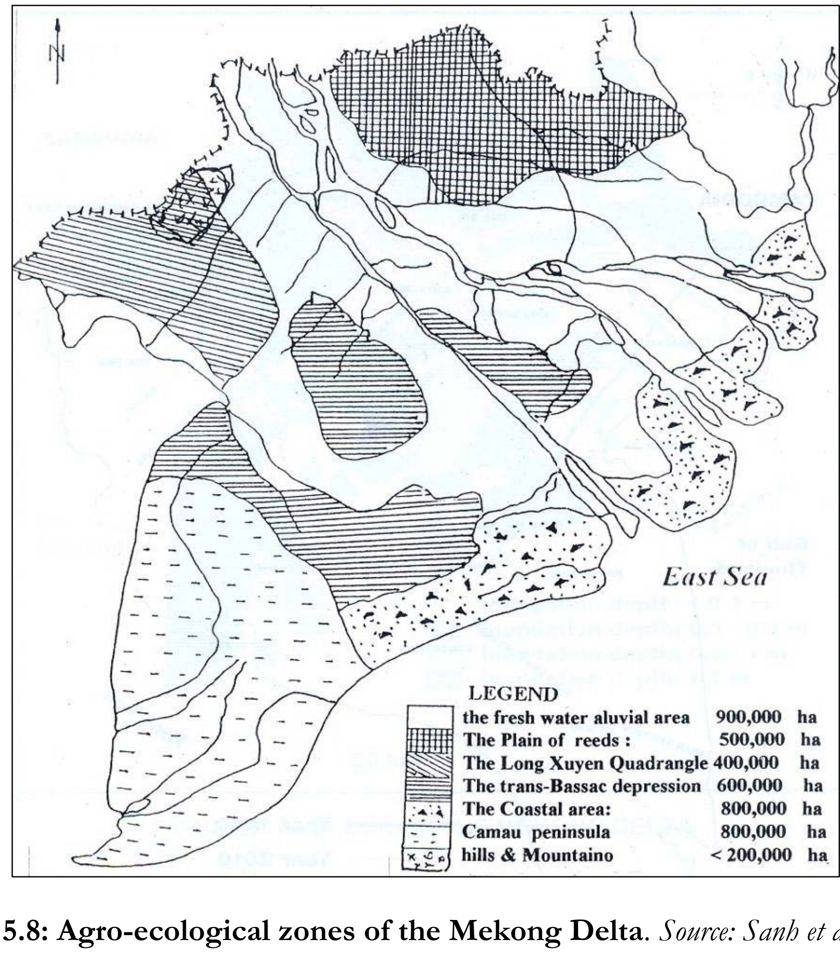

Figure 5.8: Agro-ecological zones of the Mekong Delta. *Source: Sanh et al. (1998)*

5.3.2 Topography in the Mekong Delta

The topography of the Mekong Delta is flat and low-lying, formed through slow alluvial depositions (Figure 5.9). The average topography of the Mekong Delta is 2 meters above mean sea level and the lowest is 0.5 meter below mean sea level located in the Dong Thap Province.

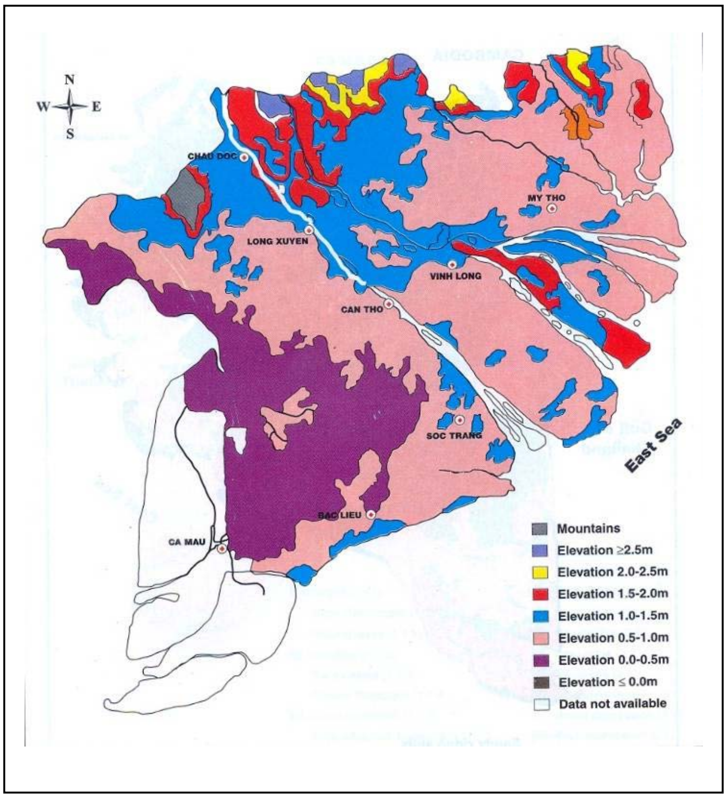

Figure 5.9: Topographic map of the Mekong Delta. *Source: Sanh et al. (1998)*

5.3.3 Economic conditions in the Mekong Delta

Of the eight agro-ecological zones of the nation, the Mekong Delta is a strategic zone for national food security. It plays the most important role for Viet Nam agricultural development in particular and for Viet Nam economic development in general. Also, it is the most downstream part of the Mekong River Basin with 17 million inhabitants living in 12 provinces and one central Can Tho city (GSO, 2006). In fact, the MD accounts for more than 27% of Viet Nam's GDP and contributes over 50% of the total aquatic volume, 80% of the total rice export value (US$ 3,246,000 per year) and 75 to 80% of the total cultivated area (GSO, 2006).

Nevertheless, the MD has been facing physical constraints that affect socio-economic development, especially related to agricultural production (Nam, 2007; Loc, 2007).

Especially, it has an area of 1.2 to 1.9 million hectares under annual floods (Minh, 2002) and the complexity, degree and frequency of the floods are increasing. Over the past 40 years, floods had occurred in the study area, in the years: 1961, 1978, 1991 and 2000. This is one of the first, and largest, concerns of policy makers, agricultural managers and local inhabitants in the region because floods are recognized as both the "enemy" and a "friend" of the local farmers. Floods can devastate crops, and result in a reduction in their productivity, and yet floods also bring much benefit to farmers such as replenishing natural fish resources, alluvium deposition as natural fertilizers for fields and the flushing of toxicity from acid sulphate soil. Flood water has been utilized to improve the quality of acid sulphate soils by taking away toxicity released from the soils.

Overall, the most serious constraints to agricultural production, and land use, in the Mekong Delta are currently recognised as (1). the status of fresh water shortage and the deterioration of water quality through the transformation of the cultivation structure accompanied by acidification due to sulphate soils in the dry season and, (2). the fact that most land areas are flooded for several months in the annual wet season, this damages agricultural and aquacultural production, threatens infrastructure in general and the agricultural irrigation system in particular. (3). the movement of the young labour force in the rural areas to the cities and (4). the lack of farmers' accessing opportunities (new technology, capital resources for production, production skills and market information) and the lack of supporting policies for farmers, and the limitation of rural vocational training as well. Those constraints reveal that farmland capability evaluation, undertaken by an integration of components in the agricultural production system, including the bio-physical and technical factors, and socio-economic parameters, is essential. The capability evaluation approach presented in this research will provide a tool to assist in meeting the goal of sustainable agricultural development in the Mekong Delta.

5.4 The An Giang Province

The An Giang Province is located between latitude $10^0 10'30"$-$10^0 37'50"$N and longitude $104^0 47'20"$-$105^0 35'10"$E in the South-West part of the Mekong Delta, nearly 200 km far away from the Ho Chi Minh City and approximately 60km far away from the Can Tho City. It is a typical upstream province of the Mekong River Basin of Viet Nam and a part of the Long Xuyen Quadrangle (Figure 5.10).

An Giang shares an approximately 90km border with the Kingdom of Cambodia and three other Mekong provinces (DNRE, 2006):

- The Kien Giang Province to the South-West (70km)
- The Can Tho Province to the South (45km)
- The Dong Thap Province to the East (108km)

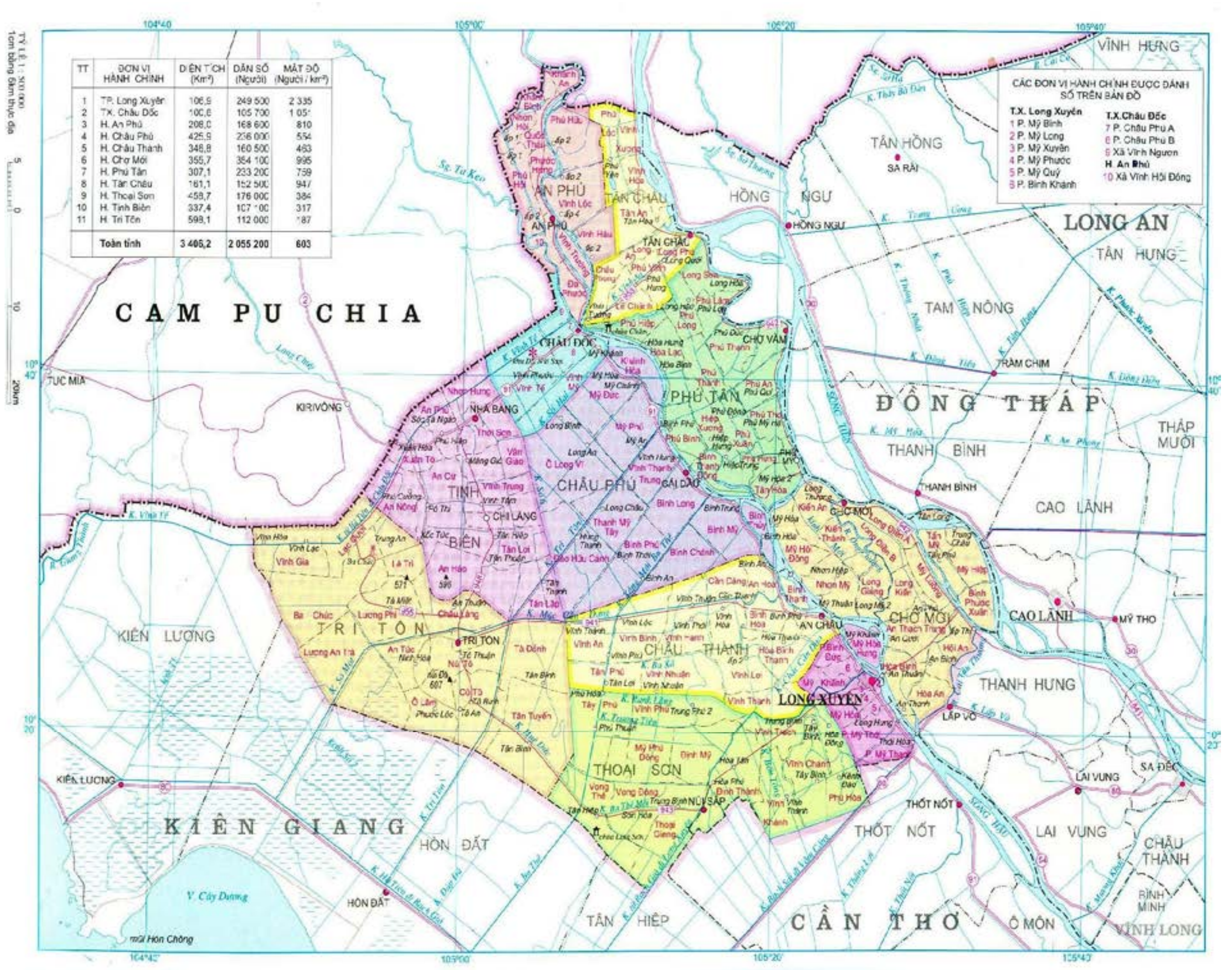

Figure 5.10: Administrative map of the An Giang Province

Source: DNRE (2006)

The An Giang Province has three international gates with Cambodia, including Vinh Xuong, Xuan To and Long Binh. These are convenient points to exchange goods, and develop the economy of An Giang, especially through exporting agricultural products like rice, sticky-rice, and fruits to Cambodian markets.

An Giang, covers a natural area of 3,535km^2, and consists of one provincial city and ten districts named Chau Doc, Cho Moi, Tri Ton, Tinh Bien, Thoai Son, Chau Phu, Tan Chau, Phu Tan, An Phu and Chau Thanh. There are two primary ecological areas, the plain ecology and the mountainous ecology. This results in a diversity of farming systems in the An Giang Province (DARD, 2008). An Giang has deltaic and mountainous topography. The delta is formed from the deposited and ancient alluvium. The mountains consist of many tops with different forms, heights and slopes and with a diversity of animal and plant varieties.

An Giang is the province that has strongly developed agriculture and fishery in the Mekong Delta. In 2005, the total agricultural production value achieved 11,526,627 VND millions (1USD ≈ 15,000 VND in 2005; 20,500 VND in 2011), aquaculture achieved 2,427,850 VND millions and the total GDP in agriculture and forestry achieved 3,655,944 VND millions, and occupied 35% of the total GDP value.

5.4.1 Natural conditions

Climate

Climate in the An Giang Province is tropical with two specific seasons, the wet (May to November) and the dry (December to April of the next year). In the wet season, heavy rain combined with abundant water from upstream areas of the Mekong River often cause partial inundation and floods (August to November) in some months, influencing agricultural production activities and the inhabitant's living conditions. Depending on annual flood changes, the flood water level varies from 371 to 417cm and the flow is from 6490 to 20700 m^3/s (GSO, 2006).

+ Cloud

Cloud quantity in An Giang is distinctly different between season, with relatively low cloud cover in the dry season (3.1/10 on average, 31% of the firmament is covered by a cloud), and much more in the rain season (6.9/10). Changes of cloud quantity by season also influence the temperature and sunshine hours in a year in An Giang. For instance, for July 2006, the average temperature in An Giang was 27.6^{0}C (low), sunshine hours was only 123.8, because cloud quantity in this month was great (Centre for hydro-meteorological forecast of the An Giang Province, 2006).

+ Temperature

The annual mean temperature is 27^{0}C, with the highest of about 26-28.5^{0}C in the months of February, March, April, and May; and the lowest of approximately 24-26^{0}C in the months of November, December, and January, in particular it was 18^{0}C in 1976 and 1998. The temperature regime in An Giang varies from place to place with the annual mean temperature in mountain areas being lower than the plain area. The difference in temperature between subsequent seasons and months in a year is marginal with change normally between 1.5 to 3^{0}C.

Figure 5.11 shows that temperature conditions in An Giang over the period 2001 to 2009 are relatively consistent, except for the dramatic change in 2006. For the agricultural sector, the amplitude between the average maximum temperature and the average minimum temperature in An Giang means the area is suitable for the growth of many kinds of crop. Particularly, rice and some upland crops usually give high yield when they are cultivated in An Giang.

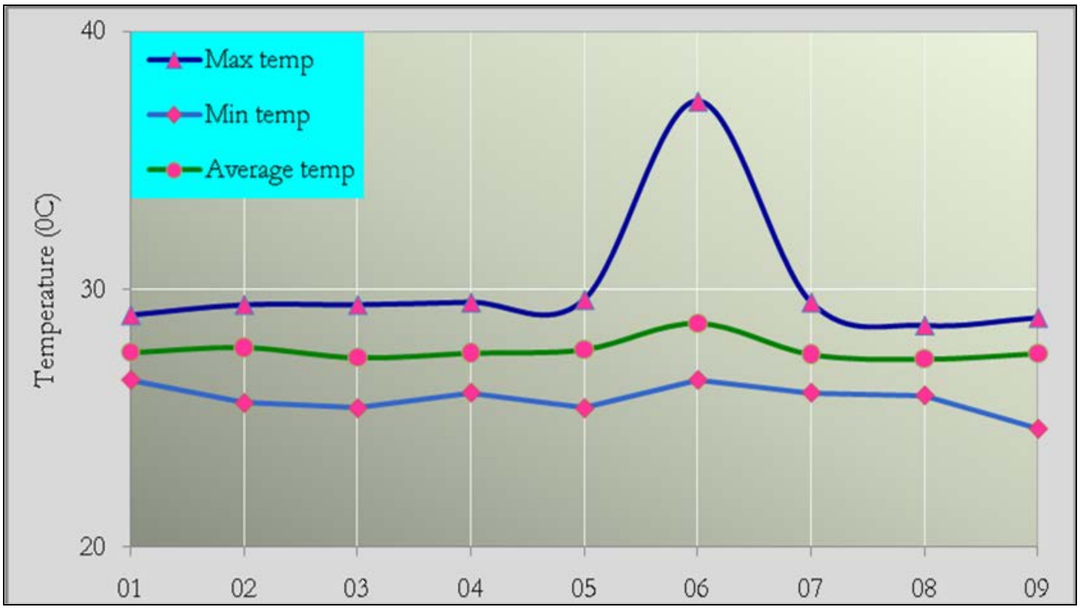

Figure 5.11: Temperature regime between 2001-2009 in the An Giang Province

Source: An Giang Statistical Bureau (2010)

+ Sunshine hours

An Giang has clear weather skies (sunshine from January to March) with ten hours of sunshine per day on average (dry season) and seven hours of sunshine per day on average (wet season). This makes An Giang the longest sunshine per day province in the nation. The total annual average sunshine hours in An Giang are 2,521, with a lowest of 153 hours (September), and a highest of 282 hours (March) which is a suitable time for drying agricultural raw products. Most farmers, who schedule their main crops like rice, legumes, and other cereals, with the harvesting period lying within January and March, utilize this natural advantage. As a result, they can save on the cost of drying and storing their agricultural products by utilizing natural sunshine instead of applying machines.

Figure 5.12 reflects that sunshine hours in An Giang change year by year and according to an intricate pattern. In 2007, the lowest sunshine hours happened in July, and the highest is in February. Nevertheless, in 2008 and 2009, the lowest sunshine hours were in September, and the highest were in March and December. Although sunshine hours continuously change between months in a year and year by year, the figures highlight that there was more sunshine hours in the months of February and March, then this reduced gradually to July and September before climbing again in the later months.

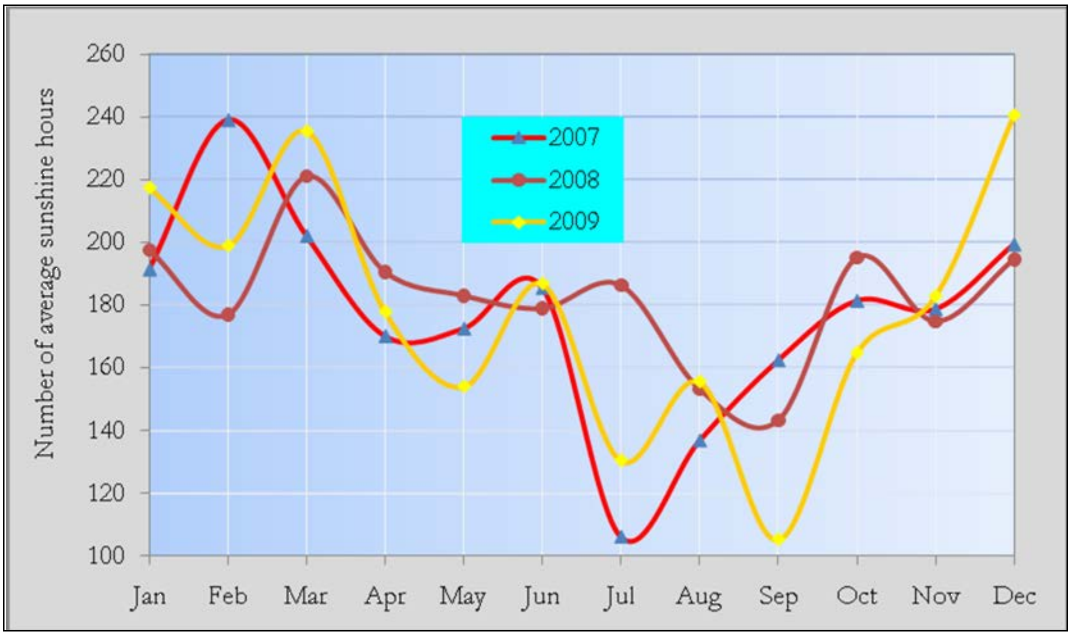

Figure 5.12: Number of average sunshine hours per month between 2007-2009 in the An Giang Province. *Source: An Giang Statistical Bureau (2010)*

+ Rain

Rain in An Giang is divided into two specific seasons, the wet and the dry season. The rain season starts in May and terminates in November bringing approximately 80% of the precipitation for the whole year. The total annual rainfall fluctuates from 1,500-1,600mm, with a maximum value of 2,100mm, and a minimum value of 900mm. Figure 5.13 below reveals that rainfall declined in recent years, especially in 2009. The maximum rainfall per month in 2007 and 2008 was about 370mm, while the maximum rainfall per month in 2009 was only around 170mm. This rainfall reduction results in many rain-fed areas in An Giang not being cultivated or having a very late cropping season. A part of the planted rice areas in the Tri Ton District and the Tinh Bien District is transferred into growing upland crops.

In general, rainfall in An Giang has three peak periods. It increases significantly in mid-April and May at the beginning of the rain season, then it falls slightly (year 2008 and 2009) or rises marginally (2007) prior to jumping in July at the mid-rain season. The highest precipitation in a year is usually in September and November at the end of rain season. With the annual rain cycle, irrigated farmland areas in An Giang can produce three modern rice crops per year, and rain-fed farmland areas can produce two rice crops per year.

Figure 5.13: Average rainfall in months between 2007-2009 in the An Giang Province

Source: An Giang Statistical Bureau (2010)

+ Humidity

In An Giang, the low moisture period (less than 80% of humidity) frequently starts in December and persists until April of the next year (Figure 5.14). In other words, low moisture levels occur in the dry season with 82% at the beginning, then a gradual decline to 78% at the mid-period before dropping to 72% at the end of the dry season. The rain season in An Giang is humid with an average moisture of around 84%, but sometimes it can peak at 90%. High humidity during the months of May to July brings suitable conditions for the development of crop pests such as insects and diseases. Therefore, farmland users in An Giang often leave their land fallow during this time instead of planting crops.

Figure 5.14: Mean relative humidity in months between 2007-2009 in the An Giang Province. *Source: An Giang Statistical Bureau (2010)*

+ Wind and evaporation

The wind regime in An Giang is seasonal, with wind to the South-West (May to October) bringing rain, and cool and warm air; from November to April of the following year, the seasonal wind is to the Northeast, with an average speed of 3m/second. The Northeast wind originates from China's tropical seas, creating high temperatures and moisture, sunshine and dry and hot air. An Giang is located in the inland area, and therefore it is not influenced by wind and typhoon.

Evaporation in the dry season is caused by high levels of sunshine and low air moisture, averaging 100 mm/month and in some specific cases (March) it can reach

160mm. In the wet season the average evaporation is about 85 mm/month; with the lowest being 52 mm/month in September and November due to abundant rain and high air moisture.

In general, climate and weather factors such as cloud, temperature, wind, sunshine, and rainfall in An Giang are mainly influenced by the two distinct seasons, the dry and the wet. The difference in the climate and the weather in the dry and the wet season generates a diversity of farming systems. The rainfall and temperature regime in An Giang is very good for the production of temporary crops like rice, vegetables, root crops, and aquaculture (DNRE, 2006).

5.4.2 Landform and soils

Soils in An Giang are diverse because they were formed by weathering and deposition by the sea and by rivers. Each area of deposition has a different environment which generates a different soil group leading to changes of soil quality, topography, eco-system, and farming practices. According to soil investigation reports, which use the FAO description system and Soil Taxonomy (DNRE, 2006), soils in An Giang can be categorized into six major groups (Table 5.2 and Figure 5.15), with each group having several soil types.

Table 5.2: Soil types in the An Giang Province

No	Soil type	**Area** (ha)	**Ratio** (%)
1	Fresh water alluvial soils	157,330	44.5
2	Acid sulphate soils	16,510	4.7
3	Acid sulphate-alluvial soils	97,474	27.6
4	Organic peat soils	1,697	0.5
5	Developed soils on ancient alluvial	25,667	7.2
6	Soils without analysis	54,873	15.5
	Total	**353,551**	**100**

Source: DNRE (2006). Data are subject to rounding

+ Fresh water alluvial soils

The origins and sedimentary environment of alluvial soils in An Giang are quite diverse. Many factors affected the sedimentary environments: sediment size, sediment regime and sediment materials that have made the soil different. Common characteristics of alluvial soils are that they are rich in organic matter, have a low pH and are less prone to corrosion and erosion. They have always been primarily enriched annually by different rates in different sediment conditions.

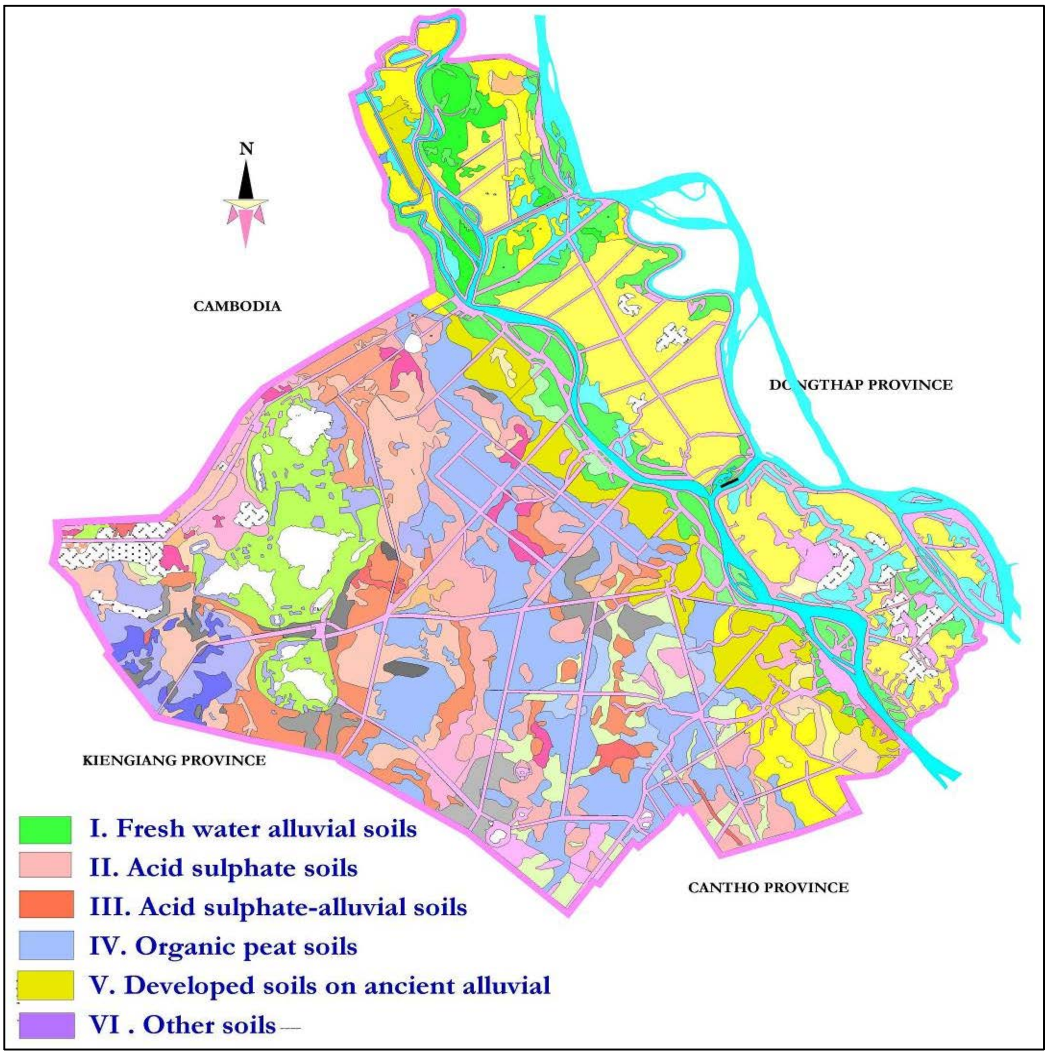

Figure 5.15: Soil map of the An Giang Province. *Source: DNRE (2006), compiled by the Author*

+ Acid sulphate soils

Acid sulphate soils in An Giang contain multiple sulphate groups ($SO4^{2-}$) and very low pH (2-3). They are distributed in mountainous areas bordering the Kien Giang Province, they are found in the Tri Ton and Tinh Bien Districts, and parts of the Chau Phu District, with a total area of about 16,510ha. These soils are formed by the inundation of the sea some 6,000 years ago, especially in the shallow bay environment, where the mangrove forests are present. Acid sulphate soils in An Giang can be categorised into several main types as presented below:

- Potential acid sulphate soils can be found mainly in the areas of the Vong Thue and Vong Dong Communes (Thoai Son District), the O Long Vi and Thanh My Tay Communes (Chau Phu District), the Tan Tuyen and Ta Danh Communes (Tri Ton District), and the Tan Loi Commune (Tinh Bien District). Depending on the different terrains, the upper layer thickness and acidity degrees will be different. Most potential acid sulphate soils have the main components of clay (40.83%), starch (45.13 %) and fine sand (4.15%).
- Soils with high acid sulphate content are distributed in the narrow valley to the west and east of the Bay Nui (seven Mountains) Region, which is located in the Tri Ton and Tinh Bien Districts. The main composition includes clay (41.31%), starch (36.68%) and sand (4.75%).

+ Acid sulphate-alluvial soils

These soils have low acid sulphate content, including developed alluvial soils affected by acidity and heavy alum soils that are matured. They are commonly distributed in areas where the terrain is relatively high such as along the foothills of the Co To Mountain, and the region's boundaries between the Chau Thanh and Thoai Son Districts. These soils have a high deposition of alluvium, and the potential alum is fairly thick (80-100cm). Clay content in these soils is very high (60.0-63.9%) but there is less starch and less sand and therefore these soils are well drained, have poor water permeability and have little flexibility.

+ Organic peat soils

These soils are characterized by a thick layer of peat (peat land containing alum), are distributed along the ancient rivers, valleys and shadow ponds in the Tra Su coastal mangrove forests, and some parts in the Tri Ton District. The peat soils in An Giang have a relatively low mineral content but very high protein content.

+ Developed soils on ancient alluvial

These soils are distributed in the high terrain (upland) of two districts, Tri Ton and Tinh Bien. They form a range of plains surrounding mountains such as Nui Dai, Nui Cam, and the Vinh Te channel that bordering Cambodia. Crops can be cultivated on ancient alluvial soils, but net profits are low because farmers have to invest highly to ameliorate the fertility of soils. Recently, to increase the capability of the land, land managers in An Giang have issued a policy that allows opening dyke systems in order to gain alluvium through the floods from the Mekong River. As a result, soil quality is improved and many farming systems e.g. green peas, soybean, and groundnut can be developed in these soils.

Overall, soils in An Giang are suitable for agricultural production, especially rice, vegetables, and other temporary crops. Soil quality has improved and productivity has increased through increased investment and the upgrading of the irrigation systems, particularly dyke systems, to manage floods, and channel systems to treat acid sulphate soils. The flexible policy on flood control by provincial authorities, which allows the water to remain on the fields for several months during flood season, has helped to improve remarkably the soil fertility because of the deposition of alluvium. Additionally, policies on encouraging the use of organic fertilizers, planting legumes, cutting down the third cropping season, and alternating crops between rice and vegetables, have resulted in soil recovery.

5.4.3 Hydrological regime and floods

The hydrological regime in An Giang depends strongly on the East Sea's semi-diurnal tidal regime, rainfall, terrain and flows of the Mekong River main branches: the Hau and Tien Rivers (annual average flow is 13,500m^3/second). Figure 5.16s shows that the highest and average water levels of the Tien and Hau Rivers measured at the two main hydro-meteorological stations in the An Giang Province (Chau Doc and Cho Moi) are very consistent. It is very low at the time of the end of the dry season, around April and after that, it increases steadily from May to September to peak in October. This increase could have been a result of high rainfall and the associated water coming from the upstream. The Tien and Hau River water levels rise is the flooding period and inundate crop fields in the An Giang Province. Annually, 70% of the natural land area of An Giang is inundated under 1-2.5m of water in the period of 2.5-5 months (August 15-December 20). However, floods in An Giang are not a natural disaster event and in some cases they generates more livelihood opportunities for farmers (fisheries) based on increased natural fish resources.

Figure 5.16a: The highest water level of the Hau River, measured at the Chau Doc hydro-meteorological station. *Source: An Giang Statistical Bureau (2010)*

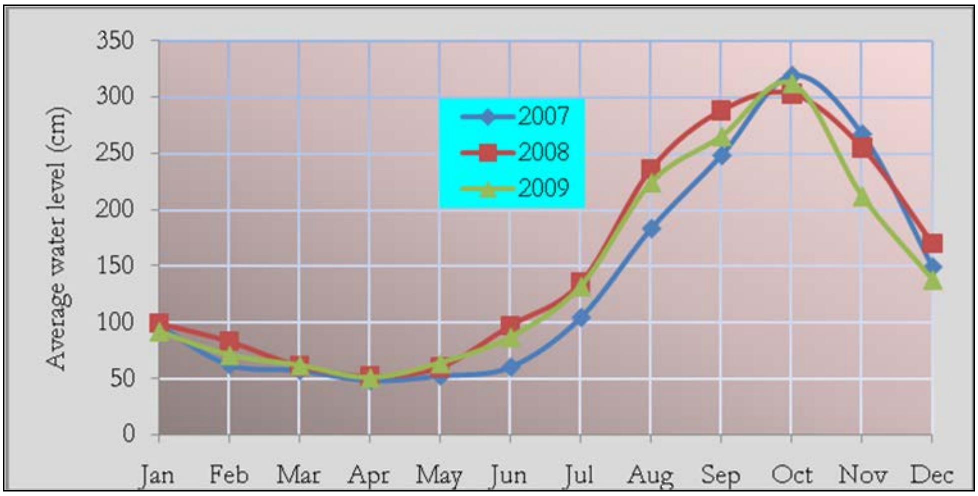

Figure 5.16b: The average water level of the Hau River, measured at the Chau Doc hydro-meteorological station. *Source: An Giang Statistical Bureau (2010)*

Figure 5.16c: The highest water level of the Tien River, measured at the Cho Moi hydro-meteorological station. *Source: An Giang Statistical Bureau (2010)*

Figure 5.16d: The average water level of the Tien River, measured at the Cho Moi hydro-meteorological station. *Source: An Giang Statistical Bureau (2010)*

In the flood season, most farming activities are curtailed. The main livelihood for local inhabitants in An Giang, to improve their daily diet nutrients and to provide income sources, are based on harvesting natural fish stocks, wild water-lily and water-cress (e.g. Figure 5.17s), which grown rapidly under flood conditions.

Moreover, An Giang has diverse natural river and channel systems with a total length of about 5,500km (1.6km/km^2). They have enough capacity to allow the regulation of water in the wet season, and to supply water for agricultural production in the dry season. Furthermore, many irrigation works are built in An Giang to control floods and for agricultural purposes.

Figure 5.17a: Farmer fishing in the flood season, in the An Giang Province

Figure 5.17b: Farmer gathering cork flower in the flood season, in the An Giang Province

Surface water

Presently, surface water in An Giang has become seriously polluted because of the catfish industry development. Abundant industrial feed for catfish, chemicals and veterinary medicines are direct pollutants of surface water. However, this issue is not considered critical because the supply and exchange capacity of surface water from the river and channel systems in An Giang flushes the toxins. Thanks to the natural river network and manmade channels, fresh water is available for all-year agricultural production and living. In the flood season, farmers can plant floating rice varieties and raise fresh water fish (green feed is available) because surface water is so abundant. In the dry season, farmers can control surface water to cultivate two or three rice crops or produce integrated farming systems (DNRE, 2006).

In recent years, the surface water resource and its quality, in An Giang in particular and the Mekong Delta in general, have been affected by hydroelectric dam construction and late flooding in upstream countries such as China and Laos, and climate change as well. For example, in the first quarter of the year 2011, salinity intrusion in the Mekong Delta coastal provinces spread widely into the inland. Meanwhile, the water level in the primary channels of two upland districts, Tri Ton and Tinh Bien, in An Giang, dried up sooner the expected when compared with recent years. Some rice fields that were based on surface water sources had not been harvested (Figure 5.18).

Figure 5.18: Traditional rice fields-loss of productivity due to drought

Ground water

Besides surface water, ground water is an important resource in An Giang. Ground water is quite abundant in An Giang, with three water layers, ranging from 60-400m in depth, commonly 90-120m. In the mountainous and inland regions, ground water is used not only for living purposes, it is also used for agricultural production purposes. Meanwhile, it is rarely used for agricultural purposes in areas along rivers or channels.

On average, to produce one hectare of rice, farmers have to use at least 14,000-25,000m^3 of water (Le, 2000), and they use about 5000m^3 of water to irrigate one hectare of vegetables, upland crops, or cash crops. Therefore, most ground water in An Giang is used for living (92%) because water requirements for crop production are very high. In the whole province, there are 7,100 drilled wells to draw water with the capacity of 100,000m^3/day. However, local authorities in An Giang recommend that farmers use the ground water source for agricultural production in the dry season, and for crops that need less water.

In An Giang, ground water is not considered important for agricultural production compared with other provinces in the Mekong Delta. Hence, the capability of farmland is influenced by the availability of the surface water source, rather than ground water.

Figure 5.19: Shadow drilled well that farmers dig to take water to supply their farms

5.4.4 Socio-economic and infrastructural conditions

+ Social conditions

Compared to most Mekong River Delta provinces, An Giang has quite a high population density (approximately 631 inhabitants/km^2, in 2007). The population of An Giang is young, the number of people at working age is 68%, and approximately 72% of the population lives in the rural areas and their main livelihood is agricultural production (An Giang Statistical Bureau, 2007). An Giang has four ethnic groups, Kinh (94.24%), Khmer (4.23%), Cham (0.63%) and Hoa (0.90%). The population distribution is uneven, settlements are mainly concentrated along roads, rivers and canals where social benefits such as electricity, water supply and transportation are available (People's Committee of the An Giang Province, 2009).

+ Economic conditions

An Giang had an average increase in GDP of about 6% between 1995 and 2001, this grew up to approximately 9% in the years 2002-2006. GDP per person in 2006 was 9.5 million VND (about $535) and this was contributed between three main economic sectors, they are agriculture, forestry and fishery (33.9%); industry and construction (12.6%); and service (53.5%) (An Giang Statistical Bureau, 2007). In most recent years, the economic structure has not changed much; the agriculture, forestry and fishery sectors still share about 35% of the GDP, and the GDP per person was approximately $850 in 2010.

Infrastructure

An Giang is one of many provinces in the Mekong Delta that has infrastructure systems (electricity, transportation, water, schools, ports, stations) developed in a synchronous way. In the rural areas, waterways and rural roads are the main means of transportation. Waterways in An Giang are so convenient for transportation with 1,026 routes (national and local levels) of length 2,432km. An Giang has a national road connecting it to Cambodia of length 93km and a provincial road system of 393.20km and 2.545km of rural roads. Irrigation systems of An Giang are very capable, ensuring water supply and drainage, flood prevention links with rural transportation and settlements distribution (People's Committee of the An Giang Province, 2009).

5.4.5 Agricultural land use

An Giang has approximately 84% (298,146 hectares) of agricultural land (Table 5.3). Agricultural land in An Giang consists of land used for annual crops (76.7%), multi-year crops (2.8%), forest (3.9%), aquaculture (0.7%) and other agricultural production purposes. Besides that, about 53,096ha (15%) of land is used for non-agricultural purposes. In recent years, agricultural land in An Giang has been extended because of land improvement and reclamation. This shows that agriculture, and agricultural land use planning, are very important in the An Giang Province (DNRE, 2006).

The structure of land use in general in the An Giang Province is quite stable, but the structure within agricultural land use and between farmland areas used for different crops in particular is changing. The change is unprompted and mostly driven by market requirements of different agricultural products. To illustrate, the planted land area[18] of paddy (Figure 5.20) in An Giang was 230,000ha in 1995, it went to 235,000ha in 2001 and stabilised until 2004, and then this area suddenly jumped to 264,000ha in 2005 before retaining an area of more than 263,000ha in later years.

Table 5.3: Land use of the An Giang Province in 2005

Land use types	Areas (ha)	Ratio (%)
Agricultural land	**298,146**	**84.3**
- Agricultural production land	281,863	79.7
+ Land used for annual crops	272,108	77.0
+ Land used for multi-year crops	9,755	2.8
- Forest land	13,842	3.9
- Aquaculture land	2,334	0.7
- Other agricultural land	108	0.0
Non-agricultural land	**53,096**	**15.0**
- Homestead land	15,423	4.4
- Specially used land	25,164	7.1
- Religion and belief land	375	0.1
- Cemetery land	234	0.1
- River, spring and specially used land	11,879	3.4
- Other non-Agricultural land	22	0.0
Unused land	**2,309**	**0.7**
- Unused flat land	542	0.2
- Unused mountainous land	1,245	0.4
- Non tree rocky mountain	522	0.1
Total	**353,551**	**100**

Note: Data as presented are subject to rounding. Source: An Giang Statistical Bureau (2005)

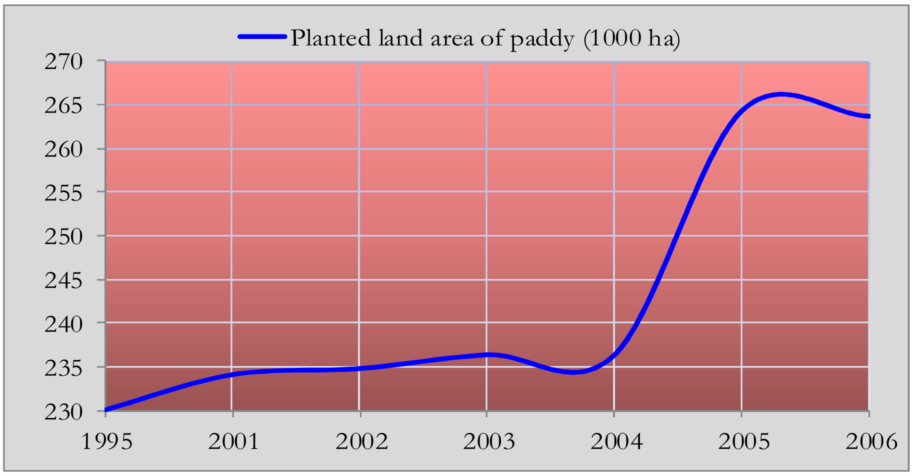

Figure 5.20: Change of planted land area of paddy between 1995-2006 in the An Giang Province. *Source: An Giang Statistical Bureau (2007)*

[18] *Planted land area is the total of sown land areas in the whole year (three cropping seasons); sown land area is the actual land area that paddy/crops sow in one cropping season.*

The accepted reason for this increase in the planted land area of paddy is that the price of rice in the Mekong Delta and in An Giang, in 2005 was very high and so many farmers transferred their farmland areas, which previously planted annual crops, to paddy (rice). The transformation of farming systems is very popular in the Mekong Delta and in An Giang. This causes difficulties for land management and development, particularly in land evaluation and planning.

Compared with other provinces in the Mekong Delta, the cropping index (FAO, 1985) in An Giang is higher. On average, the index is 2.5, especially in some districts in An Giang such as the Cho Moi District the cropping index is 3.5, farmers can produce seven rice seasons in two years. The high cropping index indicates that the farmland in An Giang is effectively utilized. Nevertheless, intensification and increase in cropping seasons will result in a decline of the capability of farmland.

In summary, the Mekong Delta in general, and An Giang in particular is a region of great agricultural potential. Natural and land conditions are most suitable for tropical farming systems. Annual crops such as rice and vegetables could be cultivated all year round with stable yields. However, in recent years due to market pressures for agricultural products, farmland use, and farming systems have been changing, and the change sometimes wastes the capability of farmland in the region. Moreover, several past studies showed that farmland in this region, was evaluated mainly in terms of physical considerations. Therefore, conducting the case study in the An Giang Province is appropriate. For this research project, the capability of farmland is investigated through multiple-disciplines using the theoretical model of an agricultural management system. The outputs of the case study not only help to refine the theoretical model, they also offer alternatives for local agricultural land planners in using and planning the farmland resource.

5.5 The Cho Moi District

Cho Moi is the selected district in the An Giang Province to execute the case study. It is one of four crucial islands in An Giang. Its natural features like weather, hydrometeorology, and socio-economic conditions are similar to the An Giang Province. Thus, in the following text the author focuses on issues relating closely to the farmland capability; because the main goal of the study is to design and test the theoretical model (agricultural management system) for land capability assessment.

Cho Moi is an island "Cù Lao in Vietnamese" with rich fresh water and alluvium. It is circled by the Tien, Hau, and Vam Nao Rivers. The Phu Tan District to the North-West (6.11km), Dong Thap Province to the North (23.22km), Cao Lanh City (Dong Thap) to the East (8.39km, divided by the Tien River) and, the Lap Vo District (Dong Thap) to the South-East (19.61km), Long Xuyen City to the South-West (18.13km, divided by the Hau River), Chau Thanh (8.34km) and Chau Phu (6.15km) Districts to the West.

Cho Moi has an area of natural land of about 35,571ha. The population was about 369,000 people in 2010, residing in 18 communes and towns, including Hoa An, Hoa Binh, Hoi An, An Thanh Trung, Binh Phuoc Xuan, My An, Long Kien, Long Giang, Nhon My, My Luong (town), Tan My, My Hiep, Kien Thanh, Long Dien A, Long Dien B, My Hoi Dong, Kien An, and Cho Moi town (Figure 5.21). The administrative centre of Cho Moi is located in the Cho Moi Town, 29 km from Long Xuyen City.

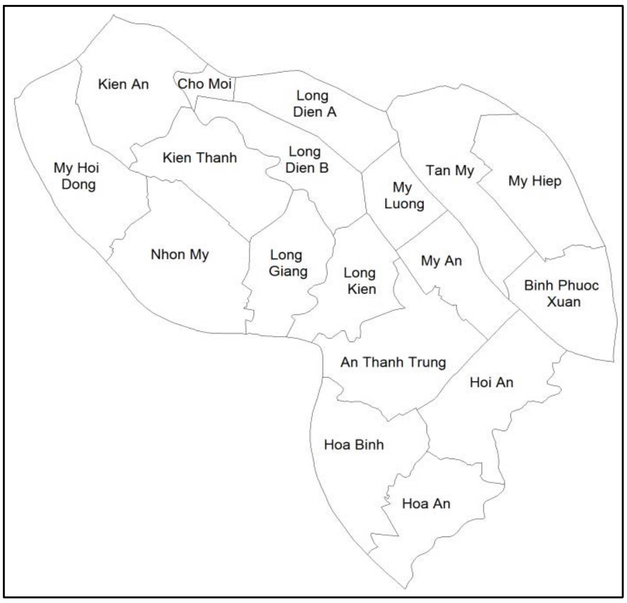

Figure 5.21: Administrative map of the Cho Moi District

5.5.1 Soil characteristics in Cho Moi

According to the Soil Taxonomy classification, soils in Cho Moi can be categorized into the following main types (Figure 5.22, Thanh, 2001; DNRE, 2006):

+tHAPf (Typic Humaquepts-Fluvic): 11,106ha, accounted for 31.2%, its main components are clay and alluvium, rich nutrient availability and well aerated, this soil is mostly distributed along the rivers;

+ eFAN (Aeric Fluvaquents): alluvial soils with slight acid sulphate, it is mainly found in the My Luong and Hoi An Communes with 4,064ha (shared 11.4%);

+ dsu HAP (Deep Sulfidic Humaquepts): occupies 3,935ha (shared 11.1%); it has a scattered distribution and can be found in the central region;

+ fUTP (Fluventic Ustropepts): occupies an area of 3,120ha, has moderate nutrient availability, and is distributed mainly in the centre of Cho Moi;

+ Sulfuric Humaquepts-Fluvic: this soil shares a small area of 1,360ha, it can be found in the An Thanh Trung Commune.

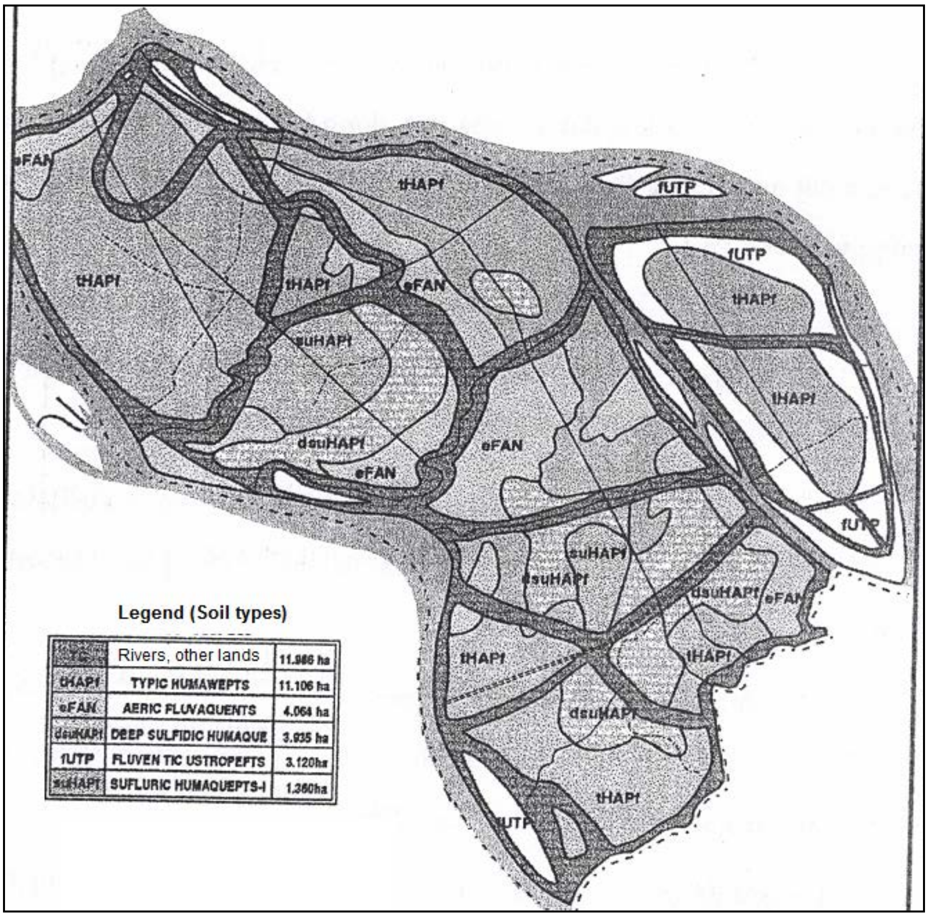

Figure 5.22: The Cho Moi District soil map. *Source: Thanh (2001)*

These soil types are distributed in an even and flat terrain, the average topography in Cho Moi is +1.3m (compared with sea level), the highest terrain is along the Tien River (1.5-2.4m), and it decreases gradually to the centre (inland) (0.7-1.2m). Topographic slope follows two directions, the East to the West, and the North to the South. Thanks to this topographic characteristic, many pump stations and channels in Cho Moi were built with starting points at the high places (along the Tien River) to supply water to the lower places. In that way, the costs for irrigation could be reduced.

5.5.2 Agricultural production in Cho Moi

Agriculture is an important contributor to the Cho Moi economic growth. Agriculture, and its services such as agricultural commodity-processing factories and companies for agricultural trade and services, have generated job opportunities and employed more than 80% of the rural labour force in the local area.

Agriculture in Cho Moi occupies nearly 75% (26,747ha) of the total natural land area. Surprisingly, planted areas for paddy (rice) was 20,259ha, accounting for 57% of Cho Moi lands between 2005 and 2010. Compared with other districts in An Giang, Cho Moi agriculture has much diverse farming systems and crops. The most dominant being rice systems, vegetable systems, corn, and sweet potatoes.

+ Rice systems

Rice in Cho Moi is cultivated under two main systems, intensive rice and rotational rice combined with other temporary crops (mainly vegetables). Rice intensification is designed to produce three cropping seasons per year (three rice), Winter-Spring (WS), Summer-Autumn (SA), and Autumn-Winter (AW). While, the rotation consists of two rice-one vegetable, one rice-two vegetables (Figure 5.23).

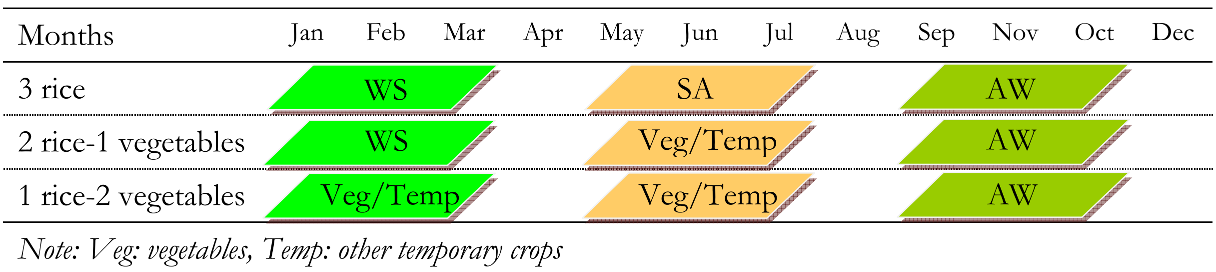

Figure 5.23: Seasonal calendar of rice farming systems in the Cho Moi District

The WS often starts at the beginning of January and harvest is at the end of March, the SA crop is grow in May and is harvested in July, and the AW is cultivated between September and November. Normally, the duration for a rice-cultivating season is three months, and the period of sowing and harvesting for all rice areas in the district is about two weeks.

Since the 1990s, thanks to the completion of the works for a closed dyke system and irrigation systems, planted land areas for the 3-rice patterns has increased substantially. It was 2,355ha in 1998, then jumped to 10,698ha in 2000, reaching 18,574ha in 2003, and retained at 16,500ha in 2009 (Cho Moi Department of Agriculture and Rural Development, 2009).

Overall, the planted land area for paddy varied significantly in the period 1995 to 2009. First, the area increased more than 15,000ha between 1995 and 2003 (39,550ha in 1995 to 56,340ha in 2003), then it declined gradually to 47,440ha in 2007, and remained around 50,000ha during the years 2008 to 2009 (Figure 5.24). Notably, although the planted area reduced more than 10,000ha in the years between 2003 and 2009, the gross output in that period still gained around 320,000ton. This could have been a result of policies on improving the capability of farmland in Cho Moi by the construction of many works for improved irrigation and dyke systems, the use of modern rice varieties and advanced technologies in rice production.

The sown land area and yield of paddy varied year-by-year, depending on annual weather, pests, flood regime, and different seasons. In three seasons of rice production, the WS had the highest sown area and highest average yield, and it was relatively stable over a number of years. The next best was the SA. Meanwhile, the AW had the lowest and most inconsistent sown area and yield (Figure 5.25 and 5.26). For instance, bacterial leaf blight (*Xanthomonas campestris* pv. *oryzae)* in 2005 led the average yield of paddy in the AW to be no more than 3.5ton/ha. In the later years 2006 to 2007, due to problematical weather, many farmers ignored the third rice season (AW), and therefore the sown area in the AW season of those years was about 13,000ha.

With a gross output of paddy of about 310,000 tons/year, Cho Moi guarantees the mission of local food security and the target for export. In the plan for developing the agricultural sector, Cho Moi does not reduce or expand the planted land area for paddy. Future trends are to combine, rotate, and transfer some suitable temporary crops onto the rice field, to maximise the land efficiency and conserve the soil fertility.

In addition, Cho Moi has completed dyke systems to prevent and control floods. This gives Cho Moi a competitive advantage compared with other places as it helps Cho Moi to actively schedule seasons of cultivation. Using the above convenience, rice in Cho Moi is planted in a different manner to other locations in the Mekong Delta, in term of cultivated seasons. As a result, the harvested outputs (rice) in Cho Moi are available as a useful source for seeding, for many places in the Mekong Delta (e.g. rice seed fields in Figure 5.27).

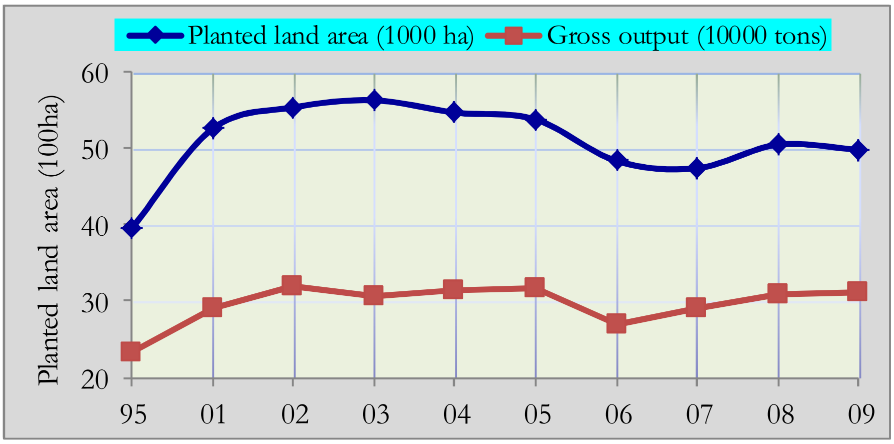

Figure 5.24: Planted land area and gross output of paddy between 1995-2009 in the Cho Moi District. *Source: An Giang Statistical Bureau (2010)*

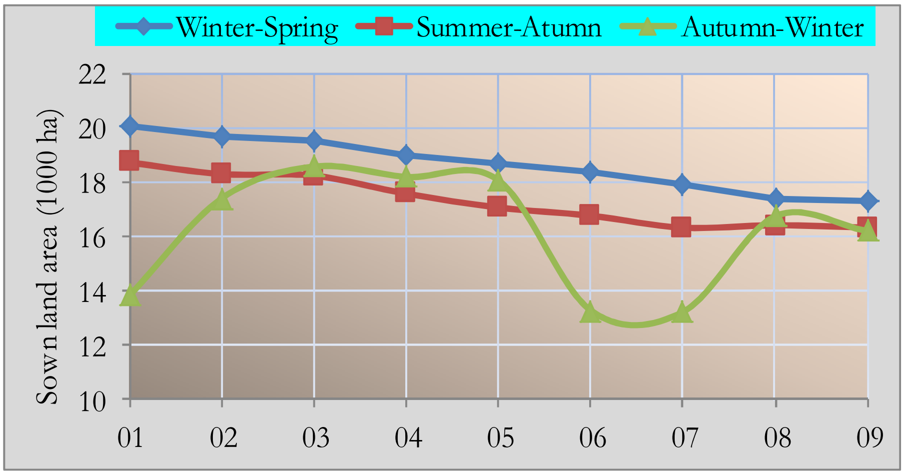

Figure 5.25: Sown land area of paddy for three different cropping seasons between 2001-2009 in the Cho Moi District. *Source: An Giang Statistical Bureau (2010)*

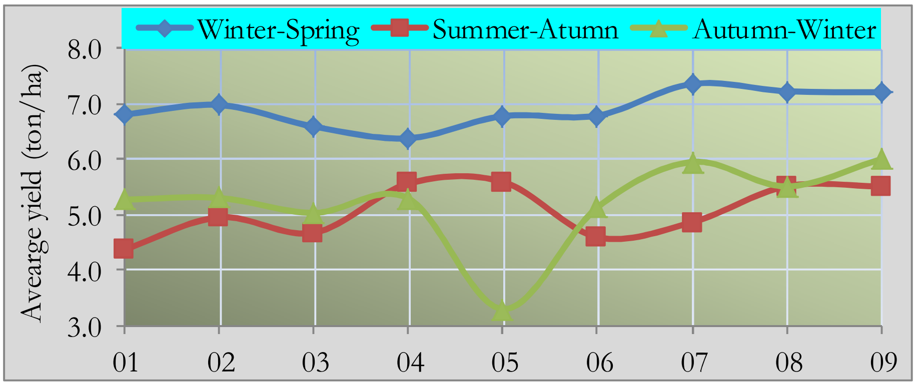

Figure 5.26: Average yield of paddy between 2001 and 2009 in the Cho Moi District

Source: An Giang Statistical Bureau (2010)

Figure 5.27: Rice seed fields in the Cho Moi District

+ Vegetables and other temporary crops

Cho Moi is the biodiversity garden island, so many kinds of vegetables and short-term crops can be found in this region. Vegetables are planted for three main purposes, fresh consumption in the local area, pickled and for export, and processing traditional medicines. Vegetables can be planted rotationally with rice systems, or intensively grown the whole year with very desirable species (Figure 5.28).

The planted area and gross output of vegetables have increased significantly in recent years. The planted area expanded from 760ha in 2001 to 22,800ha in 2009. The gross output jumped rapidly from 183,000 tons in 2001 to 572,000 tons in 2009 (Figure

5.29). This growth is due to policies on rotating rice and vegetables as a replacement for previous rice intensification systems in Cho Moi. The success of vegetables produced on the rice fields in the lowland areas is a controversial trend requiring crop scientists to find solutions for sustainable agricultural development in the Mekong Delta.

Vegetables are intensively cultivated the whole year round in both the upland and lowland areas. Most popular are leaf vegetables for eating and spicy vegetables such as hot pepper, long pepper, ginger, root-onion and leaf-onion. Their growth duration is slightly shorter so farmers can plant many seasons per year.

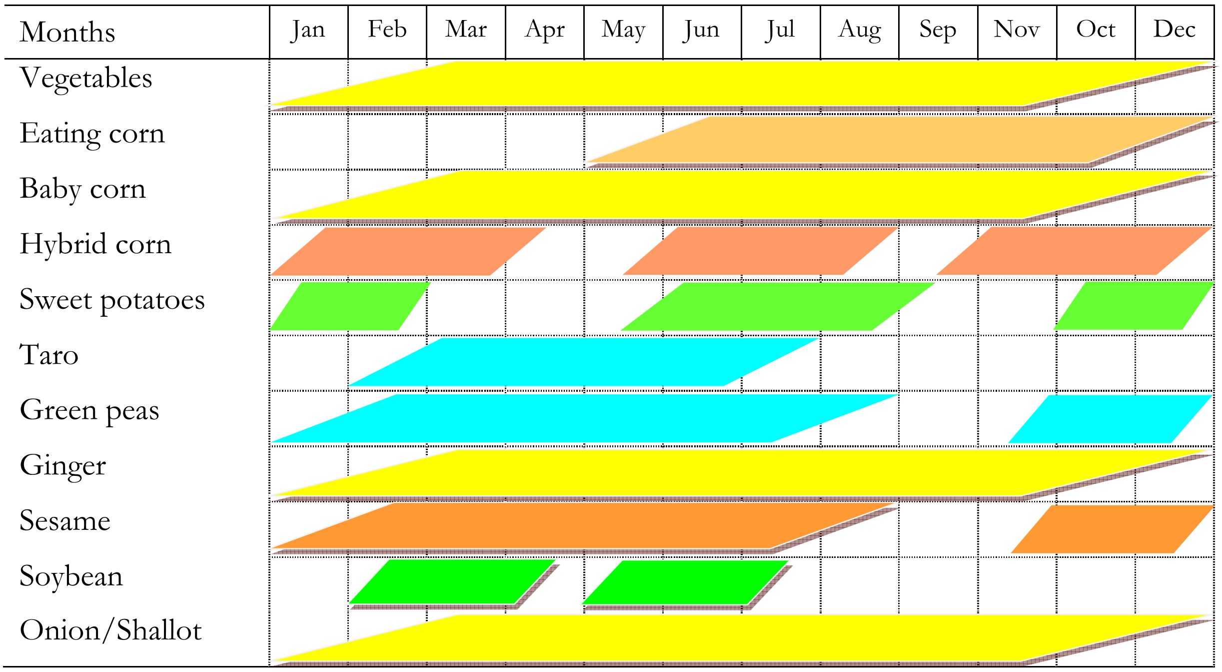

Figure 5.28: Seasonal calendar of vegetables and some important temporary crops

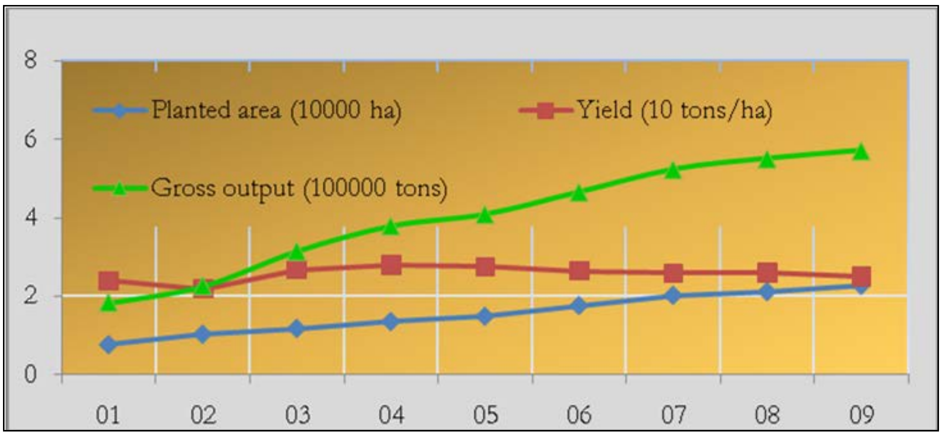

Figure 5.29: Planted area, yield, and gross output of vegetables between 2001 and 2009 in the Cho Moi District. *Source: An Giang Statistical Bureau (2010)*

Figure 5.30: Intensive vegetables system in upland areas in the Cho Moi District

Figure 5.31: Rotational rice and vegetables/temporary crops in the Cho Moi District

Besides rice and vegetables, tubers (root crops such as sweet potatoes, taro, and cassava), legume (green peas, soybean) and corns are common and important temporary crops. They can be rotated together, with rice, vegetables, or grown intensively. Predominantly, corn is very common, which includes three types: baby corn, production for export; traditional corn, corn for local consumption (eating); and hybrid corn, production for feeding husbandry and fish.

During the last decade, the planted area for corn varieties has increased marginally; yields have risen slightly in the years 2001 to 2003 and stabilised during 2004 and 2009 at less than five tons/ha. On the contrary, gross output of corn varieties has climbed steadily. The gross output was 8,410 tons in 2001; rising to 13,420 tons in 2005, and then soared up to 19,980 tons in 2008 before it declined to 16,030 tons in 2009 (Figure 5.32).

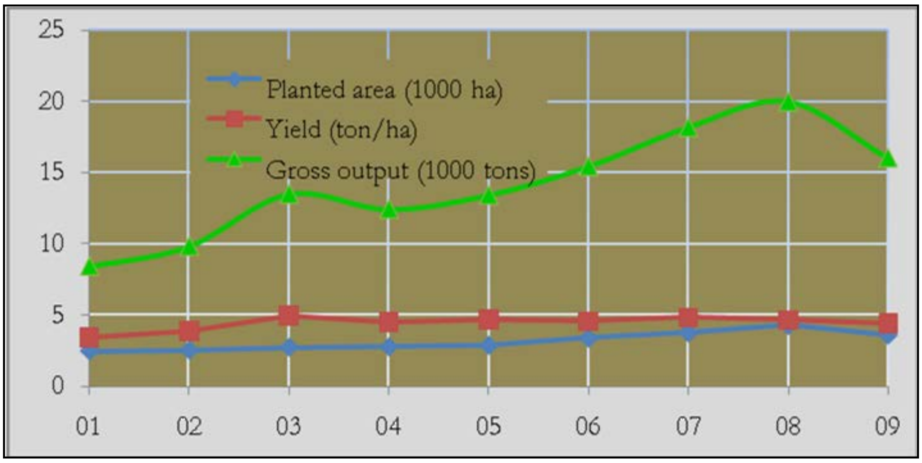

Figure 5.32: Planted area, yield, and gross output of corn between 2001 and 2009 in the Cho Moi District. *Source: An Giang Statistical Bureau (2010)*

Today, an integrated farming system of baby corn and husbandry is a preferred model which is designed to optimise the farmland capability, and to progress sustainable agricultural development. After harvesting baby corn, its by-products are used for feeding animals, and the organic fertilizers that animals generate are reused to produce gas at the farm scale, and to resupply the corn field. In this way, farmers can increase their income sources, reduce their production costs, and simultaneously improve their farmland capability.

In brief, Cho Moi is an agricultural region with diversified farming systems. Its farmland capability is utilised effectively through practicing locally adaptable temporary crops like rice, vegetables, corns, tubers and other species. Changes in land use are popular in the Mekong Delta, however, it does not occur much in Cho Moi. Thus, selecting Cho Moi to conduct the case study, by means of testing the theoretical model for an agricultural management system to determine the capability of farmland is very reasonable. This testing will reflect the characteristics and the nature of the theoretical model that need to be adjusted and updated to create the appropriate model.

5.6 Summary

An introduction to the research area is essential because it clarifies and helps in the understanding about how the theoretical model design is transferred to a practical application. The model design is modified and tested based on the practical context in the research area. Moreover, information provided in this chapter is useful proof and evidence for the interpretation and explanation of results in the later chapters (results and discussion).

First, the author highlighted Viet Nam as an agriculture based country, which has eight typical agro-ecological regions, spanning from the North to the South, with the total agricultural land areas being 9,436,000ha. Agricultural systems vary from region to region, and the most common systems in the delta areas are rice systems, vegetables, upland and other temporary crops.

Second, the Mekong Delta was described as the "rice basket" of Viet Nam and Southeast Asian. Further, soil conditions, topography, agricultural production socio-economic characteristics in the Mekong Delta were also mentioned. The most remarked points were that the Mekong Delta natural conditions such as soils, climate, and water source are suitable for agricultural development. However, this region is facing constraints like market pressures in production, floods in the wet season, and impacts of climate change e.g. salinity intrusion.

Finally, natural factors consisting of cloud, average temperature, sunshine hours, average rainfall, humidity, wind and evaporation, landforms and soils, hydrological regime and floods, and water sources in the case study area (An Giang Province and Cho Moi District) were outlined in this chapter. Particularly, the status and existing information relating to agricultural land use, farming systems and their features such as the seasonal calendar distribution, yields, and planted areas were provided and analysed.

The statements above help to consolidate and simplify the steps that are illustrated in the case study process. More importantly, the results of adjusting the theoretical model and testing the practical model in the later chapters (Results and discussion) are interpreted and analysed based on the content presented in this chapter.

CHAPTER 6: CASE STUDY IMPLEMENTATION

6.1 Introduction

The main purpose of this chapter is to present the case study implementation that is the second phase of the research. The major content in the current chapter includes important steps that describe the process of testing the developed (theoretical) model, based on available and collected data, as well as other required inputs according to the specific context in the study area. First, the proposed farming systems for farmland capability determination are identified for testing the model design. They include rotational rice-vegetables, single rice, and single vegetable systems. Based on those farming systems, the theoretical model is adjusted to create a practical model that suits the study area context. Then, land characteristics in the practical model are considered and examined with respect to the capability of farmland. After that, an on-site farmland investigation is conducted in accordance with the farmland characteristics contained in the practical model. Ultimately, farmland capability at the case study site is analysed, determined, and presented through matching farmland characteristics with land use requirements.

The case study was conducted in the An Giang Province, Mekong Delta, Viet Nam, where agricultural land use and farming systems have been continuously changing (*see the background of the study area, Chapter 5*). The case study investigation is summarized in Figure 6.1, and involves six main tasks listed below:

(1). Determining suitable farming systems for farmland capability determination;

(2). Modifying the theoretical model and standardising the capability classes

(3). Revealing the factors which impact upon the farmland capability

(4). Undertaking the farmland surveys;

(5). Analysing the capability of farmland; and

(6). Modelling the capability of farmland.

The detailed description of these tasks is now presented.

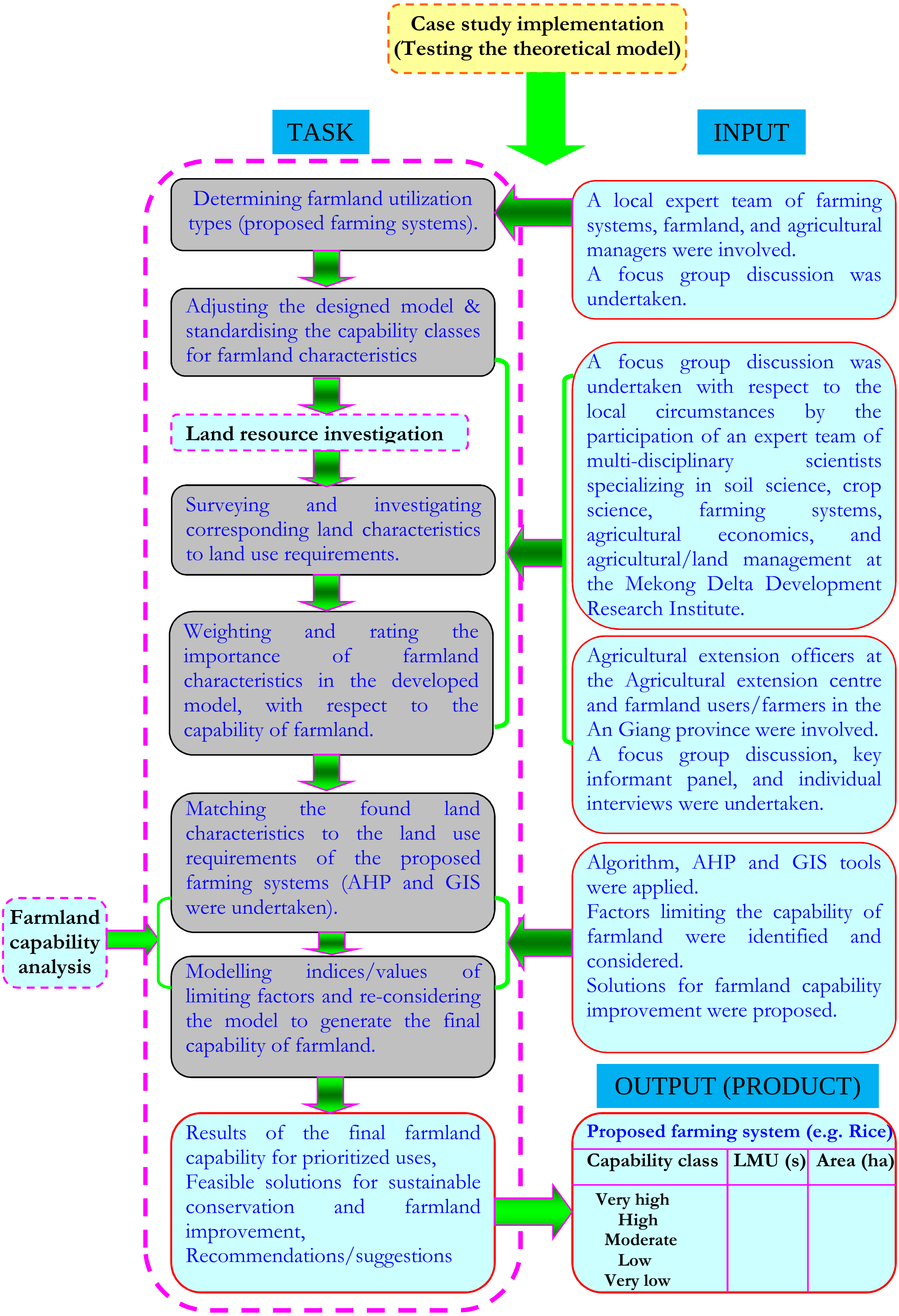

Figure 6.1: The conceptual flowchart of the case study approach

6.2 Key steps for undertaking the case study

6.2.1 Determining the proposed farming systems

Determining the farmland utilization types (proposed farming system(s) (PFS)) is the first and most important step in conducting the case study because the farmland capability is evaluated, or determined, for a specific use (FAO, 1976; 1985; 1993). In other words, the theoretically designed model of the AMS for determining the capability of farmland will be tested by its application to specific farming systems. As presented (*see item 4.4.1, Chapter 4*), the PFS were identified based on three key principles: attributes of the PFS (FAO, 1976), current farmland utilizations, and planned farmland utilization types for planning future farmland use in the local area.

Based on these principles, associated with Guideline[19] (1), a team of agricultural management, farmland, and farming system experts at the An Giang AEC were invited to identify the PFS for farmland capability determination. This was done through a focus group discussion, and the PRA tool (FAO, 1991b; 1999a) was applied.

The identification of the PFS was objective, and mostly dependent on local conditions. For example, rice production systems include:

- Winter-Spring rice+Summer-Autumn-Autumn-Winter fresh water shrimp;
- Winter-Spring rice+Spring-Summer rice+Fish;
- Winter-Spring rice+Spring-Summer Upland crops-Summer-Autumn rice; and
- Three seasoning rice (Winter-Spring, Spring-Summer, Summer-Autumn), were the PFS for farmland capability evaluation in the Co Do District, Can Tho City, Mekong Delta, Viet Nam (Thao, 2008). These systems were proposed because they play an extremely important role in terms of income sources and livelihood opportunities for local inhabitants. They dominate a larger part of the agricultural areas when compared with other PFS. A very important reason for their selection was that these systems were identified by local farmland planners for future utilization.

6.2.2 Adjusting the model design and standardising the capability classes

Based on the generated PFS, an expert team of multi-disciplinary natural resource managers (FAO, 1995) at the MDI were invited to adjust the theoretical model

[19] *Guidelines are used for data collection. Refer to Appendices 2 to 6 (Guidelines 1 to 5)*

through a focus group discussion with the Guideline (2), in order to make the theoretical model suit the Viet Nam Mekong Delta context.

The expert team at the MDI included several people representing the following disciplines:

- Soil science
- Crop science
- Agricultural economics
- Farming systems
- Agricultural management (consisting of farmland)

Experts discussed and consistently adjusted six components in the AMS for the farmland capability determination, by removing unsuitable components and adding more suitable components. The fundamental criterion for expert adjustments was that adjusted components have to impact significantly upon the farmland capability for the PFS that was formed in the previous step.

For each adjusted component in the AMS, experts short-listed class-determining factors[20] (*Table 2 in Guideline 2*) that were expected to contribute to the farmland capability. Adjustments to components and factors in the AMS were based on the consideration of the farmland capability at different administrative scales, ranging from farm, hamlet, commune, district and the provincial level.

During the theoretical adjustment, relationships and interactions between factors in the AMS were taken into account. Individual factors that have a minor or indirect impact upon the farmland capability were merged to become one, this ensured that the significance, or importance, of adjusted factors, in the AMS, associated with the farmland capability for the PFS, were equal.

Indicators or criterion, measurements, and measured units for class-determining factors (farmland characteristics) in the AMS were clearly defined by experts and with respect to the farmland capability for the PFS. For example, the flood factor could be

[20] *In this study, class-determining factors, weighting factors or factors in the AMS have the same meaning. They are criteria for determining the capability of farmland*

defined and measured by (1). the duration/period of floods with measured unit as month or day, and (2). the depth of floods with measured unit as meter or centimetre.

Experts at the MDI continued standardising values or indices for each class-determining factor in the AMS for the PFS, corresponding to five capability classes as formed in the theoretical model: very high, high, moderate, low, and very low capability. This standardisation was different between factors and the selected PFS, and depended on local standardised circumstances (e.g. Table 6.1).

The outcome of the model design adjustment was the creation of the Viet Nam, Mekong Delta model. This refined model was then tested through matching investigated data of land characteristics (theoretical) to requirements of each land use type in the research site (practical) to determine the farmland capability.

Table 6.1: Standardising indices of physical farmland characteristics for several farming systems in the Can Tho Province, Mekong Delta, Viet Nam.

Proposed farming systems and physical farmland characteristics	**Capability classes**				
	Very high	High	Moderate	Low	Very low
***WS rice-SA-AW fresh water shrimp**					
Depth of pyritic layer (cm)	Non-pyrite, 120->80	80-50	<50	-	-
Time of inundation (month)	<3	4	5	>5	-
WS rice-SS rice + Fish					
Depth of pyritic layer (cm)	Non-pyrite, 120->80	80-50	<50	-	-
Time of inundation (month)	<3	4	5	>5	-
WS rice-SS Upland crops-SA rice					
Depth of pyritic layer (cm)	Non-pyrite	120->80	80-50	<50	-
Time of inundation (month)	<2	3	4	>4	-
WS rice-SS rice-SA rice					
Depth of pyritic layer (cm)	Non-pyrite, 120->80	80-50	<50	-	-
Time of inundation (month)	<2	3	4	>4	-
Intensive fish					
Depth of pyritic layer (cm)	Non-pyrite, 120->80	80-50	<50	-	-
Depth of inundation (cm)	<60	60-100	>100	-	-

**WS: Winter-Spring, SS: Spring-Summer, SA: Summer-Autumn, AW: Autumn-Winter. (Thao, 2008)*

6.2.3 Weighting the importance of farmland characteristics using the AHP

After the theoretical model was adjusted and the capability classes were standardised, components and factors in the AMS were weighed and rated by experts at the MDI with respect to the farmland capability for the PFS. The AHP technique was applied as a guideline to the weighting.

According to Baniya (2008, p. 59), the principal assumption of the AHP tool is that comparison between two elements is achieved by considering their real-time importance, and by basing the outcome on three principles: decomposition of the overall goal (capability), comparative judgement of the criteria, and synthesis of the priorities. First, weighting components and factors[21] in the AMS were structured into a hierarchical form. This was the most creative and important part of the decision making on land capability assessment (Bhushan and Rai, 2004). The farmland capability determination located at the highest level in the hierarchy was the ultimate goal of the case study. The subsequent levels were components in the AMS, and were used to support the goal. Factors under each component settled at the lowest position in the hierarchy (Figure 6.2).

Many alternatives need to be evaluated and compared at the lowest level in the hierarchy for farmland capability determination. Decision criteria relevant to the goal were identified and arranged in the hierarchy illustrated in Figure 6.2. Such a structure allows for the incorporation and accommodation of both qualitative and quantitative criteria for assessing farmland capability. With this in mind, GIS has emerged as a useful computer-based tool for spatial description and manipulation of the outcome from the farmland capability determination (Baniya, 2008, p. 59).

The comparison between components and corresponding factors (class-determining factors) in the AMS was the fundamental function of the AHP. The components and factors were compared in pairs with respect to each other based on the qualitative scale as described in the Table 6.2. Experts could rate the comparison between two components, or factors, as equal, marginal, strong, very strong, or extremely strong, based on the importance in relation to their contribution to the farmland capability.

[21] *Components and factors in the AMS that needed to be weighted*

The options were collected in a specially designed format as shown in Figure 6.3. "E" in the green box marked "very strong" indicates that B is very strong compared with A in terms of the criterion on which the comparison was being made. The comparisons were made for each criterion and converted into quantitative numbers as displayed in Table 6.2 (Bhushan and Rai, 2004, p. 16).

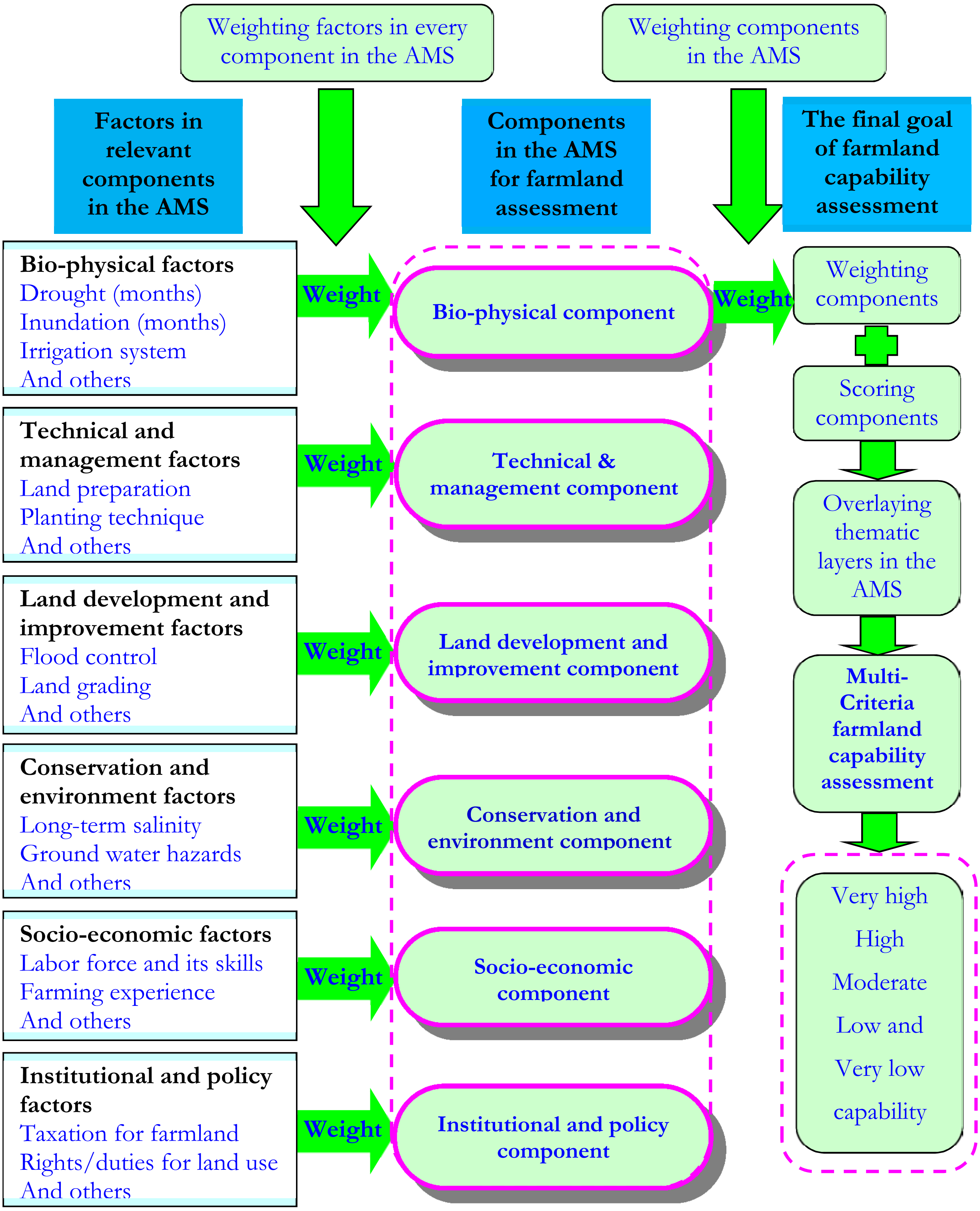

Figure 6.2: Weighting factors and components for farmland capability determination

Table 6.2: The fundamental qualitative scale used in pair-wise comparisons

Intensity of importance	***Definition***	***Explanation***
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8		Intermediate values to reflect fuzzy inputs
Reciprocals of above	If activity ***i*** has one of the above non-zero numbers assigned to it when compared with activity ***j***, then ***j*** has the reciprocal value when compared with ***i***	A reasonable assumption
1.1-1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

Source: Saaty and Vargas (2001, p. 6); Saaty (2008a, p. 257; 2008b, p. 86) and Bhushan and Rai (2004)

A								E		B
	Extremely strong	Very strong	Strong	Marginally strong	Equal	Marginally strong	Strong	Very strong	Extremely strong	
	9	**7**	**5**	**3**	**1**	**3**	**5**	**7**	**9**	

Figure 6.3: Format for pair-wise comparisons. *Source: Bhushan and Rai (2004, p. 16)*

The pair-wise comparisons of various components, or factors in the AMS generated by experts were organised into a square matrix (Table 6.3s). The diagonal elements of the matrix are 1, when the factor in the row is more important than the factor in the column, the value varies between 2 and 9 (w***i***/w***j***). Conversely, the value varies between the reciprocals between 1/2 and 1/9 (for example, Tables 6.3.2, 6.3.3 and 6.3.4 represent the selection of suitable rice varieties in Viet Nam, Mekong Delta).

As shown in the Table 6.3.2, comparing criterion MTL to criterion OM, a score of 2 indicates that MTL is more important than OM in relation to the suitable cultivation in the Mekong Delta, and a score of 1/2 (IR) indicates that MTL is of little significance relative to IR. All scores can be assembled in a pair-wise comparison matrix with 1s placed on the diagonal, from the upper left corner to the lower right corner (e.g. MTL to MTL is 1) and reciprocal scores in the lower left side of the matrix of pair-wise comparisons (e.g. if MTL to OM is 2, then OM to MTL is 1/2).

Table 6.3.1: The matrix of pair-wise comparisons

(W*i,j*) = Wi/Wj	**W_{11}=1**	W_{12}	W_{13}	W_{1n}
i, j = 1, 2, …n	W_{21}	**W_{22}=1**	W_{23}	W_{2n}
W: Weight	W_{31}	W_{32}	**W_{33}=1**	W_{3n}
	W_{n1}	W_{n2}	W_{n3}	**W_{nn}=1**

Table 6.3.2: An example of the pair-wise comparison matrix of criteria in the AHP

Goal[22]	***MTL***	***OM***	***IR***	***VD***
MTL	**1**	2	1/2	3
OM	1/2	**1**	1/3	1
IR	2	3	**1**	4
VD	1/3	1	1/4	**1**

(Note: The selection of suitable rice varieties in Viet Nam Mekong Delta)

The numbers in the matrix of pair-wise comparisons were converted to decimals to make them easier to work with, and then column totals were obtained (Table 6.3.3).

Table 6.3.3: The matrix of pair-wise comparisons in decimal numbers

Goal	***MTL***	***OM***	***IR***	***VD***
MTL	1.000	2.000	0.500	3.000
OM	0.500	1.000	0.333	1.000
IR	2.000	3.000	1.000	4.000
VD	0.333	1.000	0.250	1.000
Total	**3.833**	**7.000**	**2.083**	**9.000**

The numbers in the matrix were divided by their respective column totals to produce the normalized matrix as shown below (Table 6.3.4). To determine the priorities for the criteria, the average of the various rows from the matrix of numbers was calculated, and ranked as in the Table 6.3.4. So, for example, the weighting results (column weights) shown in the Table 6.3.4 were the cultivated suitability priority of four rice varieties when planted under Viet Nam, Mekong Delta conditions.

---

[22] *Suitable rice varieties in Viet Nam, Mekong Delta; MTL, OM, IR and VND are local names of rice varieties cultivated in the Mekong Delta*

Finally, the AHP set out the priorities of the sub-components in the AMS and the weights of each class-determining factor with respect to the ultimate goal of farmland capability determination for the PFS. These priorities were multiplied by the weights of the respective criterion with the capability scores[23] to determine the capability indices of farmland.

Table 6.3.4: The normalized matrix of pair-wise comparisons

Goal	*MTL*	*OM*	*IR*	*VD*	Weights	Ranking
MTL	0.261	0.286	0.240	0.333	0.2800	**2**
OM	0.130	0.143	0.160	0.111	0.1361	**3**
IR	0.522	0.429	0.480	0.444	0.4687	**1**
VD	0.087	0.143	0.120	0.111	0.1152	**4**
Total	**1.000**	**1.000**	**1.000**	**1.000**	**1.0000**	
λmax = 4.031, CI = 0.010, RI = 0.89, CR = 0.012					**∑ = 1 (100%), n = 4**	

Saaty and Vargas (2001, p. 9) point out that the AHP includes a consistency index for an entire hierarchy, and therefore it is necessary to consider whether the pair-wise comparison has been consistent at each level in the hierarchy, in order to accept the results of the weighting, or to investigate the problem and revise judgements. The Consistency Ratio (CR) indicates how much variation is allowed for weighted results. A higher value (number) means less consistency, whereas a lower value (number) means that there is more consistency in judgements of the pair-wise comparison matrix. The CR is expected to be less than 10 percent because it implies that the judgement is small compared to the actual values of the eigenvector entries.

The CR is obtained by comparing the Consistency Index (CI) with the appropriate number from the following set of Random consistency Index (RI) numbers (*see Table 6.4*) using the formula CR = CI/RI. Each average random consistency index is derived from a sample of randomly generated reciprocal matrices using the scale 1/9, 1/8, 1/7…1…7, 8, 9 (Saaty and Vargas, 2001, p. 9).

Table 6.4: Average Random consistency Index (RI)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.52	1.54	1.56	1.58	1.59

Source: Saaty (2008a)

[23] *Capability scores are obtained by the farmland investigation, then classified as described in Table 6.5.1*

The CI is calculated as CI = (λ_{max} - n)/(n – 1), where n is the number of criterion (components/factors in the AMS) in each pair-wise comparison matrix, and λ_{max} is the maximum Eigen-value of the judgement matrix that is calculated by the following formula.

$$\lambda_{\max} = \frac{1}{n} \cdot \left[\frac{\sum_{n=1}^{n} W_{1n}}{W_{11}} + \frac{\sum_{n=1}^{n} W_{2n}}{W_{22}} + \frac{\sum_{n=1}^{n} W_{3n}}{W_{33}} + \cdots\cdots + \frac{\sum_{n=1}^{n} W_{nn}}{W_{nn}} \right]$$

In this case study, the weighting was firstly conducted at the lowest level of the hierarchy which dealt with the class-determining factors in the AMS, if CR $\leq$ 0.1 (10%), which means the matrix was consistent and the AHP analysis could continue; in contrast, if CR > 0.1, the assessment requires a revision of the judgements because the matrix was not consistent. Then, the weighting for higher level components in the AMS was applied, and λ_{max}, CI, and CR were formed by applying the same formula and requirement. The results of weighting using the AHP were merged with farmland characteristics found by the farmland investigation, in order to determine the capability indices of farmland.

6.2.4 Surveying and investigating land characteristics

Data collection of farmland characteristics was the main activity of the case study and the research. It provided necessary input material for testing the theoretical model design. Required data for the research included available and new data, which were expected to be relevant to components in the AMS, particularly climate, hydrology, topography, soil, land use, agricultural production (crops and farms), demography, socio-economic, and land policies. Data sources consisted of field surveys and secondary data collection from various individuals and organizations.

Primary data sources

Primary data collection was conducted in the three selected communes in the Cho Moi District, An Giang Province. Semi-structured questionnaires (*Guidelines, see Appendices 2 to 6*) were adjusted and re-tested with respect to the Viet Nam context prior to the formal data collection. A Participatory Rural Appraisal (PRA) approach (FAO, 1991b, 1999a; Jain and Polman, 2003) was the fundamental guidance (*see Appendix 1*) for focus group discussions, individual interviews, and key panel interviews, which were undertaken in the research. Prior to the field work, direct contact was made with provincial and local research participants and farmers to make sure that they were available and willing to provide the data.

At the end of the field work, seminars were organised in the locality to gain feedback and confirmation on the data collected. Here, necessary adjustments to the original approach were made, to secure consistent data.

Secondary data sources

A majority of secondary data (including spatial and non-spatial) were collected from the Mekong Delta Development Research Institute (MDI) and the An Giang Agricultural Extension Centre (AEC). Especially, data on demographic, socio-economic, and land use were based on public publications of statistical yearbooks of the Viet Nam General Statistics Office (GSO), the local bureau of statistics offices and the Viet Nam Ministry of Natural Resources and Environment. In addition to these, data on agricultural production and management, farmland capability, the environment, meteorology and hydrology were also gathered from local departments of agriculture and rural development in the An Giang Province.

The forms of the data were published reports, thematic base maps, and documents in paper and electronic versions, which were required for the regional, provincial to commune level of analysis.

Data collection description

After selecting the proposed farming systems for farmland capability determination, adjusting the theoretical model, developing a system for farmland capability classification, and standardising the capability classes for farmland characteristics, the data collection process was undertaken.

For focus group discussions, a team of several participants were invited to be interviewed. The content of the required data that needed to be gathered was based on the Guidelines (*see Appendices 2 to 6*). Questions in the Guidelines were presented and discussed to obtain a consistent set of provided data. The participants' ideas were equally considered during the discussion. Ultimately, a summary of the results of the discussion was presented to participants in order to verify and confirm the accuracy, consistency, and credibility of the provided data, and sometimes adjustments to the provided data were made by the consensus of all participants.

For individual interviews, the face-to-face interview style was used based on the semi-structured questionnaire. At the end of the interview, the content of the collected data were verified and approved by the data providers.

During data collection, photographs of farming systems, the landscape, and sometimes farmers were taken. The photographs were mostly taken in the fields associated with the proposed farming systems.

In this case study, the focus group discussion, key informant panel interview, and individual interview approaches were used to collect the data. These approaches are presented below:

The focus group discussion at the An Giang AEC

The main purpose of this activity was to interact with local extension officers in the An Giang Province to select suitable farming systems for farmland capability assessment.

- Aims were to:
    - identify the proposed farming systems (land utilization types) in the An Giang Province and the research sites for farmland capability determination;
    - consider overall views about the research sites (farmland capability, agricultural production, irrigation system, drainage system, etcetera);
    - prepare and make contact with farmers for the development of further key information sessions, group discussion with farmers, and farmers' individual interviews;
    - collect secondary data related to agricultural production and farmland capability in the An Giang Province and the research sites;
    - consult with farmers in selected research sites in the An Giang Province.

- Participants were seven senior extension officers at the AEC
- Location: meeting room at the AEC
- The semi-structured questionnaire was used (Guideline 1)

The expected outputs of this activity were the identification of suitable farming systems. Based on these systems, experts at the MDI assisted with the adjustment of the theoretical model.

The focus group discussion at the MDI

The main purpose of this activity was to interact with experts at the MDI to adjust the theoretical model to the local situation. It was then called the Viet Nam, Mekong Delta model (practical model). This was done by removing, merging and nominating several factors and components in the AMS.

- Aims were to:
    - adjust the developed model;
    - develop a farmland capability classification system;
    - apply weightings and rate the importance of components and in the AMS in relation to the capability of farmland;
    - collect secondary data related to agricultural production and farmland capability in the An Giang Province and the research sites.
- Participants were five experts in soil science, crop science, agricultural economics, farming systems, and agricultural management (including farmland)
- Location: meeting room at the MDI
- The semi-structured questionnaire was used (Guideline 2)

The output of this activity was a model suited to the Viet Nam, Mekong Delta context for use in data collection and testing.

A key informant panel interview at the AEC

The main purpose of this activity was to work with senior extension officers at the AEC in data collection. The required data was based on the adjusted model and related to farmland capability, agricultural production, meteorology, hydrology, climate, the environment, and floods at the province and district levels.

- Aims were to:
    - collect actual conditions of the farmland at the research sites at the province and district levels
    - consider the status of agricultural production and farmland capability at the province and district levels
    - prepare for further data collection at the commune and farm levels (contact with farmers)
    - collect secondary data at the province and district levels
- Participants were five senior extension officers at the AEC
- Interview location: at participant's office or local community meeting house at the research sites
- The semi-structured questionnaire was used (Guideline 3)
- Five key extension officers (informants) who participated in the group discussion were invited to be interviewed individually. Semi-structured interviews were undertaken. The form of the semi-structured interviews was driven, to some degree, by a predetermined order but there was still flexibility to adapt to the real-time circumstances. As well as Guideline 3 outcomes, information regarding local issues, such as support policies and developed plans for agricultural production and farmland capability, were also considered.

The outputs of this activity were a set of data at the province and the district levels. These data were used for testing the Viet Nam, Mekong Delta model.

The group discussion in the selected communes in the An Giang Province

The main purpose of this activity was to work with extension workers, and to collect data at the commune and farm levels.

- Aims were to:
    - collect actual conditions of the land in research sites at the commune and farm levels
    - consider the status of agricultural production and farmland capability use at the commune and farm levels
    - collect secondary data at the commune level

- Participants were ten selected/experienced farmers and three senior extension officers at the province, district and commune levels
- Location: local community meeting house
- The semi-structured questionnaire was used (Guideline 4)

The output of this activity was a set of data at the commune level that was used for testing the Viet Nam, Mekong Delta model.

Farmer's individual interviews

The main purpose of this activity was to work with farmers (farmland users) for data collection. There were three types of farmer that were invited to be interviewed: rotational rice-vegetable farmers, rice farmers, and vegetable farmers.

- Aims were to:
  - collect actual conditions of the land in the research site at the farm level
  - consider the status of agricultural production and farmland capability at the farm level
- Participants were 30 farmers practicing the PFS for farmland capability determination in the local area. Selection of interviewees was done using a random sampling method under the PFS they were cultivating. The sampling and interviewing activities were facilitated by local experienced extension officers nominated by the AEC.
- Interview location: the farmer's house or at their fields
- The semi-structured questionnaire was used (Guideline 5)

The output of this activity was a set of data at the farm level that was used for testing the Viet Nam, Mekong Delta model.

6.2.5 Matching actual land characteristics with land use requirements

The activity of farmland capability analysis was undertaken by matching the actual value of the land characteristics, obtained by the land investigation, with land use requirements, to determine the initial farmland capability. First, the actual value of each land characteristic (class-determining factor) was compared with the capability standards in the farmland capability classification system. This system was designed as part of the theoretical model and adjusted by experts, in order to identify the capability class for each land characteristic. The comparison task was conducted the same way for all adjusted farmland characteristics. These capability classes were then converted into scores, as presented in Table 6.5.1.

Table 6.5.1: Actual value classifications for capability classes and indices

Capability classes	Scores	Capability indices
Very high	9	> 7.5
High	7	7.5-6.1
Moderate	5	6.0-4.6
Low	3	4.5-3.0
Very low	1	< 3.0

Scoring was based on the AHP technique (Saaty and Vargas, 2001; Saaty, 2002)

The next step was determining the capability of farmland by examining the adjusted components and factors in the AMS. Specifically, the weighting of the components and factors, and the actual values of factors were integrated and analysed. The capability of farmland was determined through the capability index using the following equation: (1): $Ci = \Sigma((W_i * w_j)*s_i)$, where Ci is the overall capability index, W_i is the weighting of components in the AMS (i=1-n), w_j: is the weighting of factors (in components) in the AMS (j=1-n), s_i is the score of factors in the AMS. The process of land capability analysis is summarized in Figure 6.4.1.

In the case study, the equation of the farmland capability index varied depending on the number of factors considered in each component and the components considered in the AMS at different scales e.g. district, commune, or farm. Therefore, equation (1) can be illustrated in detail by Figure 6.4.2, Table 6.5.2, and the equation (2):

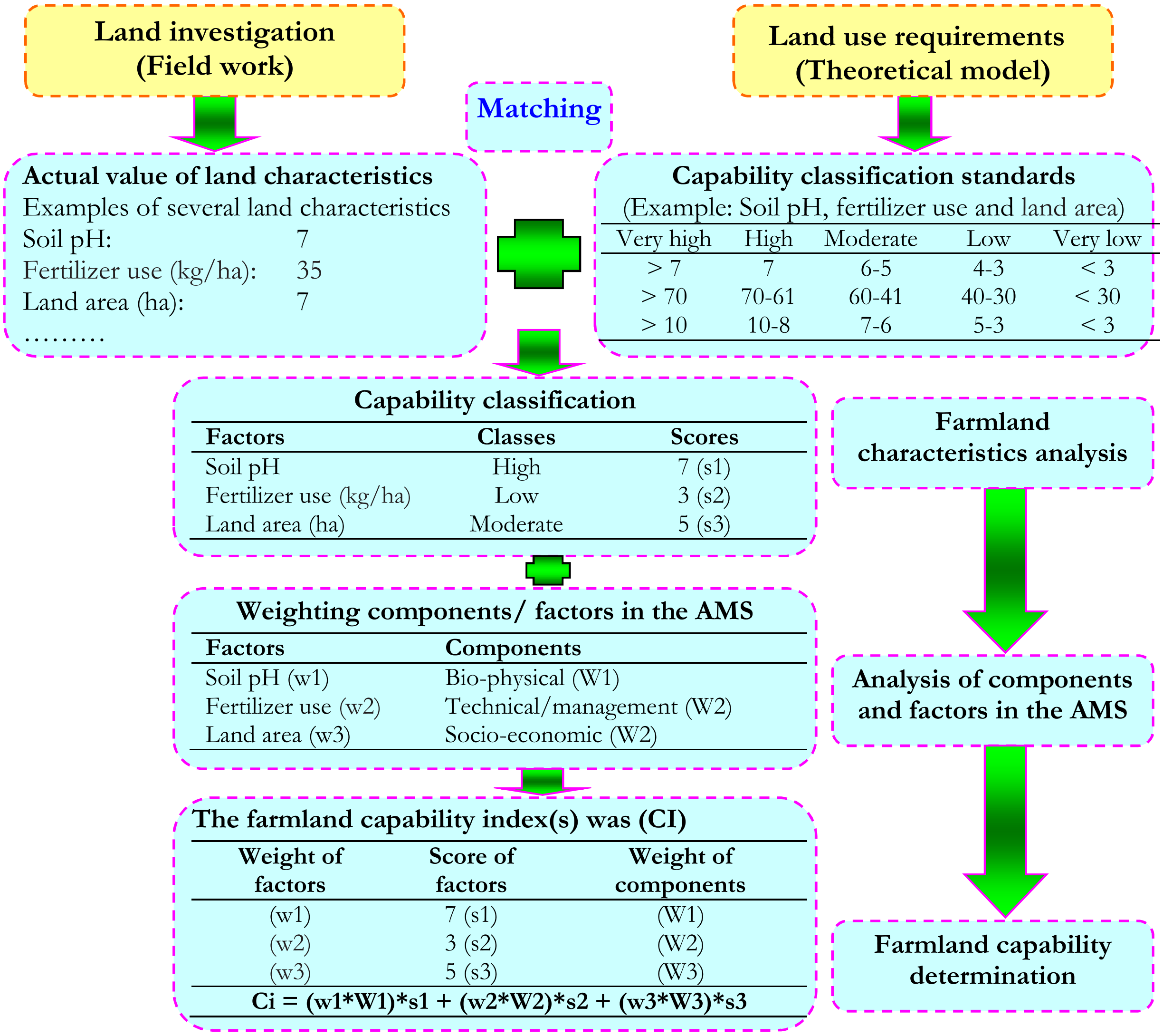

Figure 6.4.1: Flowchart of farmland capability analysis using AHP

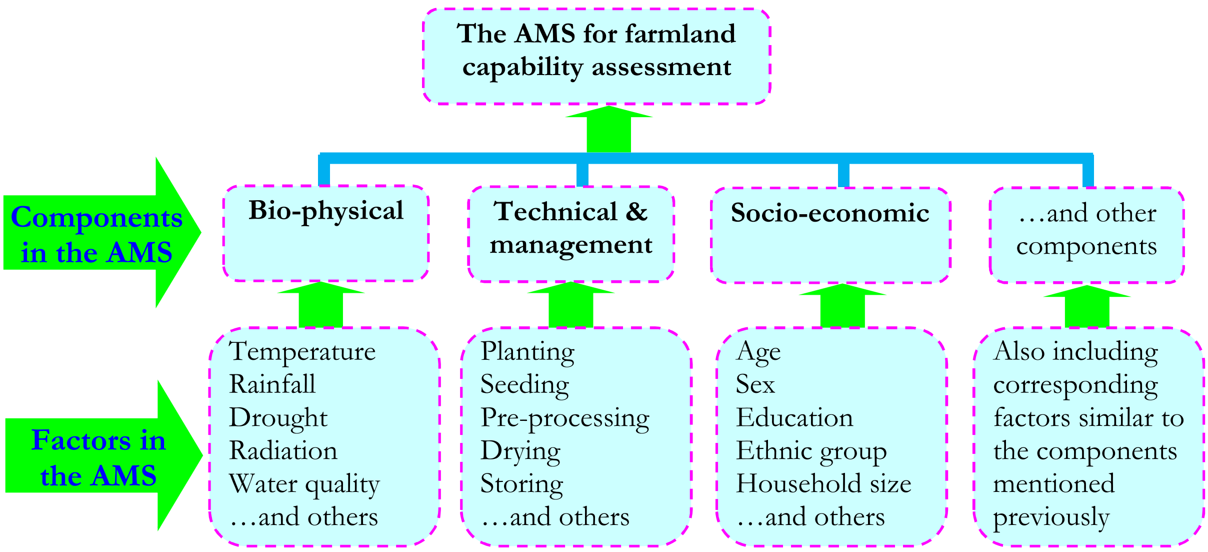

Figure 6.4.2: Flowchart of factors and components undertaken in the AMS for farmland capability assessment

Table 6.5.2: Illustration of factors and components in the AMS and their weightings/scores for calculating the farmland capability index

Components	Factors	Component weightings (W)	Factor weightings (w)	Factor scores (s)
Bio-physical		**W1**		
	Drought duration		w1	s1
	Inundation duration		w2	s2
	…others			
Technical & management		**W2**		
	Seed sector		w3	s3
	Mechanisation		w4	s4
	…others			
Socio-economic		**W3**		
	Labour-force		w5	s5
	Production cost		w6	s6
	…others			

The equation (2):

$$Ci = (W1*w1)*s1 + (W1*w2)*s2 + (W2*w3)*s3 + (W2*w4)*s4 + (W3*w5)*s5 + (W3*w6)*s6$$

Capability indices of the AMS were then converted into capability classes (such as very high, high, moderate, low, and very low capability) to generate the initial farmland capability maps. Ultimately, the farmland capability maps were presented using the GIS tool. ArcGIS 9.0 was the actual software used for the analysis of the thematic layers of the study area map; and MapInfo 9.0 software was used for the analysis, storage, query, export, and conversion of the GIS data collected from various sources.

During the farmland capability analysis, thematic maps represent evaluation criteria where alternatives such as very high, high, moderate, low, and very low capability are used to indicate the degree of capability with respect to the criteria. The importance of these classes to the final goal (capability) was obtained from the results of applying weights and the rating criteria as presented. The application of a GIS to farmland capability analysis and the presentation of farmland capability maps, are shown as Figure 6.5.

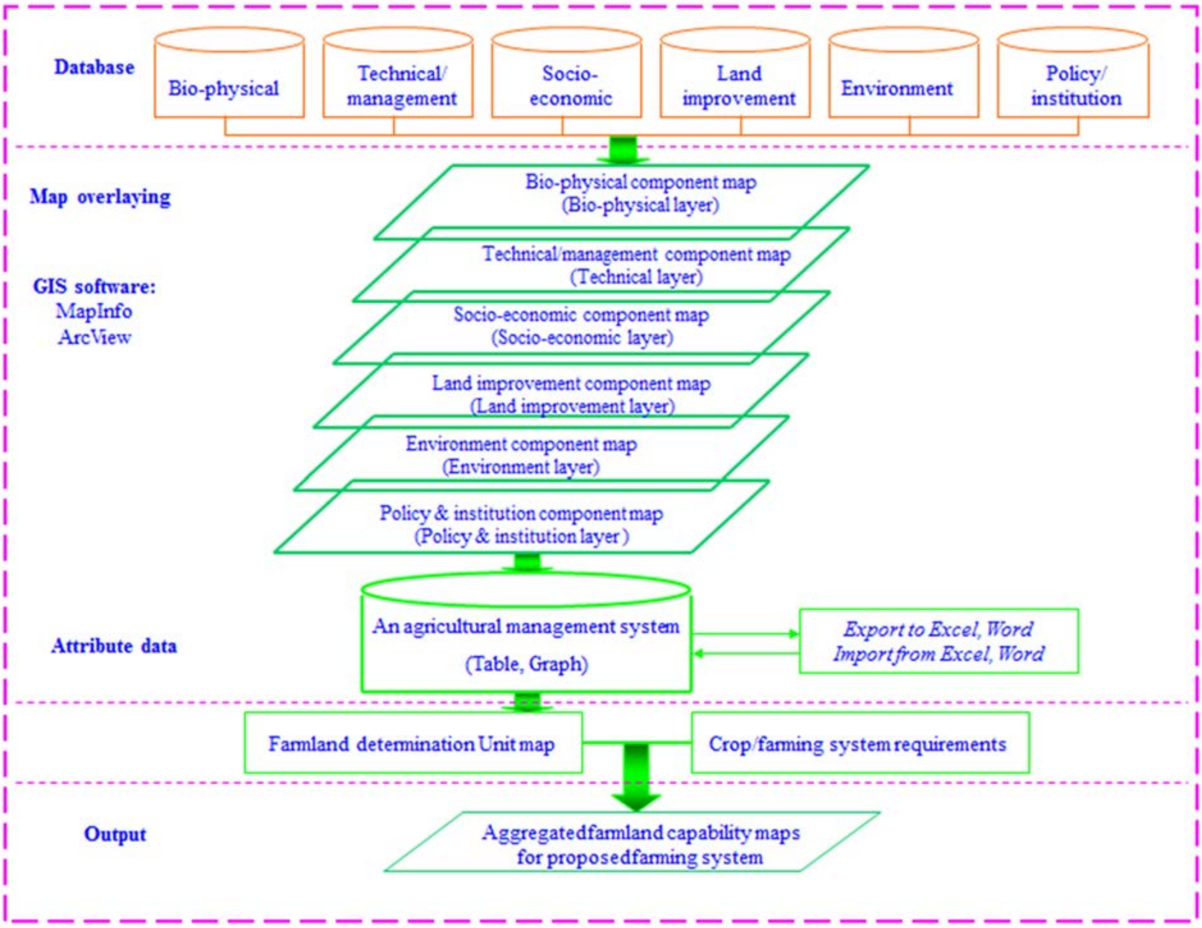

Figure 6.5: Flowchart of farmland capability analysis using a GIS

6.2.6 Indices modelling to improve the capability of farmland

The farmland capability has just been determined, ranging from very low to very high capability for the PFS. It is a capability based on aggregated factors and components in the AMS. This means that those factors that have a low on-ground capability value result in a poor capability for the farmland. Therefore, to improve the capability of the farmland, the value of limiting factors need to be increased.

First, factors limiting to the capability of farmland were isolated. The actual on-ground value of each limiting factor was then modelled by introducing feasible solutions, which were expected to upgrade the capability of the farmland. For example, a value of the average annual rainfall (AAR) of 40mm leads to a low farmland capability for irrigated rice production in the An Giang Province. The farmland capability for rice is expected to increase (high capability) when the AAR is ≥ 100mm, and in this case several feasible solutions could be proposed such as cultivating rice between June and October because the AAR between June and October is > 100mm, or alternatively additional water could be supplied for rice production if it is cultivated in other months.

The importance of the limiting factors and the priority of feasible solutions for farmland capability improvement were categorised using the AHP tool. The purpose of this is to highlight that the increase in farmland capability can only be achieved when limiting factors were improved.

Ultimately, the expected farmland capability maps were generated by introducing modelled values for limiting factors and rematching modelled farmland characteristics with the land use requirements. These modelled farmland capability maps were stored, managed and screened using the GIS tool.

6.3 Summary

In summary, the case study included six main steps. First, suitable farming systems were identified by local agricultural experts. Base on that, the theoretical model was adjusted and modified; the farmland capability classes were standardised to suit the local context. Third, factors in the AMS were revealed in term of impacting upon the farmland capability. Then, farmland investigation and field survey activities were undertaken to obtain actual land characteristics. The next step was farmland capability analysis based on actual land characteristics and the land use requirements of land utilization types. Finally, the values of actual land characteristics were modelled to improve the farmland capability, and then the final farmland capability maps were generated.

CHAPTER 7: FINDINGS FROM THE THEORETICAL MODEL ADJUSTMENT AND CASE STUDY IMPLEMENTATION

7.1 Introduction

Developing a theoretical model for the Agricultural Management System (AMS), to determine the land capability, and for testing the developed model, is the ultimate objective of this study. This chapter presents the results of converting the theoretical model design to an applied model design where three farming systems, five administrative scales and different aspects of land capability are proposed. Continuously, the chapter reports on important components and factors involved in the AMS for land capability assessment, at selected scales, and for selected farming systems. It then describes the impact of specific factors on different aspects of land capability, as well as determining reasonable classes for the land capability classification and the standardised capability value for factors. Further, the weight, and importance, of those components and factors in contributing to the land capability are determined. Then, land capability analysis is undertaken by comparing actual land characteristics with land use requirements. The land capability is then mapped by using a GIS. The final section in this chapter is devoted to modelling the land capability and introducing feasible solutions to modify and improve the land capability in the study area.

7.2 Results of converting the theoretical model to a practical model

7.2.1 Proposed farming systems for land capability assessment

Land evaluation can be comprehended as the process of assessing land performance when used for specified purposes (FAO, 1985). It is a method used to explain, or predict, the utilised potential of land (Van Diepen *et al.*, 1991). Once land potential is determined, land use planning can proceed rationally, at least with respect to the capability of the land resource (FAO, 1993). The underlying principles in the study of land evaluation reveals that the land capability is based on specific land uses, and a specific land use is defined in more detail as a farming system (FAO, 1985).

Land capability assessment forms the central part of land evaluation in general, and defining alternative land uses is the first step in land evaluation (FAO, 1976; FAO, 1985; FAO, 1993; The State Planning Commission, 1989; Hashim *et al.*, 2002; Ritung *et* *al*., 2007; Rahimi Lake *et al*., 2009; Fu, 1998; Giap *et al*., 2005; Son, 2005; Thapa and Murayama, 2008; De la Rosa and Sobral, 2008). Nomination of suitable farming systems is the first activity in the current study, and then the theoretical model is modified to suit each farming system. This is one of the key steps in land evaluation (FAO, 1976; 2007b). The nomination depends on the specific purposes and objectives of the land evaluation in various localities, as well as the objectives of a project or study.

Overall, farming systems in the Mekong Delta, and specifically in the research area, are diverse and vary from place to place. Each farming pattern has specific requirements, which are dependent on cropping season, topographic condition, and a farmers' cultivation customs. The natural conditions in the Cho Moi District (i.e. the study area) are suitable for the development of rotational farming systems. In particular, biophysical and climate features, for example, fresh water source, annual average temperature, sunshine hours, humidity, and soil properties are suitable for annual crops, including rice, vegetables, corn, and spices (Cho Moi Department of Agriculture and Rural Development, 2009).

Agricultural production is the act of utilising the land resources to create products for human consumption. Therefore, production combines both the land characteristics, including land qualities, with human attributes. Production potential is based on the land capability and investments, such as materials and outside services that are employed by land users. In other words, farmers who decide the types of land use and the land use characteristics, directly impact on the land capability and the viability of farms. Farmers in the Cho Moi District have experience in well-established cultivation habits, and skills to grow rice and vegetables, as many generations have relied mainly on those crops for their livelihood. This is one of the most important criteria to ensure the prosperity of farms because the success and efficient use of the land resources in the Cho Moi District are influenced by the farmers attributes.

According to the results of secondary data analysis and field investigation, rice (paddy) and vegetables are the most popular systems, for annual cropping in the Cho Moi District. To support this observation, reports on present land use, and future land allowance, used for land use planning to 2015, in the Cho Moi District (Cho Moi Department of Agriculture and Rural Development, 2009) show that the majority of land areas are used for rice and vegetables production.

In the study area, rice and vegetables have played an important role in creating income, job opportunities, and diversified diets, for local inhabitants. Moreover, these crops also ensure hunger elimination, reduction in poverty, food security, as well as contributing significantly to the local GDP and economic growth.

Until recently (2010), there has been no systematic land capability assessment for single rice and vegetable, or the combination between rice and vegetables systems in the Cho Moi District. The latest land evaluation was undertaken in 2005 as an agricultural overview and focused on physical land suitability (DNRE, 2006). Due to market pressures (agricultural product consumption), farming systems here are constantly rotating and changing. Farmland capability determination for monoculture and rational farming systems are needed at the local level.

After careful consideration of the specifications of farming systems, such as economic efficiency, share of planted area and future development opportunities, the land management experts verified that three major systems comprising rotational rice-vegetables, mono rice, and vegetables, are suitable for farmland capability assessment (testing of the model).

The verification is aligned to the fundamental principles of land evaluation in that land assessment involves the analysis of more than a single land use. The assessment has significance if the land capability for any given use can be compared with at least one, and usually several different, alternative uses. If only one land use is considered then there is the danger that, while the land may indeed be capable, or non-capable, for that use, some other more beneficial use may be ignored (FAO, 1976, 1985, 1993, 2007b).

Factors in the model design would be built in to the AMS to determine the land capability for selected farming systems. When the model is refined to work well on rice and vegetables, it can be flexibly applied for many other crops because rice and vegetables systems contain the most important attributes and characteristics of agricultural systems in the research area. Furthermore, the results of testing the model on single and rotational farming systems will disclose to land users which capability levels apply to their land resources. Associated with and depending on ownership, farmers can improve the farmland capability, or select relevant alternatives, to maximise their outcomes from land resources. Thus this critical evidence can be used by land managers in the local area to allocate land use.

7.2.2 Proposed scales for land capability assessment

Land evaluation involves multi-dimensional analysis drawing on disciplines related to soil, climate, socio-economics, and the environment. The analysis can be carried out at different scales, from field (farm), provincial, regional, to the national scale (Bouman *et al*., 1999; Giampietro *et al*., 2009). Objectives will be different at each of these scales, but common outputs are designed to show the appropriate potential of the land at corresponding scales.

The results of land evaluation at the local farm scale will show the gaps and limiting factors of the land potential, thereby identifying desired solutions used in turn to amend and improve the land use. Land evaluation at the regional scale offers an overview of the land potential that is vital in land development and land use planning.

The concepts of "land capability" and "land suitability" described in the literature review, refers to capability as the inherent capacity of the land to perform at a given level for a general use, rather than the adaptability of a given land area for a particular land use type. Therefore, land capability classification gives a grading of land for broad scale agricultural uses. Whereas land suitability is an assessment of the fitness and the degree of appropriateness of a given type of land for a specified kind of land use (FAO, 1976; 1993; Rowe *et al*., 1981; The ACT Parliamentary Counsel, 1999; Verheye, 1996; Choudhury & Jansen, 1998).

Land capability and land suitability have a close relationship. Land suitability considers how suitable a particular site is for a specific use, and this depends on the land capability and a range of other factors such as proximity to centres of population, land tenure, and consumer demand (The ACT Parliamentary Counsel, 1999; Grose, 1999).

Often, land evaluation is undertaken by determining the land suitability considered according to land mapping units (land units) (FAO, 1976; 1985; 1993; Baniya, 2008, Trung, 2006; D'haeze *et al.*, 2005; Giap *et al*, 2005), which refer to an area of land demarcated on a map and possessing specified land characteristics and land qualities (FAO, 1976; 1993). On the other hand, land use planning is applied to administrative units at the local to regional level (FAO, 1993; Bouman *et al.*, 1999; Rowe *et al.*, 1981). Of course, the objective of land suitability evaluation is to determine adaptability of given land units to a specific land utilisation type by comparing soil properties and land qualities with land use requirements, whilst planning focuses on land use, which relates to human activities and social attributes. In other words, the management of land to meet human needs (FAO, 1993).

The results of land suitability evaluation show which lands are suitable for specific use types. The results are useful for rational land use planning because land evaluation is part of the land use planning procedure (FAO, 1993). Nevertheless, land evaluation doesn't decide the plan for using the land. Planning has to consider many related aspects, and most important is the socio-economic development policies, the trade-off between environmental and economic benefits and the sustainability of land utilisation types as well.

Similarly, many previous land evaluation studies in the Mekong Delta also followed the Land Units (LUs), for specific Land Utilisation Types (LUTs) (Trung, 2004; 2006; Minh, 2003a; 2003b; Son *et al.*, 2008). By this means, land evaluation concentrates mainly on the physical aspects because LUs are mapped based on natural, physical land characteristics, or qualities, such as soil type, inundation level, salinity distribution, etcetera. So, to obtain adequate information for land use planning, results of land evaluation need to be combined with supplementary information based on socio-economic, institutional and policy considerations at different administrative scales.

The goal of this study is to test an agricultural management system (model design) developed to determine the land capability. The model design includes not only land suitability; it also covers a range of fields contributing to the land capability e.g. socio-economic and policy, technical and management. With the goal in mind, and after much discussion on "suitability and capability", a group of land use experts unanimously agreed that land capability assessment, in the current study, should be done using administrative scales, instead of by land units as done previously in the area.

In Viet Nam, the Land Law (2003) stipulates that present land use be revised every five years and land potential evaluation, and land use planning, be conducted every ten years. Empirically, land evaluation is expedited according to land mapping units (land units), and those conducting the study are mainly land experts from the Ministry of Natural Resources and Environment (or provincial experts within the same disciplines). The land use planning process at the national level (master plan) is organized and conducted by the Government, with the final decision maker being the Prime Minister. The local planning process (detailed plan) is done by the provincial people's committee, in accordance to administrative levels, from the province to the commune. Land experts in land use planning procedure are used as consultants.

Interestingly, the lowest administrative unit (level) in Viet Nam is the commune. The criteria for creating the boundaries between communes are based on socio-economic traits, such as population, number of households, infrastructure (hospitals, schools, markets, and roads), total land areas, geographic position, and local policy (Law on Government Organization, 1992). In positioning the administrative boundary, land potential and land units are not considered. Besides, due to the high population density (Mekong Delta: 436 persons/km^2; An Giang: 636 persons/km^2, GSO, 2008), several communes in the study area are located in the same land unit. Therefore, land capability assessment in this study by administrative units (scales) is more applicable than by the land unit.

The latest studies in the Mekong Delta showed that evaluating agricultural land capability by administrative units is also effective for land use planning (Bon, 2010), particularly where physical land conditions complement the land use types. In this area, the market pressure in consuming agricultural products is an emerging issue, and land potential needs to be considered in multi-disciplines such as socio-economic, technical and management, rather than focusing only on physical parameters. In this case, land evaluation by administrative unit is proposed.

To illustrate this, Hang (2010) conducted research relating to participatory land evaluation and land use planning in the Tra Vinh Province (Mekong Delta). The author defined that any land areas classified as high capability (suitability) were those where farming systems practiced on the land give the highest economic efficiency. Rice, watermelon, and several vegetables were systems proposed for land evaluation.

The results showed that the weight of technical and socio-economic criteria (factors) is heavier than the weight of physical criteria in the land evaluation procedure. The explanation was due to the actual physical land qualities including soil properties, water availability, rainfall, temperature in Tra Vinh being very good for growth of selected crops, therefore limitations from physical land qualities are not considered significant.

Whereas, other factors such as seeds (technical), years of experience, land areas (management), educational standard, market and credit accessibility (socio-economic) can have significant limitations to the economic efficiency of selected crops. The land evaluation objective is to determine limitations so that the land capability can be increased by the introduction of external inputs and solutions. As a result, local stakeholders encourage land evaluation and planning by administrative units because available information on those fields, at the administrative scales, is more applicable than at land units. The selection of administrative scales and boundaries for land capability assessment may face with difficulty if the commune covers many land units with distinct characteristics. It is because the difference of land characteristics between land units within the commune. In this case, the selection of administrative scales or land units for land capability assessment needs to be carefully considered.

In the model design, there were five administrative scales proposed. These scales are province, district, commune, hamlet, and farm. After adjustment by modifying the theoretical model to suit the local context for testing, the practical model has three selected administrative scales: district, commune, and farm.

District scale: is at a regional level. At this scale the land capability is determined for the overall land use types (e.g. temporary crops, rain-fed crops). Important components involved in land evaluation are land development and environment, and socio-economic and policy. Land managers at the district level have the legal right to allow land users to change or not, within and between their land use types. Any land evaluation, land use planning, policies on land capability improvement, land remuneration and allocation, land lease and transfer are also proposed and expedited from this level. The district level is the level at which the Government controls most issues related to land management, and land users cannot access land managers at the district level to discuss and negotiate matters related to their land resources.

Commune scale: is at the local level. At this scale the land capability is determined for specific farming systems (e.g. intensive rice, intensive vegetables). Components that are crucial in land evaluation are bio-physical characteristics, land development and the environmental factors. Land managers at the commune level, are intermediaries and consultants for land users and land managers at higher levels (district, province) such as at the district level. Land users can easily access land managers at the commune level to negotiate any issues related to their land resources.

Farm scale: is the lowest production unit (patch) for expediting the land capability through specified land utilisations. The impact of factors in the AMS on the land capability is very clear and specific for each farm. The greatest concern of land users at this scale is how to maximise their land capability through technical interventions. The most important components in the AMS for land capability assessment are technical and management in nature. Performance of the land at the farm level is dependent on the land users' attributes. Land users actively use the land, change their land use types, and improve their land resources in accordance to the land law legislated by the Government.

The application of the three administrative scales in the process of farmland capability determination, for different land utilisation types, will be discussed in detail in the following sections of this chapter.

7.2.3 Land capability consideration in land assessment

According to the UNEP (2002), land refers not only to soil, but also to plants, animals, landforms, climate, hydrology, geology, topography, vegetation systems and fauna, together with the socio-economic attributes, the human settlement pattern and physical results of past and present human activity (FAO, 1976; 1985; 1993; Rowe *et al*., 1981; Rossiter, 1996; The State Planning Commission, 1989; FAO/UNEP, 1997; Sombroek, 1996; and FAO, 1995). Thus the use of lands is directly affected by bio-physical, socio-economic, and environmental factors.

The view, of land and land resources, above asserts that the capability of land is determined from knowledge that is integrated from multi-interactive disciplines. So the land capability needs to be examined using many aspects. Referred to in previous studies (Chuong, 2007; Rossiter, 1995; Samranpong *et al*.; Bouman *et al*., 1999), and the literature review (FAO, 1985; 1993; 2007b; Mohamedl *et al*., 2000), associated with land evaluators, and agronomists' knowledge, three core aspects of the land capability are a concern in the practical model:

(1). Productive capability (productivity, crop yield);
(2). Economic capability (net income, profits);
(3). Sustainable capability (environment).

To clarify, a land area is classified as high capability for a certain farming system, when the system (crop) can give maximum yield and maximum net income (profits) from this area. Moreover, the system can be sustained for a long time, and has minimal damage and negative impacts upon the environment.

Land capability in this study requires that selected components and factors in the AMS be classified as one of three capability aspects: productivity; economic sustainability; and environmental sustainability. Factors that have no influence on the land are ignored.

7.2.4 Selected components for land capability assessment

Land resources can be deemed to support sustainable land use after the capability assessment has been considered from the point of view of the economic, the societal, and the environmental goals. The relevant issues and impact indicators of the sustainability of land use systems need to be identified and assessed (Walter and Stutzel, 2009a; 2009b). A careful balance of those issues is a required principle in land capability assessment.

The FAO (2007b, p. 3) expresses two trends that land evaluation experts need to concern themselves with, to integrate the best methods for land evaluation. The first is recognition of the larger functions and services of the land. Land performs a multitude of key environmental, economic, social and cultural functions, vital for life. The second is the growing recognition given to stakeholders, ranging from international and regional organizations, national governments, non-governmental organizations and commercial organizations to, most importantly, villages, rural communities and individual farmers and other land users.

Moreover, each technique or method of land capability evaluation is associated with different specific principles, which depend on local objectives and specific conditions. However, the FAO (1976, 1985, 1993, 2007b), as well as by Rowe (1981), Rossiter (1996), Ritung *et al.* (2007), and The State Planning Commission of Western Australia (1989) have integrated and refined the following general principles in land evaluation.

- Land capability assessment must consider all relevant land characteristics including soils, climate, topography, water resources, vegetation, farming systems, technical, management, socio-economic conditions, and infrastructure;
- The main objective of land assessment is to predict the benefits to and prosperity of farms, in the local area and the region, where the benefits and prosperity can be sustained without damage to the environment;
- Assessments should be undertaken in terms of the biophysical, technical, economic, social and political context of the area concerned**.** The political context is a macro-issue; it sometimes is changeable and suitable at a regional scale only.

The structure for selecting key components in the AMS, to determine the land capability, is based on the land evaluation principles presented above, and with respect to the three administrative scales (district, commune, and farm) and the three farming systems, which have been selected for the study area.

In the theoretical model outlined in Chapter 4, six major components were considered: (1). biophysical, (2). technical and management, (3). land development and improvement, (4). conservation and environmental, (5). socio-economic, and (6). institutional and policy. Every component encompasses many different factors which influence the land capability. A focus group made up of local experts in the study area analysed the principles of the land evaluation, in order to adjust and modify the model design. The feedback was, that no additional components needed to be nominated for the AMS because the six existing components in the AMS covered most land characteristics that were needed for land evaluation.

However, to suit the research area context, several components needed to be revised and amended. The "bio-physical", "technical and management" components did not change because they were suited to the study area context. The "land development and improvements", and "conservation and environmental" components were merged to become the "land development and environmental" component. Also, the "socio-economic", and "policy and institutional" components were merged to form the new "socio-economic and policy" component.

The modification and adjustment of the components was based on the focus group agreement and the contribution of each component to the land capability, as well as the number of factors each component contained. Components such as land development, improvements, conservation, and the environment consisted of minor factors, and in some case these factors overlapped. The purpose of this study is to clearly identify the individual importance of every factor in relation to the land capability. Thus, the selection of components for the practical model, to determine the land capability, should be clear and appropriate.

The policy and institutional component has a great influence on land use but not much influence on land capability. Alternatively, the socio-economic component impacts substantially upon the land capability, and has a close relationship with the institutional and policy component. So, in this research project, the policy and institutional component has been merged with the socio-economic component.

The purpose of adjusting and modifying components in the AMS is to create a new model that suits the Viet Nam, Mekong Delta conditions (practical model), and to make sure the model design works efficiently. After adjustment, the main components below were included in the practical model:

(1). Bio-physical

(2). Technical and management

(3). Land development and environment

(4). Socio-economic and policy

Within each selected component, factors were revised and modified.

7.2.5 Selected factors for land capability assessment

Defining land use requirements is essential in land evaluation, and they are in turn described by the land qualities needed for sustainable production. A land quality is a complex attribute of land that has a direct effect on land use. Most land qualities are determined by the interaction of several land characteristics, measurable attributes of the land (FAO, 1993). Selecting important and suitable factors in the AMS is a vital step to convert the theoretical model design to the practical model, by identification of land use requirements. The land capability is displayed by matching actual land characteristics with land use requirements.

The principles underpinning the selection of factors in the practical model were based on selected farming systems, examined aspects of the land capability, and proposed land evaluation scales. During the selection of factors, the knowledge of local land experts, with respect to the research area, was used to determine the key criteria to be used for the land capability assessment.

From their in-depth knowledge of the study area, land experts advised that the factors in the AMS relevant to the practical model, must meet the following requirements:

(1). Significant and direct impact upon the land capability in terms of productivity, economic efficiency, and the environmental sustainability. The impact has considerable limitations (causes difficulties, obstacles, constraints), rather than being advantageous and supporting the land capability. The land capability will be improved and increased when the current and potential limiting factors are amended. Many factors such as "solar radiation, annual average temperature, annual average rainfall, annual average humidity, water quality for irrigation" have significant impacts upon the farmland capability. However, upon investigation it was found that the actual values of these factors in the research area do not limit the land capability, therefore they were not considered in the practical model;

(2). Actual values of factors (actual land characteristics) clearly differed between locations (from place to place), for example, one commune to another commune, one farm to another farm. This was because when communes and farms have the same land characteristics, the land capability assessment doesn't vary significantly. This means the practical model could not work efficiently;

(3). The impacts of factors upon the capability of farmland must be measurable, or predictable (by known indicators).

Factors that did not satisfy any of these three requirements above were not considered in the practical model for determining the land capability. Overall, a majority of factors were not considered, primarily because of requirement (1), whilst a minority, were not considered because of requirements (2), and (3) (*see Appendix 7*).

An important consideration was that the universal set of factors for land evaluation should not be recommended because every study site required different land indicators. The theoretical model was designed for universal application, while the factors selected in the practical model respected a specific context. Certain factors were not considered in the practical model mainly because they were not deemed suitable for the study area context. This explains why the FAO (1976, 1985, and 1993) recommended that the framework for land evaluation not be treated as a universal method; it should be flexibly applied, based on specific conditions. Further, criteria for land evaluation are then considered to be dependent on local area conditions.

The selection of factors for land capability assessment is undertaken according to specific scales (i.e. district, commune, and farm) and according to farming systems (rotational rice-vegetables, single rice, and single vegetable). Several factors were selected because they suited these scales and farming systems. In contrast, some others were not selected because they did not satisfying a specific scale, or and farming system. Along with factor selection, the numerical value assigned to each factor was adjusted, and clarified to ensure that the influence of each factor on the land capability could be measurable. Indicators to measure the impact of factors upon the land capability measurable units of factors were defined and verified, for each scale and farming system. Moreover, description and interpretation were carried out to clarify and define qualitative factors.

For example, "irrigation system" refers to systems of controlled applications of water to supplement the selected farming systems (FAO, 1985). Particularly, "drainage system" refers to the oxygen availability management, indicated by the speed of water infiltration or the soil condition describing the duration and level of water saturation and inundation (Ritung *et al.*, 2007, p.5). In this study, factor "irrigation and drainage system" is defined as infrastructure, or facility systems (conditions) used for water supply and sewerage (for fields) in the local area. At the district and commune scales, it was defined through a qualitative evaluation and was mainly based on the percentage of estimated farmland areas having complete irrigation and drainage systems. At the farm scale, it was defined based on the costs that farmers pay for water supply and sewerage. Detail interpretation of indicators, and measurable units, of factors, is presented in Appendix 8.

Results in Table 7.1 show that factors in the practical model vary between administrative scales. Several factors are used for all three scales, while some others are used for only one or two scales. Nominating factors for each scale is based on their suitability to the scale. The aim is to measure accurately the actual value of every factor at the relevant scale. In principle, selecting appropriate factors for a specific scale will result in significant and correct results in land evaluation at that scale. To illustrate this, the factor "distance from the house to farms" cannot be suitable for the district scale, because it is very difficult to measure the average distance from the house to farms for all the households in the district. Furthermore, it doesn't impact on the farmland capability at the district scale. Hence, this factor is proposed only for the farm scale because it is easily measured, and it makes an important contribution to the farmland capability at the farm scale.

Table 7.1: Components and factors selected in the practical model

No	Components and factors	Administrative scales		
	1. Bio-Physical component	District	Commune	Farm
1	Common pests	☑	☑	
2	Annual dry/drought period	☑		
3	Annual inundation period	☑		
4	Irrigation and drainage system	☑	☑	☑
5	Aeration condition		☑	
6	Available nutrients		☑	
7	Flood level	☑		
8	Availability of transport facilities		☑	☑
9	Traffic system	☑		☑
10	Distance from house to farms			☑
	2. Technical and management			
11	Seed sector	☑	☑	
12	Seed quality for cultivation			☑
13	Land preparation technique			☑
14	Planting technique			☑
15	Pre-processing technique			☑
16	Storing technique			☑
17	Drying technique			☑
18	Fertilizer and insecticide use management			☑
19	Applied ability of mechanisation	☑	☑	
20	Water and pest management	☑	☑	
21	Farm size			☑
	3. Land development & environmental			
22	Flood control ability	☑	☑	
23	Irrigation engineering (construction)		☑	
24	Long-term salinity, landslip, landslide	☑		
25	Environmental hazards	☑		
26	Environmental control ability	☑	☑	
	4. Socio-economic and policy			
27	Livelihood opportunities for farmers	☑	☑	
28	Labour-force (for farming activities) in the local area		☑	
29	Production costs	☑	☑	
30	Membership of any social organizations			☑
31	Farming experience/skills of farmers			☑
32	Farmers' accessibility to agricultural services		☑	☑
33	Credit allowance for farmers		☑	
34	Laws for natural resource management	☑		
35	Policies used for agricultural production consumption	☑		

At the district and commune scales, many factors in the technical component are not considered. While at the farm scale, no factors in the land development and environmental component are selected. The different participation of factors in the practical model between scales shows that the land capability determination and its consideration vary from scale to scale. The land assessment in the current study provides a thorough systematic overview of the land capability because it is implemented from the district to the farm scale.

7.2.5.1 Factors' contribution to the land capability

The farmland capability is manifest by the success of the farming systems and the prosperity of farms. Factors that are selected in the practical model for determining the farmland capability relate to one of the three capability aspects of farming systems (productive, economic, and sustainable). Table 7.2 reflects that the economic potential of farming systems is the main concern in the study area. Many factors are proposed in the practical model because they indicate the economic potential. The productive potential is also vital and it is the second most important potential, contributing to the ultimate economic potential. If a certain farming system has a high productive potential, it is expected to also have a high economic potential.

The sustainability of farming systems when studied on specific land also is perceived as a compulsory capability criterion in land evaluation. In this study, the sustainable capability of farming systems is indicated by their environmental impacts and development potential. The integration of the productive, economic, and sustainable capability of farming systems into the AMS allows the farmland capability to be evaluated by multi-disciplinary fields. As a result, by considering and analysing relationships and interactions within, and between, those capability aspects suitable solutions for increasing the land capability can be determined.

Table 7.2: Land capability aspects that factors impact upon

No	Factors in the practical model	Capability aspects		
	1. Bio-Physical	Productive	Economic	Sustainable
1	Common pests	☑	☑	
2	Annual dry/drought period	☑	☑	
3	Annual inundation period	☑	☑	
4	Irrigation and drainage system	☑	☑	
5	Aeration condition	☑	☑	
6	Nutritional availability	☑	☑	
7	Flood level			☑
8	Availability of transport facilities		☑	
9	Traffic system		☑	
10	Distance from house to farms		☑	
	2. Technical and management			
11	Seed sector	☑	☑	
12	Seed quality for cultivation	☑	☑	
13	Land preparation technique	☑	☑	
14	Planting technique	☑	☑	
15	Pre-processing technique		☑	
16	Storing technique		☑	
17	Drying technique		☑	
18	Fertilizer and insecticide use management			☑
19	Applied ability of mechanisation	☑	☑	
20	Water and pest management	☑	☑	☑
21	Farm size		☑	
	3. Land development & environmental			
22	Flood control ability			☑
23	Irrigation engineering (construction)		☑	
24	Long-term salinity, landslip, landslide			☑
25	Environmental hazards			☑
26	Environmental control ability			☑
	4. Socio-economic and policy			
27	Livelihood opportunities for farmers			☑
28	Labour-force (for farming activities) in the local area		☑	
29	Production costs		☑	
30	Membership of any social organizations		☑	
31	Farming experience/skills of farmers	☑	☑	
32	Farmers' accessibility to agricultural services	☑	☑	
33	Credit allowance for farmers		☑	☑
34	Laws for natural resource management			☑
35	Policies used for agricultural production consumption		☑	☑

Factors selected in the practical model are related to various farming systems, and administrative scales. Factors for rice cultivation differ from factors for vegetables. Factors at the district scale vary from factors at the commune and farm scales. In this study, land capability at the district scale was considered for general utilisation purposes in relation to agricultural production, mainly concentrating on temporary crops. However, land capability at the commune and farm scales were determined for more specific farming systems, such as rotational rice-vegetables, rice, and vegetables.

In fact, identifying capability aspects and selecting factors in the AMS for land capability assessment were done simultaneously. First, factors that have an influence on the land capability for at least one of the three defined capability aspects are considered, and then the final selection is made when those factors satisfy essential requirements (1), (2), (3) as presented in the previous discussion section.

7.2.5.2 Determination of dominant factors

Land evaluation is the process of predicting land capability and performance in given areas according to specific types of use (Rossiter, 1996). Land capability results are categorised as classes from high to low capability. According to the FAO (1985), Baniya (2008), during the process of ranking land suitability, it is necessary to identify dominant factors; these are called as class-determining factors (criteria), FAO (1985). They are decisive and irreplaceable factors in land evaluation, for example: soil type, terrain, topography, depth of land layers.

Dominant factors play a decisive role in land suitability classification. When a dominant factor has the lowest potential (meaning highest limitation) level, the land potential is ranked at the corresponding level, for example: if a dominant factor is at S3 (Marginally Suitable), the other factors are at S2 (Moderately Suitable) and S1 (Highly Suitable), then the suitability level is ranked S3. Other factors, which contribute to the land potential but only marginally affect the land suitability ranking, can be grouped as ordinary ones (FAO, 1985).

Several land evaluation studies use dominant factors as the limitations to rank the land suitability classes. This is easily understood and applicable because the application of some land use types will be inefficient, and in some cases fail to gain the prosperity, when practiced on land with strong limiting factors. The deterioration brought by transforming the tiger shrimp culture to rice cultivation in the Mekong Delta in 2005 is a clear example (Dien *et al.*, 2005). Farmers built ponds on the rice fields to hold salt water in, to raise tiger shrimps. At the start, the aquaculture of tiger shrimps gave higher profits compared with rice cultivation because one kilogram (kg) of shrimps was equivalent in value to 180 kg of rice (2005). Unfortunately, in later years shrimp farms were wiped out because of acid sulphate infection. Shrimp farmers lost and couldn't continue their careers because of the high costs associated with acid sulphate improvement. Desolate, farmers could not return to traditional rice farming systems because the land was now saline.

The purpose of the current study is to determine the overall land capability through the AMS. Land capability classification is undertaken equally between capability factors and is based on their actual value and weight. If the capability classification is determined by dominant factors, then the capability of other impact factors will be ignored. After the determination of dominant factors, the land capability will be addressed by introducing feasible solutions and by introducing external interventions. Dominant factors having poor actual values before weighting is applied will be modelled to predict the overall land capability in the study area.

In the case study, a factor is categorised as "dominant" when it has a large impact on the overall land capability. Moreover, it has positive influence on other ordinary factors within and between components in the AMS, in contributing to the land capability. When a desired amendment is proposed to deal with a limitation of the dominant factor, to increase the land capability, ordinary factors also have a positive impact on the land capability. By this mean, one external input can address several limiting factors at once. This is the goal of efficient and sustainable land use because land capability can be improved with a single intervention. An investment which can improve many factors resulting in an income in the land capability is the most advantageous type of land capability assessment undertaken through the AMS. The AMS is designed so that relationships and interactions of factors within and between components are considered and analysed.

For instance, the seed sector is rated as a dominant factor. This is because the seed sector has a substantial influence on the land capability, as well as impacting on other factors in contributing to the land capability. When the seed sector is organized and operated well at the district and commune scales, it results in improved planting seed quality at the farm scale as well. Whereupon pests are reduced, production costs decline, crop yield is maintained, and ultimately farms give higher profits for land users. In addition, due to good quality seeds being used for cultivation, farmers can cut down the application of chemical fertilizers and pesticides. As a result, this has a direct positive impact on the environmental hazards and land potential. In other words, the seed sector is a special capability factor in land development and management because it can interact and change the role of other factors in contributing to the land capability.

The literature review associated with the field survey and expert discussion, have identified a list of capability factors, which are categorised as either dominant or ordinary factors (Table 7.3). The relationship with the crop and the degree of influence are the sole considerations for this categorisation (Baniya, 2008, p. 156).

In Table 7.3, the biophysical component has only two dominant factors i.e. common pests and, irrigation and drainage system. Dominant factors in the technical and management component are seed sector, seed quality, land preparation technique, fertilizer and insecticide use management, applied ability of mechanisation, and water and pest management. The remaining factors are rated into the ordinary group.

All land development and environmental factors are dominant because they impact and relate closely to managing and developing sustainable land capability. In contrast, most factors in the socio-economic and policy sector are in the ordinary group, except for farming experience, farmers' accessibility, and policies used for agricultural production consumption.

Table 7.3: Dominant and ordinary factors for selected farming systems

No	Selected factors (characteristics)	Category	
	1. Bio-Physical	Dominant	Ordinary
1	Common pests	☑	
2	Annual dry/drought period		☑
3	Annual inundation period		☑
4	Irrigation and drainage system	☑	
5	Aeration condition		☑
6	Nutritional availability		☑
7	Flood level		☑
8	Availability of transport facilities		☑
9	Traffic system		☑
10	Distance from house to farms		☑
	2. Technical and management		
11	Seed sector	☑	
12	Seed quality for cultivation	☑	
13	Land preparation technique	☑	
14	Planting technique		☑
15	Pre-processing technique		☑
16	Storing technique		☑
17	Drying technique		☑
18	Fertilizer and insecticide use management	☑	
19	Applied ability of mechanisation	☑	
20	Water and pest management	☑	
21	Farm size		☑
	3. Land development & environmental		
22	Flood control ability	☑	
23	Irrigation engineering (construction)	☑	
24	Long-term salinity, landslip, landslide	☑	
25	Environmental hazards	☑	
26	Environmental control ability	☑	
	4. Socio-economic and policy		
27	Livelihood opportunities for farmers		☑
28	Labour-force (for farming activities)		☑
29	Production costs		☑
30	Membership of any social organizations		☑
31	Farming experience/skills of farmers	☑	
32	Farmers' accessibility to agricultural services	☑	
33	Credit allowance for farmers		☑
34	Laws for natural resource management		☑
35	Policies for agricultural product consumption	☑	

The rating of all dominant and ordinary characteristics is based on the selected farming systems, and at the different selected scales. Agronomic characteristics of crops, attributes of the farming system, and current cultivation conditions in the study area, are key references for the rating.

Dominant factors vary between components proposed in the AMS. This generates valuable results in the land capability modelling. The modelling considers multiple-aspects which impact upon the land capability. The modelling of the dominant factors is discussed later in this chapter.

7.2.5.3 Selected factors for farming systems at the commune scale

In the present study, land capability is determined at the three selected scales. At the district scale, the land capability is considered for general agricultural production. At the commune and farm scales, the land capability is considered for three proposed farming systems. Therefore filtering is necessary for each scale and system so that factors in the AMS can be determined for use in the land capability assessment procedure. The text in this and the next section will present selected factors for farming systems at the commune and farm scales.

Data in Table 7.4 show that at the commune scale, selected factors for the rotational rice-vegetables system are combined from factors for the single rice, and single vegetables systems. Noticeably, aeration condition, nutritional availability, production costs, and credit allowance for farmers are not land characteristics considered for the rice system. Meanwhile, common pests, availability of transport facilities, livelihood opportunities for farmers, and labour force for farming activities are not considered for vegetables system.

In the Mekong Delta, rice is planted under inundation conditions (water rice), and it can be developed on the poor to rich fertile soil (De, 2008). Land users can easily improve soil fertility and aeration condition by applying organic and chemical fertilizers and by reasonable water management on their rice fields as well. In contrast to rice, vegetables require a good aeration condition and fertile soil for growth. Farmers lose production, or receive low profits, when they cultivate vegetables on land with poor aeration condition and poor fertility (Nguyen, 2008).

Production costs and credit allowance are not considered in land capability assessment because costs invested for rice production are substantially less than vegetables. Recently, thanks to the program "three reductions three gains[24]", rice farmers in the study area have greatly reduced their investments in rice production while still maintaining the same level of output. Even though a large decline in investment has occurred, vegetables production still needs more investment than rice, when comparing the same planted area unit. This explains why aeration condition, nutritional availability, production costs, credit allowance features are not considered for the rice system.

Table 7.4: Factors required for selected farming systems at the commune scale

No	Factors in the practical model	Farming systems		
	1. Bio-Physical	Rotational rice-vegetables	Rice	Vegetables
1	Common pests (%)	☑	☑	
2	Irrigation and drainage system	☑	☑	☑
3	Aeration condition	☑		☑
4	Nutritional availability	☑		☑
5	Availability of transport facilities	☑	☑	
	2. Technical and management			
6	Seed sector (%)	☑	☑	☑
7	Applied ability of mechanisation (%)	☑	☑	☑
8	Water and pest management	☑	☑	☑
	3. Land development and environmental			
9	Flood control ability (years)	☑	☑	☑
10	Irrigation engineering (construction)/stations	☑	☑	☑
11	Environmental control ability	☑	☑	☑
	4. Socio-economic and policy			
12	Livelihood opportunities for farmers (%)	☑	☑	
13	Labour force (for farming activities) in the local area	☑	☑	
14	Production costs (USD/ha)	☑		☑
15	Farmers' accessibility to agricultural services	☑	☑	☑
16	Credit allowance for farmers (USD/ha)	☑		☑

For vegetables, common pests are not considered in land capability evaluation because statistical data overtime show that the outbreaks of pests such as insects and disease while commonly occurring for rice, rarely occur for vegetables. In addition, vegetable

[24] *Three reductions: seeds, insecticides, and nitrogen fertilizers; three gains: yield, product quality, and economic efficiency.*

production in the Cho Moi District (study area) is on a small scale and harvesting duration is distributed during the cropping season. Products are used for domestic and local consumption, farmers use primitive transport facilities in the local area to convey their vegetable products. Accordingly, common pests and availability of transport facilities are not used in assessing the land capability for vegetable systems.

Due to the specific attributes of farming systems, rice production needs a large number of workers (labour force) at the peak periods in the cropping season i.e. sowing and harvesting. At this time, farmers need to hire more labourers from outside their family. During other periods, farmers use family labour to run on-farm activities. Moreover, rice is cultivated by seasons, with approximately three months being a cropping season. Farmers have down time (free time) between two consecutive seasons, and therefore the rice system needs the farmer to develop other livelihood opportunities during their free time in the rice production. This is an important requirement for the sustainable development of a rice system because if farmers only cultivate rice, they have a low income. As a result, during the free time farmers move to the urban area to find other jobs, which offer a higher income compared with rice production, or they change from rice to another farming system.

On the other hand, vegetable production needs a minority of workers but in a frequent and continuous working condition. As well as in rotation with rice production, the vegetable system is cultivated the whole year round, and the planting and harvesting time is not concentrated in a short time period like rice. Therefore, two land characteristics of livelihood opportunities and labour force are not considered in the land capability assessment for the vegetable system, at the commune scale.

7.2.5.4 Selected factors for farming systems at the farm scale

Similar to the commune scale, selected factors at the farm scale are dependent on farming systems. Factors required for rotational rice-vegetables are a combination of the factors required for the single rice and the single vegetable systems.

As presented in Table 7.5, the transport system (internal transport system on the farm) factor is required in the land capability assessment for vegetables, but not for the rice system. The land area used for rice production in the study area is relatively consolidated. The internal transport system on rice farms is not considered important because the rice cultivation regions are protected by the state (public) bank and dyke systems. In rice production, farmers use these banks and dykes for transport purposes.

Table 7.5: Factors required for selected farming systems at the farm scale

No	Factors in the practical model	Farming systems		
	1. Bio-Physical	Rotational rice-vegetables	Rice	Vegetables
1	Irrigation and drainage system	☑	☑	☑
2	Availability of transport facilities	☑	☑	☑
3	Traffic system	☑		☑
4	Distance from house of farmers to their farms (km)	☑	☑	
	2. Technical and management factors			
5	Seed quality for cultivation	☑	☑	☑
6	Land preparation technique	☑	☑	☑
7	Planting technique	☑	☑	
8	Pre-processing technique	☑	☑	
9	Storing technique	☑	☑	
10	Drying technique (drying yard, m^3)	☑	☑	
11	Fertilizer and insecticide use management	☑	☑	☑
12	Farm size (ha)	☑	☑	
	3. Socio-economic factors			
13	Membership of any social organizations	☑	☑	☑
14	Farming experience (year)/skills of farmers	☑	☑	☑
15	Farmers' accessibility to agricultural services	☑	☑	☑

In addition, every rice farm has a small boundary-bank system to distinguish the land area between farms. This bank system can be used for transport. Also, before sowing and after the harvesting of the rice, mechanisation can be applied to the land as the rice fields are empty, allowing transport to travel on the land.

By contrast, the transport system is important for vegetables at the farm scale because the planted areas are fragmented into regions. It is common for vegetables to be planted next to the farmer's house (home garden), the harvesting time of vegetables is long, and depending on the market demands, vegetables are produced at a small scale and mainly for local consumption. Farmers frequently travel on to vegetable farms to take care of, and to harvest products, particularly for harvesting leaf vegetables. This explains why the factor "distance from the house of farmers to their farms" is important for vegetable systems.

Factors such as land preparation, planting, pre-processing, storing, and drying technique, as well as farm size are not considered as land characteristics for vegetable systems because they are not suitable for this farming system in the study area.

Adjusting the design components and factors in the AMS aims to generate a practical model for testing, which includes suitable land characteristics required for land capability assessment in the study area. Correct relationships and interactions within and between adjusted components and factors contributing to the land capability are vital. Restating, the purpose of this research is to identify what key components and factors are required for an effective AMS, and to identify why they are important for the land capability. For these reasons, analysis into how factors operate in the AMS is needed to reveal their influences on the land capability. The analysis will be discussed in the land capability analysis section in this chapter.

7.2.6 Land capability classification system

7.2.6.1 Classes for land capability classification

Developing a system for land capability classification is a necessary step in land evaluation. The land capability is classified into groups, which reveal degrees of capability, or capability levels, of the land to land users and land managers. In the theoretical model, land capability was rated into five classes, comprising very high, high, moderate, low, and very low capability.

In the study area, previous studies on land evaluation were considered to be land suitability evaluation (DNRE, 2006) in accordance with the FAO (1976) approach. The land suitability is classified into five suitability levels: S1 (high suitability), S2 (moderate suitability), S3 (low suitability), N1 (currently not suitable), and N2 (permanently not suitable). The land capability classification in the theoretical model is similar to the FAO (1976) land suitability classification, and this, with modification, was applied in the case study area. Thus, the land capability classification in the theoretical model is applied to the study area without alteration.

The land capability is performed using specified land utilisation types, which occur in the study area. A land area is classified as very high capability when it brings prosperity using a specific land use. The classification components are productive, economic, and sustainable capability. In contrast, the lowest class of land capability limits the growth and development of farming systems.

Similarly, factors in the practical model were rated into five capability classes (Table 7.6). Factors with a high capability class have very good potential to influence, or contribute to, the general land capability, for a specific use. Factors with a low capability class cause negative impacts on the land capability.

Table 7.6: Factor capability rating classes with respect to the farmland

Class	Capability	Degree of limitation	General Description
1	Very good	None to very slight	The critical limits indicate that in terms of the given factor, the land is highly capable for the specified land use.
2	Good	Slight	The critical limits indicate that in terms of the given factor, the land conditions are slightly adverse for the specified land use.
3	Fair	Moderate	The critical limits indicate that in terms of the given factor, the land is marginally capable for the specified land use.
4	Poor	Severe	The critical limits indicate that in terms of the given factor, the land is marginally not capable for the specified land use (usually for adverse benefit/cost reasons).
5	Very poor	Very severe	The critical limits indicate that in terms of the given factor, the land is permanently incapable for the specified land use.

Source: adopted from FAO (1985)

The contribution of factors to the land capability is determined by their actual value. The actual value of a factor is compared with the standardised value of every capability class to determine which capability class the factor belongs. Meanwhile, the capability of land is identified through the capability index, which is a multiplication of the actual value of each factor and the weighting given to that specific factor. The results of standardising the capability values for factors are presented below.

7.2.6.2 Standardised capability values for factors

According to the FAO (1976, 1983, 1984, 1985, 1991, 1993, 2007b), Ritung *et al.* (2007), Rowe *et al.* (1981), there has been no universal method, or technique, for standardising capability values for land use requirements in land evaluation. The standardisation is dependent on specific criteria, standards, and conditions in a given area, where the land evaluation is undertaken. Land use requirements change from place to place, even for the same land use type. Therefore, values for land use requirements must take into consideration the local conditions and for this expert knowledge is utilised. This study combined the FAO guidelines (1976, 1985, and 1993) with expert knowledge to develop standardised values. Presented in Tables 7.7, 7.8s, 7.9s, are the standardised qualitative and quantitative values.

The land capability is determined by using both qualitative and quantitative factors. In the past, most land evaluation was qualitative, and based on expert judgment. Multi-disciplinary input from experts such as soil surveyors, soil scientists, and agronomists was utilised. Using their experience and knowledge these experts interpreted field data of the land and made it understandable for planners, engineers, extension officers and farmers (Baniya, 2008). Land evaluation studies, driven by physical suitability and crop yield, usually focused on qualitative factors like nutrient availability, soil fertility, oxygen availability, water availability, irrigation and drainage systems. In contrast, quantitative factors are particularly important for economic land evaluation (FAO, 1985; Samranpong *et al.*, 2009).

Today, the rapid changes and diverse requirements of land utilisation types have enabled land evaluators to consider relationships and interaction between land resources and land use through linking qualitative and quantitative land evaluation.

Land capability assessment involves integrated analysis which must consider specific qualitative and quantitative impact factors. This assessment relates not only to technical and biophysical parameters, but also to the socio-economic indicators. There is insufficient evidence to conclude that the land capability is high or low if the analysis is based on a single qualitative or quantitative factor.

The expert interpretation of soil properties and crop requirements need to be linked, and cross-checked, with the quantitative economic simulation and prediction models of economists. Several studies (Rahimi Lake *et al*., 2009; Ha *et al*., 2006) show that harmonious mixing between qualitative and quantitative factors in land evaluation is essential since the land potential is multi-faceted and hence must be considered after disciplinary input.

The land capability in the current study was determined after consideration of a range inputs such as the biophysical, technical, socio-economic, environmental, and policy. Therefore, standardised values for factors have to involve qualitative and quantitative attributes.

Besides qualitative and quantitative attributes, the standardised values of factors vary between, and within, selected administrative scales and selected farming systems. In some cases, the measurement method and the unit of standardisation for values are also different. For instance, the capability values of factor "flood control ability" are defined by qualitative levels i.e. very well, well, moderate, poor, and very poor, for farming systems at the district scale. But at the commune level, it is measured by quantitative units. This difference is one of a number of requirements to ensure that the land capability determination is accurate and relevant at different selected scales. The land capability is considered carefully from the general to the specific scale. These standardised values are like toolkits which match with actual land characteristics allowing the analysis and revelation of the land capability.

Table 7.7: District level - Requirements for growth of overall agricultural systems

No	Factors (land use requirements)	Standardised values for capability classes				
	1. Bio-Physical	**Very high**	**High**	**Moderate**	**Low**	**Very low**
1	Common pests (%)	<15	15-25	>25-35	>35	-
2	Annual dry/drought period (month/year)	<2	2-3	>3-4	>4-5	>5
3	Annual inundation period (month/year)	<2	2-3	>3-4	>4	-
4	Irrigation and drainage system	Very well	Well	Moderate	Rain-fed	-
5	Flood level (m)	<1	1-1.5	>1.5-2.5	>2.5-4.5	>4.5
6	Traffic system	Very well	Well	Moderate	Poor	-
	2. Technical and management					
7	Seed sector (%)	>70	70-50	<50-30	<30	-
8	Applied ability of mechanisation	Very well	Well	Moderate	Poor	Very poor
9	Water and pest management	Very well	Well	Moderate	Poor	Very poor
	3. Land development and environmental					
10	Flood control ability	Very well	Well	Moderate	Poor	Very poor
11	Long-term salinity, landslip, landslide (dangerous degree)	Very low	Low	Moderate	Severe	Very severe
12	Environmental hazards	Very low	Low	Low-moderate	Severe	Very severe
13	Environmental control ability	Very well	Well	Moderate	Poor	Very poor
	4. Socio-economic and policy					
14	Livelihood opportunities for farmers	High potential	Potential	Fair	No potential	-
15	Production costs (USD/ha)	<500	500-600	>600-700	>700	-
16	Laws for natural resource management (ha/household)	>10	10-7	<7-5	<5	-
17	Policies used for agricultural production consumption	Very suitable	Suitable	Fair	Not suitable	-

Table 7.8.1: Commune level - Requirements for growth of rotational rice-vegetables system

No	Factors (land use requirements)	Standardised values for capability classes				
	1. Bio-Physical	**Very high**	**High**	**Moderate**	**Low**	**Very low**
1	Common pests (%)	<10	10-15	>15-20	>20-25	>25
2	Irrigation and drainage system	Very well	Well	Moderate	Rain-fed	-
3	Aeration condition	Very well	Well	Moderate	Poor	Very poor
4	Available nutrients	Very fertile	Fertile	Moderate	Poor	Very poor
5	Availability of transport facilities	Readily available	Available	Seasonal	Not available	-
	2. Technical and management					
6	Seed sector (%)	>80	80-60	<60-40	<40	-
7	Applied ability of mechanisation (%)	>90	90-70	<70-50	<50	-
8	Water and pest management	Very well	Well	Moderate	Poor	Very poor
	3. Land development and environmental					
9	Flood control ability (years)	<2	2-3	>3-4	>4-5	>5
10	Irrigation engineering (construction) (stations)	>6	6-4	3-2	<2	-
11	Environmental control ability	Very well	Well	Moderate	Poor	Very poor
	4. Socio-economic and policy					
12	Livelihood opportunities for farmers (%)	>70	70-50	<50-30	<30	-
13	Labour force (for farming activities) in the local area	Readily available	Available	Seasonal	Not available	-
14	Production costs (USD/ha)	<500	500-600	>600-700	>700	-
15	Farmers' accessibility to agricultural services	Very easy	Easy	Moderate	Hard	Very hard
16	Credit allowance for farmers (USD/ha)	> 1000	1000-800	<800-600	<600-400	<400

Table 7.8.2: Commune level - Requirements for growth of rice system

No	Factors (land use requirements)	Standardised values for capability classes				
	1. Bio-Physical	**Very high**	**High**	**Moderate**	**Low**	**Very low**
1	Common pests (%)	<10	10-15	>15-20	>20-25	>25
2	Irrigation and drainage system	Very well	Well	Moderate	Rain-fed	-
3	Availability of transport facilities	Readily available	Available	Seasonal	Not available	-
	2. Technical and management					
4	Seed sector (%)	>80	80-60	<60-40	<40	-
5	Applied ability of mechanisation (%)	>90	90-70	<70-50	<50	-
6	Water and pest management	Very well	Well	Moderate	Poor	Very poor
	3. Land development and environmental					
7	Flood control ability (years)	<2	2-3	>3-4	>4-5	>5
8	Irrigation engineering (construction) (stations)	>6	6-4	3-2	<2	-
9	Environmental control ability	Very well	Well	Moderate	Poor	Very poor
	4. Socio-economic and policy					
10	Livelihood opportunities for farmers (%)	>70	70-50	<50-30	<30	-
11	Labour force (for farming activities) in the local area	Readily available	Available	Seasonal	Not available	-
12	Farmers' accessibility to agricultural services	Very easy	Easy	Moderate	Hard	Very hard

Table 7.8.3: Commune level - Requirement for growth of vegetables system

No	Factors (land use requirements)	Standardised values for capability classes				
	1. Bio-Physical	**Very high**	**High**	**Moderate**	**Low**	**Very low**
1	Irrigation and drainage system	Very well	Well	Moderate	Rain-fed	-
2	Aeration condition	Very well	Well	Moderate	Poor	Very poor
3	Available nutrients	Very fertile	Fertile	Moderate	Poor	Very poor
	2. Technical and management					
4	Seed sector (%)	>80	80-60	<60-40	<40	-
5	Applied ability of mechanisation (%)	>90	90-70	<70-50	<50	-
6	Water and pest management	Very well	Well	Moderate	Poor	Very poor
	3. Land development and environmental					
7	Flood control ability (years)	<3	3-4	>4-5	>5-7	>7
8	Irrigation engineering (construction)/(stations)	Very well	Well	Moderate	Poor	Very poor
9	Environmental control ability	Very well	Well	Moderate	Poor	Very poor
	4. Socio-economic and policy					
10	Production costs (USD/ha)	<1000	1000-1200	>1200-1400	>1400	-
11	Farmers' accessibility to agricultural services	Very easy	Easy	Moderate	Hard	Very hard
12	Credit allowance for farmers (USD/ha)	> 1000	1000-800	<800-600	<600-400	<400

Table 7.9.1: Farm level - Requirements for growth of rotational rice-vegetables system

No	Factors (land use requirements)	Standardised values for capability classes				
	1. Bio-Physical	**Very high**	**High**	**Moderate**	**Low**	**Very low**
1	Irrigation and drainage system	Very well	Well	Moderate	Rain-fed	-
2	Availability of transport facilities	Readily available	Available	Fairly available	Not available	-
3	Traffic system	Very well	Well	Moderate	-	-
4	Distance from the house of farmers to their farms (km)	<2	2-3	>3-4	>4-5	>5
	2. Technical and management					
5	Seed quality for cultivation	Very well	Well	Moderate	Poor	-
6	Land preparation technique	Very well	Well	Moderate	Poor	-
7	Planting technique	Very well	Well	Moderate	Poor	-
8	Pre-processing technique	Very well	Well	Moderate	Poor	-
9	Storing technique	Very well	Well	Moderate	Poor	-
10	Drying technique (drying yard, m^3)	>400	400-300	<300-200	<200-100	<100
11	Fertilizer and insecticide use management	Very well	Well	Moderate	Poor	-
12	Farm size (ha)	>2	2-1	<1.0-0.5	<0.5	-
	3. Socio-economic					
13	Membership of any social organizations	District	Commune	Hamlet	-	-
14	Farming experience (years)/skills of farmers	>5	5-4	<4-3	<3	-
15	Farmers' accessibility to agricultural services	Very easy	Easy	Moderate	Hard	Very hard

Table 7.9.2: Farm level - Requirements for growth of rice system

No	Factors (land use requirements)	Standardised values for capability classes				
	1. Bio-Physical	**Very high**	**High**	**Moderate**	**Low**	**Very low**
1	Irrigation and drainage system	Very well	Well	Moderate	Rain-fed	-
2	Availability of transport facilities	Readily available	Available	Fairly available	Not available	-
3	Distance from the house of farmers to their farms (km)	<2	2-3	>3-4	>4-5	>5
	2. Technical and management					
4	Seed quality for cultivation	Very well	Well	Moderate	Poor	-
5	Land preparation technique	Very well	Well	Moderate	Poor	-
6	Planting technique	Very well	Well	Moderate	Poor	-
7	Pre-processing technique	Very well	Well	Moderate	Poor	-
8	Storing technique	Very well	Well	Moderate	Poor	-
9	Drying technique (drying yard, m^3)	>400	400-300	<300-200	<200-100	<100
10	Fertilizer and insecticide use management	Very well	Well	Moderate	Poor	-
11	Farm size (ha)	>2	2-1	<1.0-0.5	<0.5	-
	3. Socio-economic					
12	Membership of any social organizations	District	Commune	Hamlet	-	-
13	Farming experience (years)/skills of farmers	>5	5-4	<4-3	<3	-
14	Farmers' accessibility to agricultural services	Very easy	Easy	Moderate	Hard	Very hard

Table 7.9.3: Farm level - Requirements for growth of vegetables system

No	Factors (land use requirements)	Standardised values for capability classes				
	1. Bio-Physical	**Very high**	**High**	**Moderate**	**Low**	**Very low**
1	Irrigation and drainage system	Very well	Well	Moderate	Rain-fed	-
2	Availability of transport facilities	Readily available	Available	Fairly available	Not available	-
3	Traffic system	Very well	Well	Moderate	-	-
	2. Technical and management					
4	Seed quality for cultivation	Very well	Well	Moderate	Poor	-
5	Land preparation technique	Very well	Well	Moderate	Poor	-
6	Fertilizer and insecticide use management	Very well	Well	Moderate	Poor	-
	3. Socio-economic					
7	Membership of any social organizations	District	Commune	Hamlet	-	-
8	Farming experience (years)/skills of farmers	>7	7-5	<5-3	<3	-
9	Farmers' accessibility to agricultural services	Very easy	Easy	Moderate	Hard	Very hard

7.2.7 Weight of components and factors

Addressing the relative degree of importance of components and factors in the land capability model is a basic objective of the study. In land evaluation, the importance of impact factors is identified and indicated by their weight (Trung, 2006; Baniya, 2008; Loan, 2010; Hang, 2010). The weighting method and the theory of the analytical hierarchy process (AHP) (Saaty and Vargas, 2001; Saaty, 2008a; Saaty, 2008b; Bhushan and Rai, 2004, *see Chapter 6*) were employed to give weights to components and factors in the practical model. Each component, or factor, and its alternatives has a different influence on the model. Depending on the degree of influence, score values for each of the alternatives were created in a priority order which is subject to analysis in a pair-wise comparison model (Baniya, 2008). Components and factors were rated according to the Participatory Rural Appraisal (PRA) technique (*see Appendix 1*) and after evaluation by land experts, which was an approach taken by Alejandro and Lopez-Blanco (2002) and Baniya (2008) for land suitability analysis.

Pair-wise comparison is first expedited in the hierarchical order of selected components. When the results of selected component comparisons were verified, further pair-wise comparison for factors within the components was carried out. The weight is allocated with respect to selected land assessment scales and selected farming systems in the given land areas. During the weighting process, it is necessary to check the Consistency Ratio (CR) (*see Chapter 6*), which is designed to verify the reliability of the comparison result. The CR has to be less than 0.10 for the comparison result to be consistent; otherwise the result needs to be revised by readjusting alternatives in the AHP matrix. Undoubtedly, the final results of weighting are also influenced by the goal of the research and the knowledge of the respondents. Therefore, it is suggested that final comparison results need to be cross-checked by stakeholders, who participated in the PRA

Weights of components for the land capability are shown in Table 7.10. The CR index is 0.073, 0.054, and 0.052 for the district, commune, and farm scale respectively (*see Appendix 9*). Each is considerably less than the 0.10 threshold which verifies that the response of participants in the weighting process is unified and correct, so the weights are acceptable and reliable. Overall, the weight value is diverse within and between scales. It is believed that the difference of the components' weight between selected scales is due to the various roles and involvements of factors in each individual component in the AMS, as well as the different concerns related to land capability management at the scales.

Table 7.10: Weights of components for the land capability

Components	Factors' weights		
	District	**Commune**	**Farm**
(1). Bio-physical	0.139	0.384	0.159
(2). Technical and management	0.082	0.126	0.589
(3). Land development and environmental	0.410	0.300	-
(4). Socio-economic and policy	0.369	0.191	0.252
Consistency Ratio (CR)	**0.073**	**0.054**	**0.052**

At the district scale, the weight value has been calculated as 0.41, 0.369, 0.139 for the land development and environmental, and socio-economic and policy, and biophysical components respectively. The land development and environment component is the first contributor to the land capability, and the socio-economic component is the second. Conversely, with weight value of 0.082, the technical and management component has the least influence on the land capability.

Over the years, environmental issues have been considered more and more in land evaluation in the Mekong Delta because they have a major influence on forwarding the target of Good Agriculture Practices[25]. Land evaluation lacking in environmental information results in failure and inefficiency when applied to specific land use.

Being well aware of the consequences above, land experts, as well as land managers, in the study area agree that the land development and environmental component was the prime criteria for judging the capability of the land at the district scale. The socio-economic and policy is the second most important component which shows the human and decision making associated with the land.

[25] *Good Agricultural Practices should be economically viable, environmentally sustainable, and socially acceptable; inclusive of food safety and quality dimensions…(Poisot et al., 2007).*

The environmental, socio-economic and policy sectors are core areas for appraising alternatives in the land use planning process (FAO, 1993) at the regional scale. When a land area has a high biophysical capability for a specified use, but the use of the land cause environment damage, and has a negative impact on the community, then another land use type should be proposed. It is clear that the types of land use which can achieve and balance the objectives of agronomic, economic, and environmental sustainability are preferred and encouraged. Particularly, environmental and land development matters are carefully appraised at the district scale in land evaluation because land managers at this level have sufficient power to legislate policies to deal with environmental impacts in land use.

Moreover, regional linkage and cooperation to reduce environmental risks and hazards, in order to convey sustainable land use and management is an emerging trend in Viet Nam, and the Mekong Delta. Formally, the linkage and cooperation was done at the district scale, and this explains why the environmental and land development component has been given the highest weighting.

At the commune scale, the biophysical component has the highest weight value of 0.384, and immediately following this is the land development and environment component with 0.300. The socio-economic and policy, and the technical and management components have less importance to the land capability analysis. This is reflected in their lower weight values of 0.191and 0.126.

The biophysical weight value of 0.384 indicates that the land capability assessment places high importance on the biophysical impacts on the land. A majority of land experts and land managers agreed that the land development and environmental component is very important in the overall land capability analysis. However, they agree that the most important component should be the biophysical. In land evaluation, the biophysical attributes are always considered first, followed by the economic and environmental aspects. The economic and environmental impact evaluation is done for a given land area when it has been determined that the area has a high biophysical capability. After considering the balance between the three dimensions above, land policy makers and land planners decide on the use of the land

and the land allocation. Furthermore, a biophysical investigation of the land is reasonable at the commune scale. Collected data is used as a reference for more in-depth surveys and fieldwork in land evaluation.

Surprisingly, the land development and environmental component is not considered in the land capability assessment at the farm scale. The most vital component at this scale is the technical and management (0.589). The socio-economic and policy and biophysical components are the second and third most influential on the land capability (0.252, and 0.159).

Unlike the district and commune scales, the environmental and socio-economic characteristics are not considered important by land users at the farm scale. Most of the land users believe that the ultimate objective in land use is to gain the highest financial benefits from a given land area. Farmers realize that environmental impacts are generated by their farming systems, and that it is easy for them to identify these impacts and to cope with them at the farm scale. Biophysical attributes are considered less important because farmers do distribute their current land use on biophysically suitable areas. Present efforts by farmers are focused on applying advanced techniques and suitable management principles, based on the socio-economic characteristics of a household to optimize the current land use.

Besides, the biophysical land capability is sustainable and supports highly prosperous farming systems when the farmer applies good techniques and reasonable management in the process of farming. An interesting lesson from recent studies on the economic viability of farms, and land capability improvement, is that technical and management interventions in the process of rice cultivation have resulted in significant positive change in the prosperity of farms and soil fertility. The rice yields and soil fertility have increased significantly when cultivating techniques such as drying the land in the short time between two cropping seasons and using organic fertilizers for rice fields, are applied (Nguyen, 2008).

Consideration of the impacts of components on the land capability was done as an overview evaluation, with their weight being appraised for overall agricultural systems. Of course, agricultural systems consist of selected farming systems. As a result, the weight of components was applied to selected common farming systems. Further, local land experts confirmed that the selected farming systems have homogeneous attributes when overview weighting is the consideration. The differences can be identified and easily distinguished using factors at the lower weighting level because the involvement of factors in the components in the practical model varies greatly. Hence factors can uncover notable differences within farming systems.

Notwithstanding, the survey results reveal that the weight of factors varies between selected farming systems and at selected scales. The variation shows that the impacts of land characteristics on the land capability are dependent on different administrative scales and different land use types. Thus, important land characteristics must be considered when introducing solutions to improve the land capability. This is because the interaction between factors in land evaluation (FAO, 1993), means that if a key limiting factor is amended, other minor factors can be impacted also.

To illustrate this, in a study relating to "community biodiversity conservation and sustainable agriculture" in the Mekong Delta, Huynh *et al.* (2010) compared two farmer groups: trained and non-trained. The training content focused on the environment, efficient production, pest management, and sustainable agriculture. The results showed that the trained farmer group had significantly lower production costs in rice production compared with the non-trained farmer group. The training activity assisted farmers to enhance their skills and knowledge in rice production. The use of pesticides, chemical fertilizers, and seeds in rice production for trained farmers was more effective than for non-trained farmers. To conclude, the authors suggested that the key factor needed for intervention to support farmers wanting to reduce their production costs in rice production is "training activity".

The weighting of components and factors in the AMS has a relationship and interdependence in land capability analysis. The weight of the component (W_c, criteria) combined with the weight of the corresponding factor (W_f, sub-criteria) gave the overall weight (W_o) of each individual factor (Table 7.11). The overall weight represents the role and possible impacts upon the land capability (Baniya, 2008). The overall weight was a product (multiplication) of the weight of components and factors.

For example, as shown in Table7.11, the weight of the biophysical component, 0.139, was multiplied by the weight of its corresponding factor, for example, common pests, 0.250, to give an overall weight of 0.035. This value was then ranked to indicate the position of the factor in the order of importance. The sum of the overall weights of all factors involved in the AMS will be 1.0 (100%).

Table 7.11: Weights of factors for the general farmland capability at the district level

Components		**Factors**		**Overall weight**	
	Wc		Wf	Wo = Wc x Wf and its ranking	
1. Bio-physical	0.139	1.1. Common pests (%)	0.250	0.035	11
		1.2. Annual dry/drought period (month/year)	0.123	0.017	14
		1.3. Annual inundation period (month/year)	0.119	0.017	15
		1.4. Irrigation & drainage system	0.303	0.042	9
		1.5. Flood level (m)	0.139	0.019	13
		1.6. Traffic system	0.065	0.009	17
2. Technical and management	0.082	2.1. Seed sector (%)	0.491	0.040	10
		2.2. Applied ability of mechanisation	0.198	0.016	16
		2.3. Water & pest management	0.312	0.026	12
3. Land development and environmental	0.410	3.1. Flood control ability	0.115	0.047	7
		3.2. Long-term salinity, landslip, landslide	0.349	0.143	2
		3.3. Environmental hazards	0.321	0.132	3
		3.4. Environmental control ability	0.216	0.089	5
4. Socio-economic and policy	0.369	4.1. Livelihood opportunities for farmers	0.156	0.058	6
		4.2. Production costs (USD/ha)	0.285	0.105	4
		4.3. Laws for natural resource management (ha/household)	0.119	0.044	8
		4.3. Policies used for agricultural production consumption	0.440	0.162	1
Total	**1**		**4**	**1**	**17**

The weighting of factors was one important criterion for the modelling of the land capability. Dominant factors with a high weighting, but poor actual value, are modelled with the expectation that they will improve and increase the capability of land. The factor modelling is reviewed in the following section of this chapter.

Adjusting the theoretical model and evaluating the importance of components and factors in the land capability model were based on a consideration of the study area context, the opinions and knowledge of local experts with respect to selected farming systems and the selected administrative scales, for land capability assessment. The overall weight of factors for the land capability assessment is an aggregation between the initial weight of components and the weight of the relevant factors. This overall weight was combined with the actual value of factors to analyse the land capability. The higher the weight is, the more important the factor is. The overall weight of all factors at the three selected scales and the three farming systems were calculated, and ranked by the degree of importance. For further detail, refer to Appendices 10 to 16.

7.3 Results of the case study implementation

The land capability is the potential of a given land area for a defined use. Capability analysis is a relevant combined study between soil properties and land characteristics along with the agronomic requirements of the plant to determine the capability of the land. Classically, suitability and capability analysis focus on physical parameters as well as ecological features; and in some cases, socio-economic parameters are also involved. For example, a study on land suitability evaluation for vegetables in Nepal (Baniya, 2008) showed that combining economic, cultural, and social attributes with physical features in land evaluation is an effective way to help farmers explore many alternatives and opportunities to utilise their land resources in different ways.

The latest land evaluation study in the Cho Moi District was a physical suitability study based on the DNRE (2006) approach. The suitability classification of the land mapping units based on a comparison of existing physical parameters with crop yield potential, has been separated into acid sulphate soil suitability, climate suitability, and nutrient suitability. This separate evaluation lacks the ability and opportunity to make improvements over existing conditions to increase the productive capacity of the land because land capability is impacted by many interacting factors.

In practice, given farming systems such as rotational crops, single rice, and vegetables cultivation in the study area are influenced by a range of fundamental parameters, including infrastructure convenience, ecological and climate attributes, cultivation experience and customs, social traits, services availability, market demands, and so forth. Hence, land capability analysis considers logically the major components in the applied model for the agricultural management system below:

- Biophysical
- Technical and management
- Land development and environmental
- Socio-economic and policy

The land capability analysis approach used in the current study is very important and significant. It not only offers land users and managers the opportunity to explore the current limitations of the land area for a particular land utilisation, it also provides the opportunity to take the necessary steps for the further improvement and development of the land to take it to a higher level of capability.

The combined capability of all influencing factors in the AMS is rated into very high, high, moderate, poor, and very poor, for selected farming systems. On the other hand, improvable factors, which have a poor actual value on the land capability, can be amended to improve the level of capability through external inputs and solutions. For instance, if pest as a factor has a poor actual value for rice production at the commune scale, it can be managed by introducing feasible solutions such as using resistant cultivars and integrated pest management applications. This means that the land capability is modelled along with associated assumptions. The modelling generates opportunity for increasing the capability level of the land. This is called modelling potential land capability. Potential capability provides the basis for the land users to adopt and invest in appropriate techniques and management approaches to achieve specific positive outcomes.

As indicated in the previous chapters, the capability of land is determined through the calculation of the Capability index (Ci), which is computed based on the actual value of land characteristics (factors) and their overall weight (Wo). Specifically, $Ci = \Sigma (Wo * Si)$, where Ci is the aggregated farmland capability index, Wo is the overall weight of factors, Si is the score of the combined factors. The actual value of factors is compared with standardised capability values for factors to identify capability classes, and then converted into scores as showed in Table 7.12.

Table 7.12: Classifying the actual value of factors for the capability classes and indices

Capability classes	Scores	Capability indices
Very high (VH)	9	>7.5
High (H)	7	<7.5-6.0
Moderate (M)	5	<6.0-4.5
Low (L)	3	<4.5-3.0
Very low (VL)	1	<3.0

Scoring was based on the AHP approach (Saaty and Vargas, 2001; Saaty, 2002)

When the land capability index is determined, it is linked with a GIS to map and screen the results of the land capability for selected farming systems, and for given scales. This is explained in the following section.

7.3.1 Farmland capability analysis at the district scale

The land capability varies with the different assessment scales. At the regional scale, the model analyses the land capability for generalized or major uses while at the local scale the model analyses the land capability for specified utilisations. The analysis of land capability in the Cho Moi District is carried out in the administrative hierarchy system from the district, to the commune and the farm scales.

At the district level, the individual capability of four refined components and the overall aggregated capability of the farmland are rated for general agricultural cultivation after considering knowledge gained from the literature and the local situation. Table 7.13 and Figure 7.1 indicate details of the diagnostic components (biophysical, technical and management, land development and environmental, and socio-economic and policy) with their capability level supporting the agricultural production. Overall, the potential of components contributing to the land capability of districts ranges from a moderate to a very high level. Nearly half the number of districts have moderate and high capability in terms of the biophysical attributes; four of the eleven districts have a technical and management component which has a very high capability. While, the land development and environmental, and socio-economic and policy component have a very high level of capability for one and two districts respectively.

Table 7.13: Current capability ratings of diagnostic components and overall capability for generally agricultural systems in the An Giang Province.

Districts	Diagnostic components				Overall capability
	(1)	(2)	(3)	(4)	(Aggregated)
Thoai Son	H	VH	H	H	H
TPLX	M	M	VH	VH	H
Chau Thanh	H	VH	M	H	H
Tri Ton	M	H	H	H	H
Tinh Bien	M	H	M	H	M
Chau Phu	H	H	H	M	H
Cho Moi	H	VH	H	H	H
Chau Doc	M	H	H	M	H
Phu Tan	H	VH	H	VH	H
Tan Chau	M	H	M	M	M
An Phu	M	M	M	H	M

Note: (1): biophysical, (2): technical and management, (3): land development and environmental, (4): socio-economic and policy

For overall farmland capability, there is no district that has a very high level (Figure 7.2). Three of eleven districts are considered highly capable for agricultural production. One district (Tinh Bien) degrades to a moderate capability because of the biophysical, land development and environmental limitations. Another district (Tan Chau) degrades due to the biophysical, land development and environmental and socio-economic constraints in crop cultivation. The last one (An Phu) drops to a moderate capability since most components, except socio-economic and policy traits, indicate the land is only moderately suitable for agriculture.

As indicated in the previous discussion, land investigation and revision, and land evaluation and planning, in the An Giang Province is executed every five and ten years respectively. There was insufficient information on land evaluation for the whole An Giang Province prior to the current study, and therefore the results of the farmland capability analysis are compared with land use planning in the local area for the period of 2005-2010. According to a land use investigation in 2005 (DNRE, 2006), the agricultural land area occupies 84.33% (298,146ha) of the total natural land areas in An Giang. Based on the physical suitability evaluation, it was planned for approximately 81.33% of the land use allocated for agricultural production up to 2010.

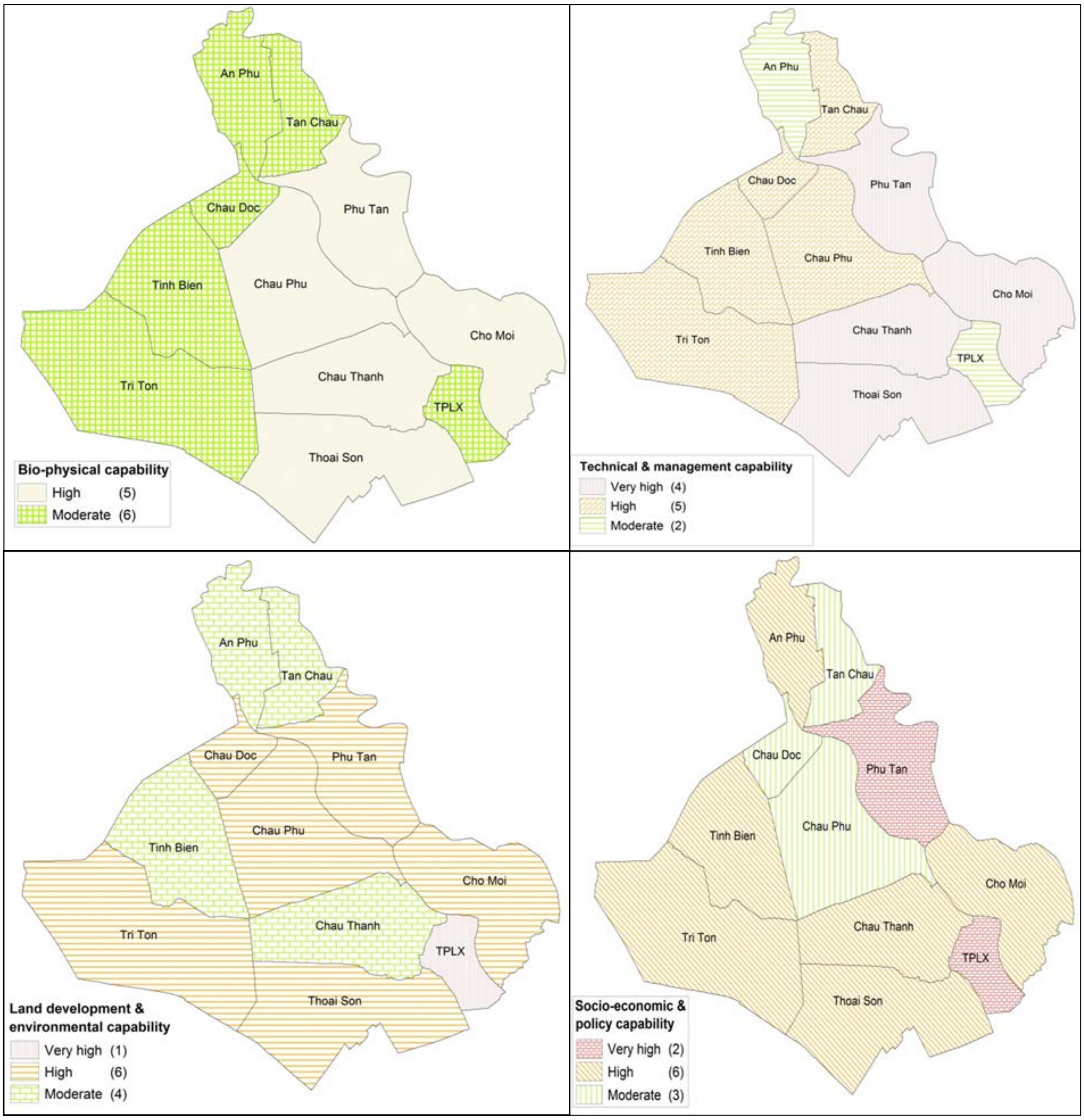

Figure 7.1: Capability ratings of components in the AMS for the overall agricultural systems at the district scale

The rationale behind An Giang allocating more than 80% of the natural land areas for agriculture was that most land areas are highly capable and suitable to develop as agricultural production systems. Land capability analysis in the current study calculates that 78.97% of the land area (eight of eleven districts) in the An Giang Province, are highly capable for agriculture (Figure 7.2). This result reveals that the majority of the land area in the An Giang Province is suitable as the agricultural production land.

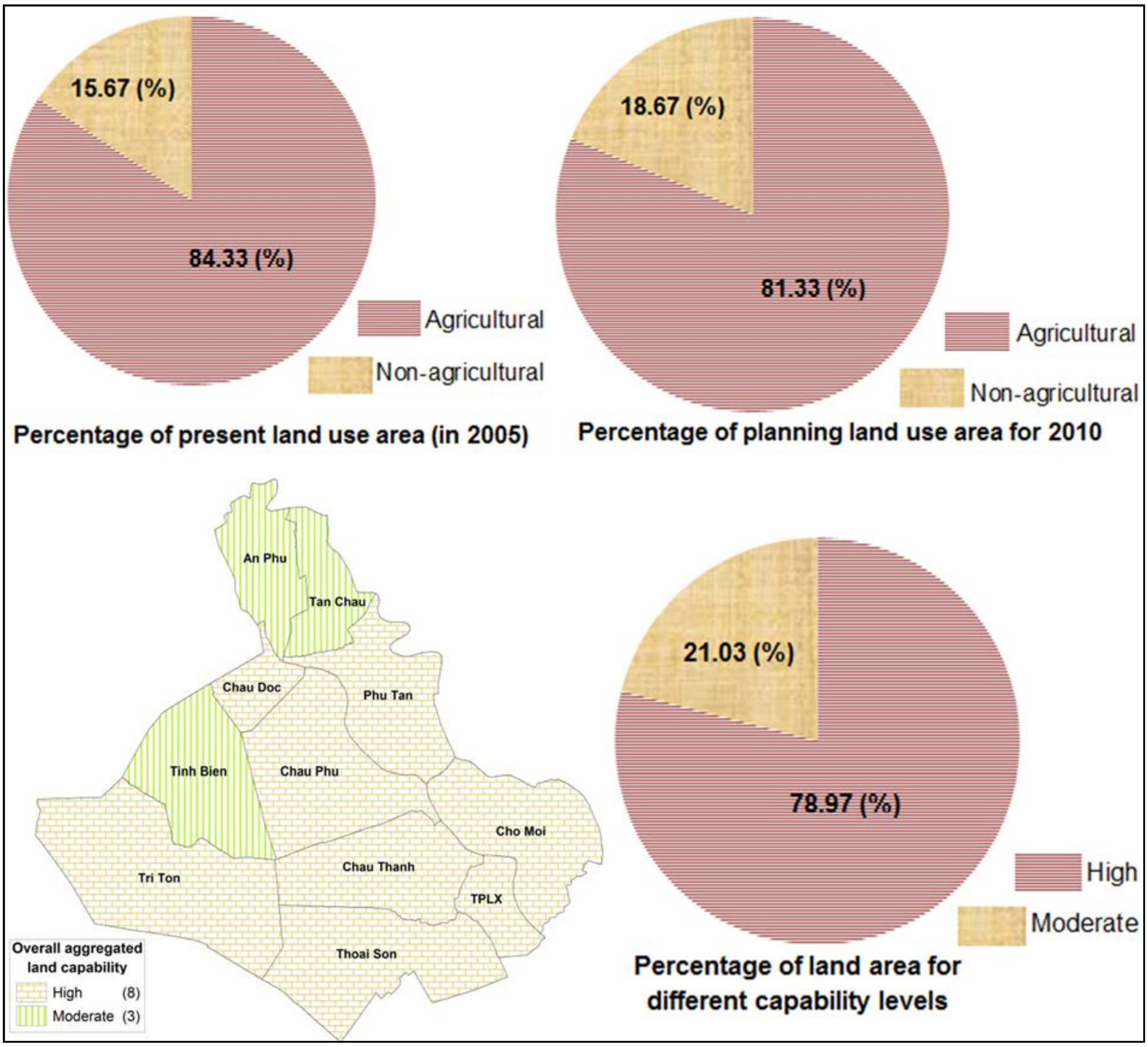

Figure 7.2: Land capability map and percentage of present land use, planning and capability levels in the An Giang Province

Presenting the land capability results on a visual map based on GIS is very important for land development and management. It contains spatial (geographical) and attribute (statistical) data, which are suitable for further land evaluation studies. For example, maps in Figure 7.1 and 7.2 reveal the location (spatial position) where land areas are moderately and highly capable. Associated with the attribute data, land users can select the most feasible alternatives to cultivate crops on their land resource. Meanwhile, capability maps help land managers to identify where and how to invest external inputs and interventions to upgrade the land capability, as well as to allocate and distribute suitable land areas for use in land use planning. In other words, database values and land information, updated and stored in the AMS, will be useful for modelling and predicting scenarios relating to land use changes, as well as being very important for agricultural production management in the local area.

Data analysis and field survey results show that there are several factors limiting the land capability in An Giang (*see Appendix 17*). Districts with moderate land capability distribution in the upstream (i.e. An Phu, Tan Chau) and the mountainous region (Tinh Bien), face many limitations in the growth and development of crops. For the Tinh Bien district, the current limitations are caused by annual drought, irregular irrigation and drainage systems, environmental hazards, and the environmental control ability. These factors have a major contribution to the land capability, but their actual value is poor in the local area context. As discussed in the background to the study areas (Chapter 5), water supplies for agriculture in Tinh Bien are based on natural rainfall and the water supply capability of man-made channels. If the dry season extends for a long time, the irrigation and drainage system cannot undertake its function, such as water supply and discharge. As a result, land capability degrades due to limitations caused by drought and limited water supply.

In contrast, the Tan Chau and An Phu districts have moderate land capability levels because of the limiting factors such as flood level, the transport system, the applied ability of mechanisation, the flood control ability, and policies for agricultural product consumption. It is confirmed that transport systems, the application of mechanisation, and policies for agricultural development, are synchronously invested and carried out in the whole of the An Giang Province. However, Tan Chau and An Phu are always influenced by the annual flooding regime, and floods come earlier and heavier compared with the remaining districts (due to the naturally geographic characteristics). In years with a high degree of floods, transport systems in the Tan Chau and An Phu Districts have been damaged and this partly limits the application of mechanisation in agricultural production, as well as causing constraints in transporting product for consumption. Therefore, to increase the farmland capability, reasonable flood control and management is needed in the An Giang Province.

The present farmland capability map is not the final step in the research for the case study. Solving and correcting limiting factors to improve the land capability is the ultimate goal of the study. If limitations (limiting factors) are improvable and changeable, then external inputs and solutions can be proposed to amend them in order to enhance the land capability. For instance, upgrading irrigation and drainage and transport systems can result in increasing the land capability in the study area. However, if limiting factors are uncontrollable like drought, salinity and landslip, the amendment is associated with very high costs and will take a long time, and in some cases the amendment may fail and be inefficient. In such a case the level of land capability remains unchanged, and therefore introducing new land utilisation types seems to be better choice.

Theoretically, the land capability can be modelled at the farm to the regional scale and can be increased to a higher level. Nevertheless, implementing the results of the modelling at the regional (district) scale is impractical and unfeasible because estimation and calculation in relation to costs, time and the efficiency of external inputs and solutions are problematic and often inappropriate. Contrary to the district scale, land capability modelling at the farm scale is very clear, specific and accurate. But, it is often unrepresentative and variable in terms of the land and agricultural management system. The results of modelling vary from farm to farm, and are very much reliant on household attributes, which are dissimilar between farms. Hence, the most effective modelling of limiting factors, to improve the land capability, in the current study, is undertaken at the commune scale. It is the lowest administrative unit at which the land capability can be mapped. Available data relating to land at the district and farm scales can be logical referenced to model the actual value of limiting factors at the commune scale.

The farmland capability modelling at the commune scale will be presented in the following section.

7.3.2 Farmland capability analysis at the commune scale

Analysing the capability of farmland at the commune scale is the main goal of this chapter. The analysis was done for three specified land utilisation types which are rotational rice-vegetables, rice, and vegetables system, and this analysis was undertaken for eleven communes in the Cho Moi District.

Table 7.14 shows the current capability of farmland for selected farming systems in the Cho Moi District of the An Giang Province. In general, farmland capability varies between communes and farming systems, fluctuating from moderate to very high capability. All communes are highly capable of sustaining rotational rice-vegetables cultivation. There are five communes (Kien An, My Hoi Dong, Nhon My, My Hiep, and Hoi An) in particular that have very high capability for vegetables. However, there are only 4 communes (My Hoi Dong, Nhon My, Long Dien A, and Hoi An) that obtain a high capability for rice production, while the fourteen remaining communes fall under moderate capability. The farmland capability is aggregated from the capability of individual components and factors in the AMS. Therefore, to investigate and identify what causes the decline in the aggregated land capability, the capability of each factor and component needs to be considered.

Table 7.14: Current farmland capability ratings for selected farming systems in the Cho Moi District

Communes	**Farming systems**			**Land areas** (ha)		
	Rotational	**Rice**	**Vegetables**	**Natural**	**Farmland**	**(%)**
Cho Moi[26]	H	M	H	327	181	55.3
Kien An	H	M	VH	2,573	2,013	78.2
My Hoi Dong	H	H	VH	2,729	1,701	62.3
Kien Thanh	H	M	H	2,263	1,025	45.3
Nhon My	H	H	VH	3,194	1,939	60.7
Long Giang	H	M	H	1,829	1,276	69.8
Long Kien	H	M	H	1,688	1,137	67.4
Long Dien B	H	M	H	1,772	1,406	79.3
Long Dien A	H	H	H	1,719	992	57.7
Hoa An	H	M	H	1,855	1,083	58.4
An Thanh Trung	H	M	H	2,857	2,361	82.6
My Luong	H	M	H	1,056	701	66.4
My Hiep	H	M	VH	2,299	1,439	62.6
Tan My	H	M	H	2,753	1,575	57.2
My An	H	M	H	1,479	972	65.8
Binh Phuoc Xuan	H	M	H	1,907	1,204	63.2
Hoa Binh	H	M	H	2,503	1,481	59.2
Hoi An	H	H	VH	2,553	1,057	41.4
Land areas are computed based on the land use structure in 2010. Total natural land includes area of naturally alluvial grounds along the Hau and Tien River . Data are subject to rounding.						

[26] *Cho Moi town (commune) belongs to the Cho Moi District.*

The results of data analysis show that many communes with low capability for the rice system are challenged by biophysical and land development and environmental factors (Figure 7.3, and Appendix 19). In these communes, pests, seed sector, applied mechanisation, and floods control are the key limiting factors. In recent years, pests are one of the common problems for rice farmers in the Mekong Delta, and in the Cho Moi District in particular.

In 2006, more than 80% of the planted rice area in the Summer-Autumn season in the Cho Moi District was lost by rice leaf blight disease (*Xanthomonas oryzae* pv. *oryzae*), and about 37% of the area declined in productivity due to pests in 2009 (Cho Moi Department of Agriculture and Rural Development, 2009). At present, pests have reduced significantly thanks to plant protection techniques, but they still have negative impacts on the land capability in the study area.

The next constraint is seeds. In principle, seed is a decisive factor that contributes to the yield potential, and it relates to the production costs and economic efficiency of any crop patterns. Many communes in the Cho Moi District, drop to low capability because of poor seed sector capability. The local seed supply system cannot meet the requirements of good quality rice seed for sowing, so farmers use the poor quality rice[27]. This can cause an increase in production costs and results in lower benefits for rice farmers compared with using good quality rice seeds for cultivation. Moreover, seed and pest factors are closely related. The application of poor quality seeds results in high costs for pest management. Thus, if the seed sector is well organized and efficiently operated, it will improve the land capability in terms of pest control.

[27] *In principle, rice used for human/animal consumption (eating only), and rice seeds used for production, cultivation.*

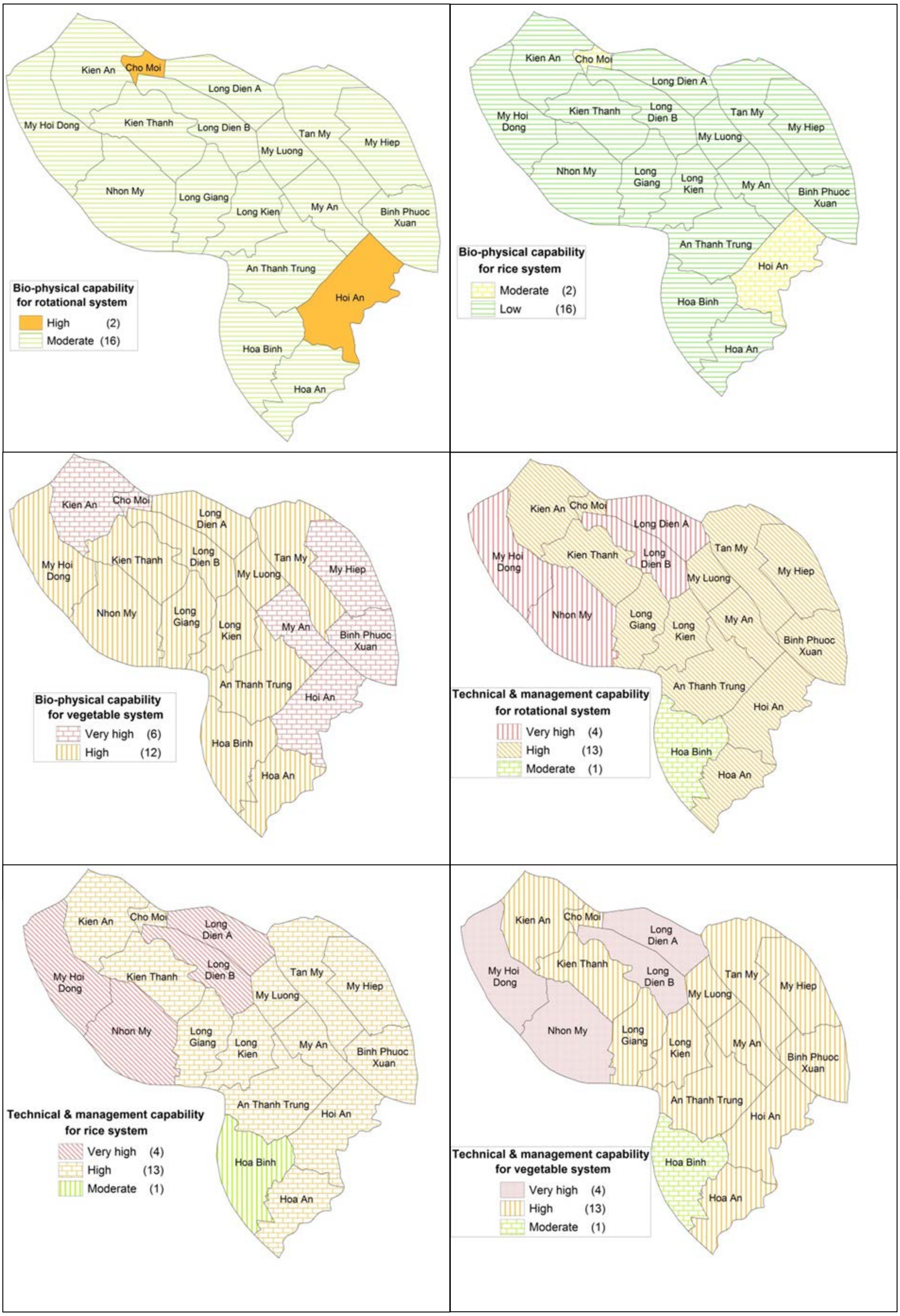

Figure 7.3: Capability ratings of components in the AMS for selected farming systems at the commune scale

Another vital limiting factor in rice production capability is mechanisation application. Recently, due to industrialization pressure, associated with unequal revenue between agriculture and other sectors, such as services and the construction and industry, the young labour force in rural areas in the Cho Moi District and the Mekong Delta in general, is moving to urban areas. Companies, especially factories, in major industrial zones like Ho Chi Minh City, attract and employ a huge number of workers. This accelerates the shortage of the labour force in the rural areas for farming activities (Le *et al.*, 2010). Hence, applying new technologies and mechanisation is an effective and reasonable solution to reduce costs in rice production.

Unfortunately, most communes in the Cho Moi District have poor actual mechanisation capability because of three main reasons. First, investment costs for mechanisation facilities such as rice harvesters are very high and it takes a long time to create economic returns. This is not tempting to investors. Second, local production conditions are not set up for mechanisation. For example, the planted rice area per farm is small and distributed sparsely. The last one is that rice farmers are reluctant to adapt to mechanisation.

The last, but not least limitation in rice production capability at the commune scale is flood control. Studies, like that undertaken by Nguyen (2008), show that reasonable flood control and organic fertilizer application, energize the fertility of soil in the Cho Moi District. The flood control factor in the present study refers to approaches to manage the floods e.g. ignoring the third cropping season to allow water to inundate into the fields. This helps to gain alluvium and to protect dams and dykes through balancing the water level inside and outside the dyke system. This factor has a poor actual value because of asynchronous flood control between farms in the local area. After several intensive seasons, rice farmers stop cultivating crops in the flooding season to improve the farmland capability thanks to alluvium deposition. But, vegetable farmers do not accept this approach because floods can damage their crops. Consequently, flood control is interrupted and ineffective.

The land capability increases to a higher level when the actual value of the limiting factors is corrected and amended. Often the correction needs intervention from external inputs or solutions. In the three farming systems in this study, land capability analysis reveals that rice has the lowest capability because of several limiting factors, and rice is a major cultivation pattern in the Cho Moi District. Therefore, the rice system was selected as an example for modelling the land capability by adjusting the limiting factors, the two remaining systems can be adjusted in a similar way.

To model the actual value of the limiting factors, a group discussion was organized to identify necessary external inputs and solutions. Participants were land users, land managers, agronomists, and land planners. To be modelled, the limiting factors must be dominant and improvable. That means if a limitation is corrected; it results in positive impacts on other ordinary factors in terms of the land capability contribution. Moreover, external inputs and solutions must be feasible and reality-based. Costs and duration to carry out the solutions to change the limitations can be estimated using knowledge and available data in the research site.

According to the focus group discussion results, there are four factors that can be adjusted to raise the land capability. The adjustment needs to consider several solutions and assumptions to undertake and overcome the limitations. Table 7.15 reports the inputs and technical details, as well as the physical and management solutions available to increase the land capability in the Cho Moi District, for rice cultivation. These solutions are not perfect, but they are the best choices using existing knowledge and under the current circumstance in the study area, which can promote the land capability increase to the highest level. Costs and time to carry out the land capability improvement can be estimated and measured for each commune. Nevertheless, their description is excluded in this chapter because the goal of the study doesn't include analysing the economic efficiency of the land capability improvement.

The farmland capability scenarios in the Cho Moi District are revealed when the solutions and external inputs shown in Table 7.15 are applied. The results of farmland modelling are then compared with the current land capability in the Cho Moi District (Figure 7.4, 7.5 and 7.6). There is a marked improvement in the land capability between the current and the modelled scenarios. The highest capability of the current farmland is the "high" level (Ci = 6.0-<7.5) for rice cultivation, which applies to four communes and shares 27.29% of the Cho Moi District land area. Fourteen other communes have a moderate capability, accounting for 72.71% of the land area.

Table 7.15: Solutions and assumptions proposed to improve the land capability at the commune scale, for rice cultivation in the Cho Moi District

Corrected factors	Feasible solutions/inputs	Important assumptions/requirements
Pest	Application of certified seeds or seeds at the higher standards, as well as pest resistance rice cultivars	More than 80% of rice farmers
	Training on plant protection for farmers	More than 50% of rice farmers
	Pest management and plant disease forecasting	Employ at least one commune extension worker
	Integrated pest management	More than 80% of rice farmers
	Reasonably seasonal calendar distribution	More than 80% of rice farmers
Seed	Build up and develop informal seed supply systems	Three seed clubs/commune
	Build up and develop formal seed supply systems	One formal seed station/district
	Seed experiment, seed quality inspection and management	One formal seed station/district
Mechanisation	Mechanisation loan application	Interest rate is zero
	Rice harvesters allocation to commune	Two machines/commune
	Reasonably seasonal calendar distribution	More than 80% of rice farmers
Floods	Reasonably seasonal calendar distribution	More than 80% of rice farmers
	Dyke/dam system upgrading and improvement	Regional dyke system

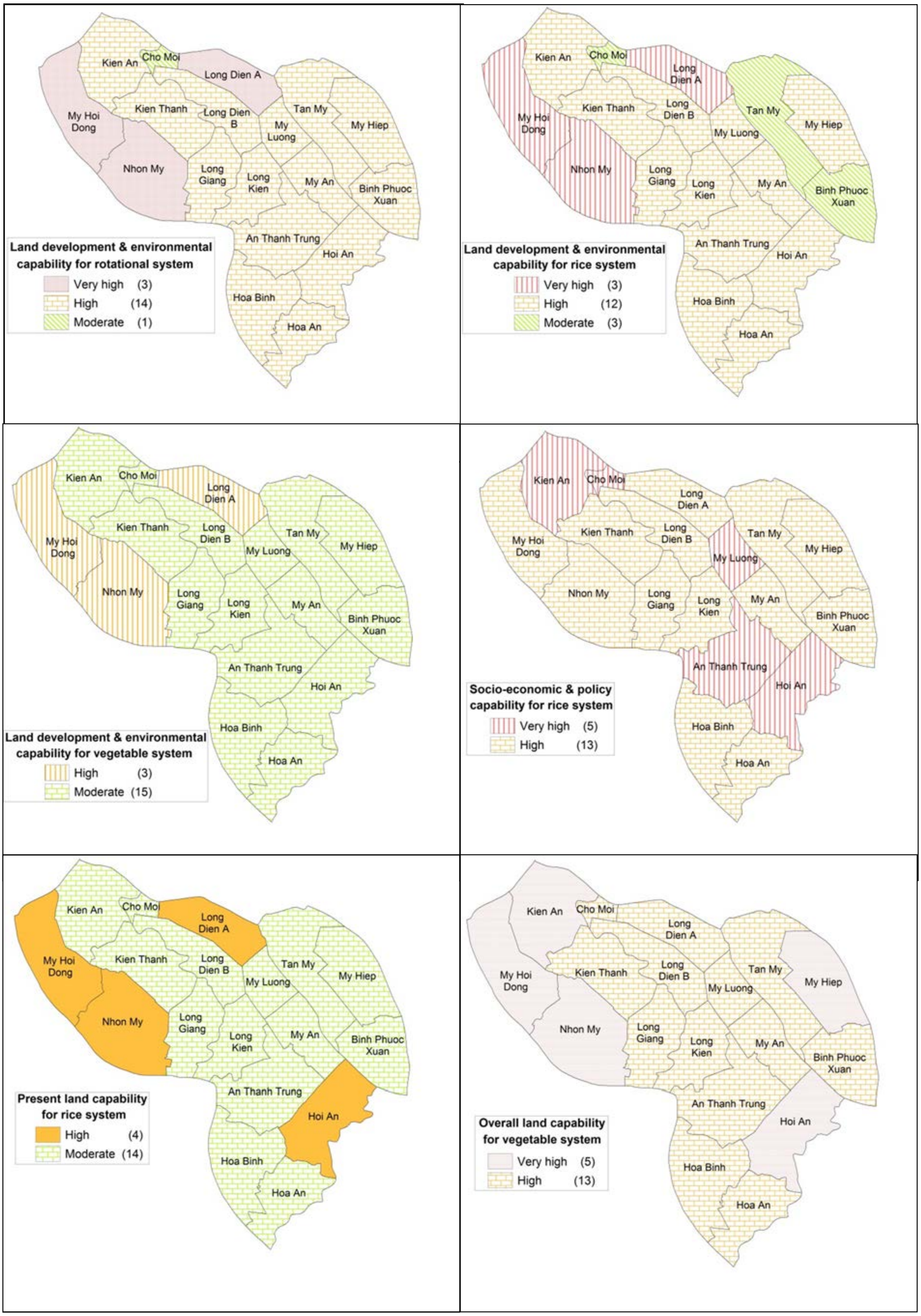

Figure 7.4: Current farmland components and overall capability ratings for selected farming systems at the commune scale

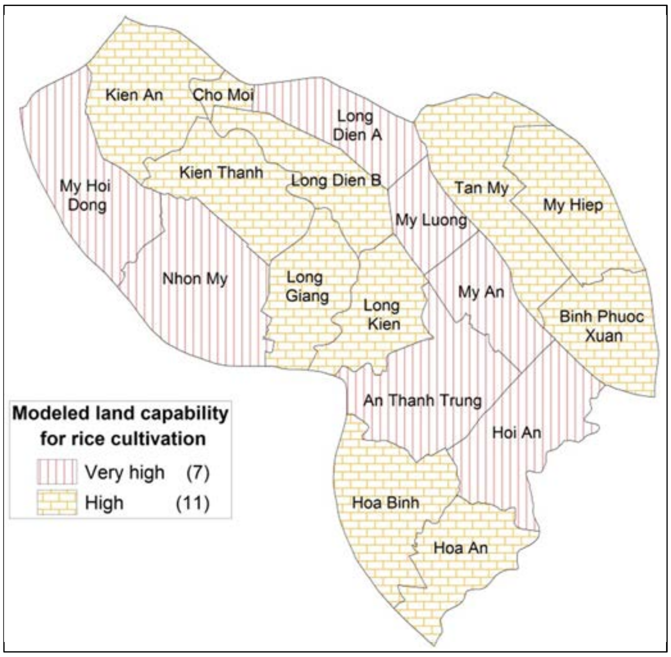

Figure 7.5: Modelled farmland capability for the rice system

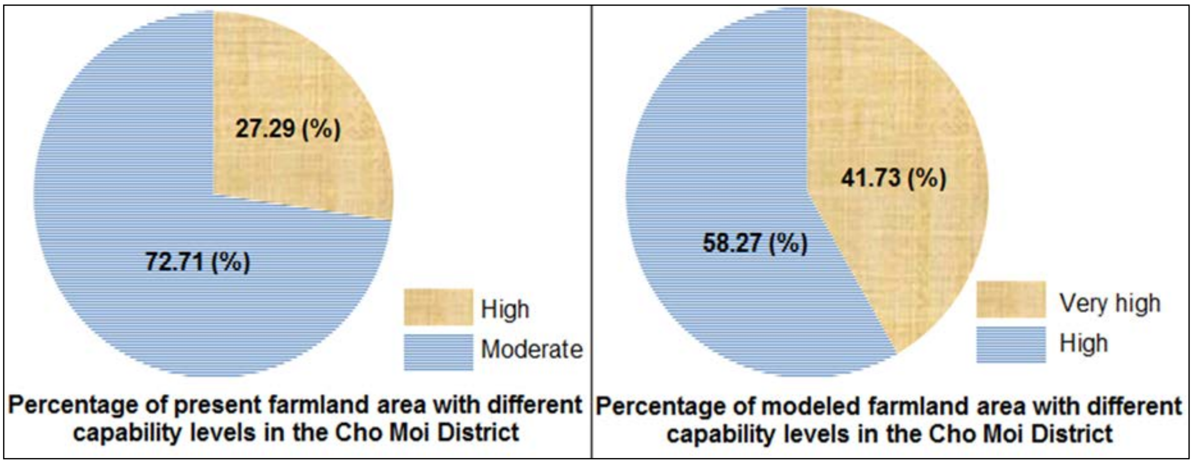

Figure 7.6: Comparison between the current and modelled farmland capability levels in the Cho Moi District according to area percentage

After amendments, the modelled farmland capability reaches the highest level at "very high" ($Ci \geq 7.5$), covering seven communes, and occupying 41.73% of the Cho Moi District land area, while the remaining land areas have a high capability level.

Data relating to the land capability analysis reveal that interventions for land improvement help to increase the land capability, from a high to a very high level for four communes, from a moderate to a very high level for three communes, and from a moderate to a high level for eleven communes in the Cho Moi District. This increase indicates that technical and management measures are necessary in sustainable development and effective land capability management in the study area.

The modelled farmland capability also indicates that the majority of the land area in the Cho Moi District is suitable for agricultural practices, particularly that the land has high and very high capable for rice cultivation. In fact, the Cho Moi District farmland is 23,544ha in total, of which 18,314ha (77.79%) were used for growing rice in 2007, and this area stabilized at over 17,332ha in 2009 (Cho Moi Department of Agriculture and Rural Development, 2009).

The current high level of planted rice area, confirms that modelling the farmland capability is feasible and reasonable in the local context because rice farmers only cultivate rice on high capability lands. In addition to upgrading the land capability, model scenarios provide an extremely visual contribution to land use planning and land management. These scenarios allow alternatives to be reviewed and provide opportunities for land users and land managers to improve and maximise the utilisation of their land resources.

Land capability assessment, through considering and analysing components and factors in the AMS, is extremely useful and provides a practical alternative for studying farming conditions in the study area, especially in terms of the distribution and allocation of crops to suitable land resources to deal with constraints such as climate change. When the actual values of the impact factors and components in the AMS are identified, land users and land managers can determine the capability of their land resources. Further, the land capability can be predicted by the introduction of modelled values of components and factors in the AMS. This offers invaluable overviews for land managers involved in sustainable land management.

7.3.3 Farmland capability analysis at the farm scale

The farm scale is the lowest cultivation unit at which the land capability is determined. Analysing the land capability at the farm scale results in systematic and thorough land evaluation and planning, for the commune and higher scales as well. In the current study, thirty farms (farmers) in three communes were investigated. Of these, ten farms in the Long Dien B Commune were surveyed and information was collected on land capability for rotational cropping; another ten farms in the Hoi An Commune were surveyed for rice, and another group of ten farms in the My An Commune were surveyed for vegetables. These communes were selected to analyse the land capability at the farm scale because they were dominant and representative in terms of the selected farming systems, compared with other communes in the study area. Further, available data on farmland capability is well published and farmers in these communes were willing to collaborate and share information on matters relating to the farmland capability.

The popular attributes of farmers (households) in the study were gathered during the farmland investigation. Briefly, the farmers' age ranged from 26 to 64; the average was approximately 46. This average age indicated that farmers were very well experienced in farming practices. Additional information about farmers such as the number of family members, number of agricultural labourers and the standard of education were also gathered and compiled (Table 7.16) to analyse the land capability. In the study area, the planted areas per household are quite small, the maximum planted area per household is 5.22 ha and the average is 1.28. Other important attributes and characteristics of farms and farmers were acquired and computed as capability factors into components in the AMS to determine the land capability index.

Table 7.16: Several main characteristics of thirty surveyed farmers (farms)

Characteristics	Min	Max	Mean	SD
Age (years)	29	64	46.47	9.10
Total family members	3	8	4.40	1.33
Agricultural labourers	1	4	2.07	0.69
Education standard*	1	5	2	0.89
Planted area (ha)	0.23	5.22	1.28	1.17

* *1: illiterate, 2: five schooling years, 5: more than 12 schooling years.*

At the farm scale, three impact components were nominated for farmland capability analysis. They were the biophysical, technical and management, and socio-economic components. Each component included many corresponding factors contributing to the land capability.

Component and overall capability indices for farming systems at the farm scale are computed and displayed in Table 7.17 and Appendices 21, 22, 23, and 24. According to the class rating of the land capability adopted in the practical model, capability indices at the farm scale vary between components in the AMS and between selected farming systems. The maximum capability index of components for the farming system reaches the "very high" level (Ci = ≥ 7.5) in all, excluding the technical and management component for the rice system, while the minimum capability index drops to a low level (Ci = 3-≤4.5). This minimum capability occurs with the technical and management, and socio-economic components for the rotational system, the bio-physical component for the rice system, and the socio-economic component for the vegetables system. The most common average capability index of components is the high level (Ci = 6-≤7.5), excluding the technical and management, and the socio-economic component for rotational system that has moderate level of capability (Ci = 4.5-≤6.0).

Table 7.17: Component and overall capability indices of farming systems at the farm scale

	Biophysical	Technical & management	Socio-economic	Overall
Rotational (n=10)				
Max	8.00	8.36	7.84	8.17
Min	5.29	3.30	4.04	4.12
Average	**6.24**	**5.80**	**5.82**	**5.87**
Rice (n=10)				
Max	7.59	7.40	7.66	7.33
Min	3.77	5.00	5.96	5.48
Average	**6.24**	**6.39**	**6.65**	**6.43**
Vegetables (n=10)				
Max	8.52	8.43	7.72	8.09
Min	5.48	4.62	4.24	4.97
Average	**7.46**	**6.02**	**6.29**	**6.32**

The results of the capability index analysis at the farm scale (Appendix 25) reveal that the biophysical component has a different average capability index for the selected farming systems (statistical significance level at α = 5%). It has a very high capability for vegetables, but a high capability for rotational and rice systems. In contrast, there is no variation between the overall average capability indices of all three farming systems.

According to the land capability classification in the practical model and the results of the land capability index calculation in the study area, the overall average land capability of the studied farms is the moderate level (Ci = 5.87) for the rotational system in the Long Dien B Commune; and the high level for rice (Ci = 6.43) and vegetables (Ci = 6.32) in the Hoi An and My An Communes respectively. However, statistical analysis results reveal that the overall average capability index of those farming systems in the three communes is not different (statistical significance level at $\alpha = 5\%$, Appendix 25). This could confirm that the actual farmland capability between investigated farms for rotational, rice and vegetables systems in selected communes is consistent and similar. In other words, the capability of farms located at a similar scale or in a similar area could have the same capability because they have the same attributes and characteristics.

Limitations to the land capability at the farm scale are different from farm to farm. In general, the technical and management, and the socio-economic factors are common constraints for rotational and vegetables systems. Whereas, the biophysical traits, are constraints for rice cultivation.

There is an interesting observation when a comparison is made between the results of the land capability for a specific land use type between the commune and farm scales, after running the practical model. The findings of the land capability analysis at the commune scale indicate that the Kien An, Long Dien B, and My An Communes have moderate, high, and high capability for rice, rotational, and vegetables cultivation respectively. At the farm scale, data on land capability analysis show that the average capability level of farms for those systems is similar to the commune scale (rice system in the Hoi An Commune and vegetables in the My An Commune, Table 7.18).

Table 7.18: The results of the land capability analysis at the commune and farm scales

Farming systems/commune	Capability level at commune scale	Capability level at farm scale
Rotational/Long Dien B	High	Moderate
Rice/Hoi An	High	High
Vegetables/My An	High	High

Farms studied in communes for farmland capability analysis are selected randomly. The fact that the commune and farm have equivalent farmland capability levels indicates that selected components and factors in the AMS for farmland capability assessment, and the AMS itself, are reasonable and suitable for the study area.

The results of the farmland capability assessment at the farm scale not only offer a useful reference for land evaluation at the commune scale, they also consolidate the consistency and accuracy of the land capability in the land evaluation systems from the local to the farm scale. Moreover, these results are critical evidence to assert that the theoretical model for farmland capability determination in the current study could be adapted to be suitable, and applicable in many scales, from the regional to the farm scale.

Land capability for the rotational cropping in the Long Dien B Commune at the commune scale differs slightly from the farm scale. Land is highly capable at the commune scale, but moderately capable at the farm scale. The possible explanation could be that running the AMS (theoretical model) at the commune scale is designed to determine the farmland capability as an overview of the whole commune. Land capability evaluation provides a general indication at the local level. Whereas, land capability analysis at the farm scale, is more detailed and hence at a higher accuracy for specific cultivation units.

Also, for the farmers investigated to test the rotational system in the Long Dien B Commune, 7 out of 10 (70%) of farmers have limitations to their land capability, mainly associated with the technical and management, and the socio-economic factors. For these farms, the big issue is how to improve the actual land characteristics to meet the land use requirements. This is the reason why results of the land capability analysis for the rotational system, in the study area, at the farm scale, are lower than at the commune scale.

It is clear that the land capability for a land utilisation type varies from farm to farm in the commune. This is because actual attributes and characteristics of the farms, which were involved in the AMS to determine the land capability, such as farming experience, accessibility to locally agricultural services, land preparation technique, and so forth, are undoubtedly different.

Since the farm investigation has a small sampling number, in some cases the actual capability of the land resources in the land evaluation could not be fully determined. This is an important observation for further land evaluation studies. Researchers need to be careful when taking samples for land capability analysis, particularly at the farm scale. To generate consistent and appropriate results in the whole land evaluation system, samples nominated for land capability analysis need to be representative and reasonably distributed at each corresponding scale.

In land evaluation and land use planning, field survey, farm investigations and land capability analysis at the farm scale are the fundamental activities needed to obtain the primary attributes of the land in true production conditions (FAO, 1993). Based on the results of the above activities, land experts can build up, develop, or adjust the main criteria for land evaluation to suit the local circumstance. This also provides a practical reference point to develop, categorise and standardise values for relevant capability levels for each criterion, as well as the overall land capability indices.

Land capability analysis at the farm level also offers useful field survey information for predicting and assessing the land capability at the higher levels such as the commune and the district. It indicates specific limiting factors to the capability of land. In turn, solutions and external inputs can be formed and proposals put forward to deal with the limitations. The solutions can involve technical intervention, management change, or improved investment which can be applied to improve individual farms. They can also be modelled to become the standard approach to improving the land capability at a wider scale. Land analysis at the farm scale not only has important significance in the whole land capability management system; it also involved a ground truthing (on-site investigation) of the land capability because the farm is the largest scale for determining the potential of the land resource.

The aggregative results of land capability assessment from lower scales to a higher scale (farm to commune, then commune to district) may cause different results than that from the analysis at that higher scale. This is because the land capability at a higher scale (e.g. district), based on the analysis of land capability of many lower evaluating units (e.g. communes). Moreover, this difference is obvious because factors considered in the AMS for farmland capability assessment at three administrative, are different.

7.4 Summary

The case study, based on the practical model, is an appropriate way to test the theoretical model. Findings in the case study provide feedback for and complement the findings of the theoretical model for farmland capability assessment. This is the overall objective of the study. This chapter presented two key parts, the results of converting the theoretical model to the practical model, and the findings in the case study implementation.

Before the theoretical model for farmland capability assessment was modified to create the practical model, three suitable farming systems comprising rotational rice-vegetables, single rice, and single vegetable, were proposed. The next step was identifying reasonable administrative scales for the farmland capability assessment. Five administrative scales i.e. province, district, commune, hamlet, and farm, were developed in the AMS to determine the land capability. These scales were refined and modified to three scales, district, commune, and farm, in the practical model as applied to the case study.

Then, three key land capability considerations were outlined before the author devoted a major section to describe selected components and factors in the practical model for land capability assessment. There are many components and factors developed in the theoretical model, these factors were adjusted according to the proposed farming systems, selected administrative scales, and the suggested aspects of land capability in the practical model. A land capability classification system and standardised capability values for factors in the AMS were developed in this chapter. The last important part in the theoretical model modification is that the weight of every land capability component and factor in the AMS were analysed and reported.

The second key content in this chapter is the results of the case study implementation through the land capability analysis at the three administrative scales. Land capability analysis in this study was carried out at the three scales, district, commune, and farm, and for three selected farming systems, rotational cropping, single rice, and single vegetable. Overall farmland capability was measured by the individual capability of components and corresponding class-determining factors in the AMS. These factors belong to the four key components: biophysical, technical and management, land development and environment, and socio-economic and policy.

At the district level, land capability was analysed for general agricultural production systems only. Analysis results showed that the land capability varies between components in the AMS and between districts, with the capability levels ranging from moderate to very high capability. These results compare favourably with current land suitability classification in the local area. Limiting factors to the land capability in mountainous areas are annual drought, irrigation and drainage system, environmental hazards, and environmental control ability. While, flood level, transport system, applied ability of mechanisation, flood control ability, and policies used for agricultural products consumption are limitations to the land capability in upstream areas.

At the commune level, overall land capability differs between communes and selected farming systems. A majority of communes have a moderate capability for the rice system whilst most communes reach a high to very high level of capability for the rotational and vegetable systems. Land capability analysis results indicate that there are many factors which currently have negative impacts on the capability of land for rice cultivation. They consist of the biophysical, land development and environmental factors like pests, seed sector, applied mechanisation, and floods control. Fortunately, modelling scenarios of land capability in the study area revealed that the land capability improves and increases significantly when limitations are removed by introducing technical and management solutions, as well as introducing externally essential inputs and investments.

At the farm scale, the results of the land capability index analysis indicated that the biophysical component has different average capability indices between the selected farming systems (statistical significance at $\alpha=5\%$). They show a very high capability for vegetables and a high capability for rotational and rice systems. In contrast, there is no variation between the overall average capabilities of all three farming systems. Limitations to the land capability are dependent on the characteristics and attributes of each farm and change for both farms and farming systems. The pattern for rice and vegetables are similar according to the results of the land capability analysis when compared with those results at the commune scale. The rotational system is slightly different between the farm and commune scale.

Land capability analysis at different scales gives a systematic and complete overview of the capability of the land resources. Meanwhile, the land capability consideration for several land utilisation types offers reasonable alternatives and opportunities for land users and land managers to maximise the land resources and to practice sustainable land management. Identification of the limitations along with land capability classification for scales and farming systems, generated by the land capability analysis, will result in improved land use planning and management. Based on the study results, land managers can develop reasonable solutions to amend the current land capability at the farm level as well as offer satisfactory policies to manage effectively the land resources in the local area.

CHAPTER 8: GENERAL DISCUSSION

8.1 Introduction

Land is a huge habitat on which humans, plants, animals, and other organisms live and develop (UNEP, 2002). Land refers not only to soil, but also to plants, animals, landforms, climate, hydrology, geology, topography, vegetation systems and fauna, together with the socio-economic attributes and land improvements (FAO, 1976; 1985; 1993; Rowe *et al.*, 1981; Rossiter, 1996).

Single land evaluation often results in a lack of understanding of the actual capability of the land resources for any land use type. It doesn't provide sufficient information for decision making relating to alternatives in the land use planning procedure. A multi-dimensional land capability assessment approach is developed in the current work through an integration of the biophysical, technical and management, land development, and socio-economic factors in the AMS. By this means the land capability assessment gives valuable information for selecting appropriate land use types in land use planning. Spatial data and related attributes relating to the land are incorporated into a system, to analyse the land capability. Moreover, AHP and GIS proved to be useful tools to improve the results in the land capability determination.

The previous Chapters 5, 6 and 7 investigated the empirical results of the theoretical model modification for land capability assessment, as well as the case study implementation and the data from the field work. The aim of this chapter is to discuss the research findings and their relationship to the existing relevant theories described in the literature review (Chapter 2 and 3).

The chapter begins with a discussion on the selection of suitable farming systems, administrative scales and consideration of the land capability in land assessment. The rest of this chapter deals with nominating effective components and corresponding factors (in the AMS), and standardising capability values for factors. The next theme of the chapter is a discussion on the importance of components and factors in the AMS in determining the land capability. The final section in this chapter discusses feedback from the case study implementation.

The discussion revisits relevant existing theories to provide background to how the practical model is adapted from the theoretical model to apply to the case study. It also links the findings in the case study implementation with existing theoretical literature in order to explain why the theory can be applied successfully in the study area.

8.2 Conversion of the theoretical to the practical model

8.2.1 Selection of suitable farming systems and administrative scales

The purpose of land evaluation is to respond to two key questions: (1). which areas of land are best suited for any specified kind of land use? and which kind of use is best suited for any given area of land? (FAO, 1993). A systematic way of doing land evaluation is clearly described in *A framework for land evaluation* (FAO, 1976) and detailed procedures are given in the guidelines on evaluation for rain-fed agriculture, irrigated agriculture, forestry and extensive grazing (FAO, 1985).

An Agricultural Management System (theoretical model) designed to determine the land capability in this study is a broad universal model. It can be modified and revised to suit its application in many parts of the world. In the land assessment approaches mentioned above, the first and most important step is the identification of promising land use types. Therefore, suitable land utilisation types need to be proposed to test the theoretical model.

The criteria for choosing the land use types for testing the theoretical model were based on the primary produce (socio-economic contributions), current land use and existing management practices. A major category of land use represents a large subdivision of an agricultural production system i.e. temporary crops are proposed to evaluate the land capability at the district scale, while more specific land utilisation types (farming systems) including rotational rice-vegetables, single rice and single vegetables systems are selected at the commune and farm scales.

The land capability is performed from the national, to the local and then the farm scales. Land capability assessment for specified land use types at the regional scale, i.e. district, is not necessary because those general land use types differ from one location to another location. At this scale, the land capability is related to general land uses and provides a broad indication of capability which is sufficient. In contrast, the land capability can be determined for specific land use types at the local scale i.e. commune and farm scales. The commune scale is the highest generalized administrative scale at which the land capability for specific uses can be mapped. Meanwhile the farm is the ultimate unit of production used to examine the land capability, for a specific use. Land capability assessment at the farm scale provides primary and specific information for predicting and evaluating the land capability at the commune and district scales. It also provides a foundation for the consistency and accuracy of the land capability assessment in the land evaluation systems from the regional (district) to the local (commune) and farm scales.

Therefore, considering the land capability for the overall agricultural production systems at the district level, and farming systems at the commune and farm levels is rational. It ensures that the land capability is appraised logically, for both the general and specific utilisation types, and from the regional to the local and farm levels.

Rice and vegetables are two dominant systems in the research area and the Mekong Delta in general (*see Chapter 5*). These systems contain the most important attributes and characteristics of popular agricultural systems, and therefore the theoretical model tested well on those systems meaning that the theoretical model can be flexibly applied to other crops and to other geographical locations.

The selection of the general agricultural systems at the district scale and three popular farming systems at the commune and farm scales for land capability assessment ensure the theoretical model is fully tested. This conforms with key principles in land evaluation (FAO, 1976; 1985) being that the land capability has to be considered for more than one land utilisation type, and examined from the macro to micro scales.

Objectively, land cannot be graded from "best" to "worst" independent of the kind of use and the management practice because each kind of use has special requirements (FAO, 1993). Therefore, introducing more than one kind of land use type in land evaluation offers many alternatives for land users and land managers. This is one of the essential conditions to make appropriate decisions for land use planning and management.

Development of the theoretical model is based on the literature review. The structure and operation of the model to determine the land capability are systematized, synthesized and refined from available land evaluation theories and methods such as those proposed by the FAO (1976, 1985, and 1993) and others. The theoretical model worked and generated outputs (land capability classification) suitable for application to the current local land capability classification. This indicates that the selection of farming systems and administrative scales was reasonable. Therefore, input components selected to design the theoretical model (AMS), were valuable and significant.

8.2.2 Consideration of the land capability

The use of the land is directly affected by the biophysical, technical, socio-economic and environmental factors. Therefore, consideration of the land capability in terms of productivity, economics, and sustainability is an integrated way of undertaking land capability evaluation. This allows the land capability to be examined from the perspective of a number of disciplines.

For land evaluation, in which land capability aspects need to be considered, success depends on defining the purpose by land evaluators and on taking note of other relevant land evaluation studies. Some studies focused on the biophysical characteristics (e.g. Thao, 2008), several studies concerned the economic parameters (Samranpong *et al.*, 2009) and others linked both the biophysical and economic factors (Baniya, 2008). Although for this research the land capability analysis considers three major aspects, comprising productivity, economics and the environment, the theoretical model design can be adapted to run successfully for different land uses. This is because the agricultural management system design includes a range of factors impacting on the land capability. By conducting the land capability analysis, the capability and limitation of individual factors in the AMS, according to different capability considerations, are identified. This is helpful in land development and improvement.

The purpose of farmland capability assessment is to determine and introduce the best uses for a given land area when undertaking land use planning. Meanwhile an important requirement in land use planning is determining how to balance the three main goals, environmental health, economic profitability, and social and economic equity.

Single focused and independent land capability evaluation could result in insufficient information being available to make informed decisions on planning the land, and in some cases could lead to a failed attempt at land use planning. A multi-disciplinary consideration of the land capability in the current study not only offers critical information for land use planning, it also reveals relationships and interactions between factors which contribute to the land capability. This approach has proved to be very useful and significant in land improvement and management.

8.2.3 Selection of components and corresponding factors in the practical model

Refining suitable components and the corresponding factors in the AMS is the most important activity to create the practical model that is applied in the study area to determine the land capability. The refinement actually determines the major groups of, and land use requirements for, given land use types (farming systems).

In reality, farming systems are diverse and variable. They vary from place to place depending on the terrain, climate and weather, cultivation custom and other related conditions. Therefore, land use requirements are different not only between land use types, but they also depend on the biophysical, technical, environmental, and socio-economic conditions of different land areas. Requirements for certain farming systems e.g. single rice cultivation in the plain area (delta) definitely differ to requirements for rice systems in the upland and mountainous areas. For example, annual average rainfall can be a key requirement for rice production in the highland areas, but it is not considered in rice production in the delta area. The logical reason is that water is always available in the delta (for rice production) and it is in short supply in the highland areas.

The central argument for the development of criteria for land evaluation is that class-determining factors (FAO, 1976 and 1985) are associated with given land areas, and also for specified land utilisation types. No universal set of requirements for a farming system is proposed because requirements for a farming system in one area may not be similar to another area. This point adds strength to the theory of developing the theoretical model. It explains how the AMS can cover, and contain factors that are required for different farming systems, and is applicable to many parts of the world.

The refinement of components and corresponding factors in the AMS is heavily influenced, and oriented by the selection of three farming systems and three administrative scales. It is also based on the knowledge of local land managers, with respect to the study area context. Factors involved in the AMS to determine the land capability vary between farming systems (rotational, single rice and single vegetable) and administrative scales (district, commune, and farm). The variation can be found in detail such as the units and forms for measurement of factors at different evaluation scales.

The criteria selected to choose factors in the AMS to implement the theoretical model were based on the factors individual capability to contribute to the overall land capability in terms of productivity, economics and sustainability. Many factors in the theoretical model are not suitable as factors impacting upon the land capability in a specific geographical area. This confirms that not all factors developed in the theoretical model can be used in the practical model to assess the land capability. However, this also raises debate regarding the perceived benefits and costs of developing an efficient agricultural management system for land capability assessment.

To understand clearly the above statement, it is necessary to revisit what constitutes the theoretical model. The theoretical model is a system, in other words, it is an integrated combination of many previous land evaluation techniques and approaches, as well as land evaluation theories that are commonly applied. The theoretical model comprises a huge number of factors which influence the farmland capability. This "global" model can be widely applied, and is suitable for adaptation for many land utilisation types. Therefore, it was acceptable that during the modification and application of the theoretical model, several factors were not required for the three selected farming systems in the study area.

Nevertheless, there have been no further factors proposed for inclusion in the practical model needed to undertake the case study. This indicates that the designed factors in the AMS are appropriate and sufficient, and the theoretical model is robust enough and acceptable for application in many geographical locations, and for many farming systems. Its development is also the ultimate goal of this study.

Moreover, various choices of factors in the AMS for land capability assessment at the district, commune, and farm scales, as well as for rotational rice-vegetables, rice, and vegetables systems show that the theoretical model provides an important foundation for, and is valuable in, determining the land capability. Through the AMS, the land capability is examined systematically from the lowest production unit, the farm, to the regional level, the district. Likewise, the land capability can be determined for many land use types. The AMS is very useful for land users and land managers in making appropriate decisions on which alternatives are reasonable in land use planning, and in optimizing their land resources.

8.2.4 Standardised capability value for factors

The overall land capability for a particular use is determined based on the contribution of individual factors in the AMS. Standardising the capability value for factors involves identifying which influence level (class) each factor is in, in contributing to the success of a specific land use. Each factor is divided into five capability classes based on an objective assessment (by land experts) of the appropriate range for each factor, and for a specific land use. The next step is to collect field data relating to each factor, which is then compared with the standardised capability values to determine which capability class the field data falls into. The final contribution of each factor is formed from the analysis of its actual value and its importance in the AMS.

A given land area has a particular capability for a specific farming system when the impact factors (land characteristics) have been calculated for that farming system. The capability of each factor, in contributing to the overall capability of a farming system, is explicitly different. Based on placing the farm based capability values into the corresponding capability classes (e.g. very high, high, moderate, low and very low), the capability class of every factor is easily determined.

Determining the capability class of each factor plays an important role in land improvement and development because factors that have the lowest capability will become the focus of proposed solutions, external inputs and investments. In this way the lowest capability class for a specific land use, on a particular area of land, can be raised to the next highest level of capability.

In the study area, there have been no uniform set of capability values for factors according to capability classes. The values are generated by the standardisation of the criteria and rules currently being applied in the study area. The reason is that the output from land evaluation studies is different between regions and localities. The standardisation considers the specific objectives and requirements of various land evaluation studies.

Moreover, criteria and standards for land capability classification are different between land evaluation study areas. For instance, the rainfall factor having a value of 6-7mm/day can indicate the land has a very high capability for rice production in the wet season, or in irrigated areas in the Mekong Delta. But, in the dry season, or in rain-fed areas, the optimal rainfall for rice production is 8-9mm/day (De, 2008). Therefore, the rating capability values and classes for factors in the AMS is based on the interpretation and knowledge of local land managers and experts with respect to characteristics and attributes of the present land use.

The theoretical model doesn't attempt to set up specific capability values relevant to capability classes, for factors, it only introduces and describes principles and activities needed to standardise the capability values. The results of standardising the capability values have shown and confirmed that the development of fixed capability values for factors is unnecessary in the AMS. This contributes to the flexible and adaptable nature of the theoretical model, which allows the model to be easily modified and applied to various contexts.

8.2.5 The importance of components and factors in the AMS

The importance of components and corresponding factors in the AMS in contributing to the land capability is indicated by their weighting. A weighting technique and a theory on the analytical hierarchy processing (Saaty and Vargas, 2001; Bhushan and Rai, 2004) are employed to weight the components and factors. Score values of each of the factors are created in priority order depending on the degree of influence of the components and factors on the land capability.

Each farming system demands different requirements for growth and development, and this is the case at every administrative scale. The land managers at each scale have different concerns in relation to the land capability. Therefore, the weight of components and corresponding factors in the AMS varies between land evaluation scales, as well as between farming systems.

A component, or factor can be very important for the land capability at the district scale, but it may be considered minor, or not considered at all at the commune and farm scales. Similarly, a factor may have an important impact on the land capability for rice production, but is may contribute less to the land capability for vegetables cultivation.

This variation above illustrates that an agricultural management system for farmland capability assessment has a diverse and complex structure. It includes many hierarchical levels and sub-systems which work together to achieve a common purpose. The lowest hierarchical level is the farm, the next higher level is the commune and the highest level in the hierarchy is the district.

According to systems theory and the characteristics of a system, such as the geographical boundary, as outlined by the FAO (1993), Haaf *et al.* (2002) and Pidwirny (2006a and 2006b), a system is a set of components which together can be used to achieve a common goal. Large systems are regularly composed of one or more smaller systems working within its various elements. Applying the characteristics of a system to the current study, allows the components and factors making up the AMS to be used to determine the land capability from the regional scale to the farm scale. These components and factors have particular attributes that may be perceived and measured according to their relationships. In other words, components and factors are separate interacting parts of the AMS and these inputs are processed to create the outputs (land capability classification).

When the importance of individual components and factors are determined, the relationships and interactions between factors in the AMS can be identified. Weighting results reported in Chapter 7 showed that relationships and interactions between administrative scales, and between farming systems, are dependent. To illustrate this, the land development and environmental component is most important at the district scale (weight is 0.410/1), but at the commune scale (weight is 0.300/1) it is less important than the biophysical component (weight is 0.384/1), and is not considered at the farm scale.

In contrast, the biophysical component has the highest impact (weight is 0.384/1) on the land capability at the commune scale, but has a low and very low influence at the district and farm scales respectively. Another illustration is that the factor "policies used for consuming agricultural products" is ranked as the most importance at the district scale, but it is not considered at the commune and farm scales.

The relationships and interactions within and between components and factors in the AMS, in contributing to the land capability, are clearly displayed. Using the AHP technique, the total weight index of components, or factors, in the AMS is 1 (equivalent to 100%). So if a component, or factor, has played a major role in the AMS then that means other remaining components, or factors, may have contributed less to the land capability.

In other words, the land capability is determined by the integration of individual components and factors. The impact of a certain component, or factor, on the land capability is always related to, and interacts with, the impact of other components, and factors, in the AMS. This is the nature of the AMS in that it uses interrelationships between elements in the system to achieve a common purpose.

Weighting components and factors in the AMS has been significant and helpful for practical land evaluation studies. It shows which factors in the system need to be improved to increase the land capability. In addition, thanks to the interactive nature and relative characteristics of factors in the system, an external investment can be used to correct many factors in order to upgrade the land capability. This is one of the benefits and advantages of using visual input (maps and table) when undertake the land capability assessment through an agricultural management system. The land capability analysis not only examines the impact of the individual land characteristics, it also considers the impact of relationships and interactions between different land characteristics on the land capability.

8.3 Feedback from the case study implementation

The case study is a critical way to test the form and applicability of the theoretical model. It is undertaken on three farming systems and at three administrative scales, with the assistance of the AHP to weight land characteristics, and uses GIS techniques to map the land capability.

It is naive to conclude that the model design is perfect for land capability assessment, since the model operation depends on various specified conditions, and inputs for running the model. However, the results of the land capability analysis displayed in Chapter 7 confirm that the theoretical model is well adjusted and works well in the study area. The correspondence between the land capability outcomes generated from running the model, and the land capability classified by the local land managers, is critical evidence confirming the model suitability.

Land assessment in the case study involves a multi-sector approach to analysis. It requires the participation of many stakeholders in determining the capability of the land. This reflects the present trend in land evaluation (FAO, 2007b). In the process of land evaluation, the land capability is synchronously examined and balanced between land characteristics. In this way, the results of land evaluation are more reliable and appropriate.

Today, the application of information technology, together with the use of support tools such as AHP and GIS, in land evaluation, is a common approach. However it is not an approach considered by planners, managers, and policy makers to land management in the Cho Moi District. Current research work exposed the need for ground truth (on-site) information to determine the land capability. Therefore, the socio-economic and technical attributes together with land quality information, are integrated in the AMS. Data in the AMS are designed to be comprehensive, systematic, easy to use and easy to update (Baniya, 2008) for land evaluation studies.

In the AMS, the land capability is examined and managed from the regional to the local and farm scales, and is suitable for many kinds of land use. Based on the land characteristics stored in the AMS, the land capability can easily be determined and predicted over a long period. When information on land quality is available, it is input into the AMS to create refined land capability output. The output can be stored in a GIS as a series database to be used for future land management.

The AHP has an important role in land capability analysis. It assists stakeholders to identify which land qualities have the most impact on the land capability. Furthermore, the AHP is also used to rank factors in the AMS in a hierarchical order in terms of their influence on the land capability. This is quite significant for land management because external investments can be used to deal with key land qualities.

Along with AHP, GIS is a helpful tool for use in land evaluation. It contains spatial information about the land that is linked to land attribute data stored in the AMS. GIS also maps, displays, and manages the land capability spatially from the regional to the farm scales. GIS provides visual overviews of the land capability for land managers, from the general to the specific. It can be used to indicate where the highly capable, or low capability land is, for given land utilisation types.

From a practical point of view, the AMS is designed to incorporate the AHP and GIS techniques providing an appropriate approach for land evaluation in the Cho Moi District and the An Giang Province, in general. Along with the physical land suitability evaluation, consideration of the socio-economic parameters, technical and management, and environmental factors in land evaluation is essential. This multi-dimensional land assessment approach offers alternatives for land managers to relieve pressures on land use due to, cultivation according to market orientation, changing farming systems, environmental pollution, and land degradation. In particular, the strength of such an approach is that the GIS based agricultural management system can effectively measure and predict the capability of farmland as well as map and monitor agricultural production.

Beside the benefits and advantages presented and discussed above, the modification of the theoretical model to determine the land capability in a specific case study area identified the following points which need to be considered:

(1). Many factors selected in the AMS are not always necessary, often only very important factors are required. If every factor is involved then that means that its impacts on the land capability will have less significance and this will produce a weak capability model. Land improvement and land capability modelling cannot be done when considering less important factors because it degrades the outcomes. Outputs from running the theoretical model will not been significant and valuable. This agrees with the theory on the AHP technique (Saaty and Vargas, 2001; Bhushan and Rai, 2004) where the number of elements in the hierarchical order for weighting should be less than fifteen;

(2). To work effectively, the theoretical model requires an accurate and consistent database system (quality of data). The database consists of primary and secondary data, which needs to be updated to the time when the land evaluation study is undertaken. A lack of available and up-to-date data will cause inaccurate results in the land evaluation;

(3). Data entered into the AMS to determine the land capability at the district and commune scales are representative data for the whole district, or commune. While data input in the AMS at the farm scale is focused on specific selected farms. Therefore, in some cases the results of the land capability assessment are slightly different. Again it is evident that the nature and attributes of the data demanded for the system are very important;

(4). Due to a lack of available data on land qualities in the study area, sample numbers for testing the model at the district and commune scales are not enough for statistical analysis to show variation of the land capability between farming systems. The results of the land capability analysis, generated from the model, are only compared with the current land use and land suitability classification in the study area. This is an unexpected limitation in undertaking the case study.

Indeed, the case study seeks to investigate exactly how the theoretical model can be adopted and how it can work using actual farm data. The case study demonstrates advantages and identifies limitations made apparent during the operation of the model. Thereby, valuable observation and supplementary information are created which complement the theoretical model.

8.4 Summary

A large part of the ultimate goal is tied to the development of the theoretical model designed to determine the land capability. This chapter clarified the links between the theoretical model and the practical model by discussing the findings of modifying the developed model and implementing the model in the case study presented in previous chapters.

Administrative scales and farming systems were selected to suit the study area context and the structure of the theoretical model. This selection allowed the model be tested systematically, from the regional to the farm scale, and for three land use types. Consideration of the land capability aspects and the refinement of the components and factors in the AMS, are influenced and oriented by those administrative scales and farming systems. The standardisation of the capability values for factors was based on the knowledge of the local land experts and land managers with respect to the research area context.

Weighting components and factors in the AMS reveals interactions and relationships between criteria for land evaluation, particularly the interrelationships within a component and between factors in the AMS in contributing to the land capability. Finally, the case study reconfirms the adaptability and applicability, as well as the benefits and advantages, of the AMS when used for land capability assessment. In addition, it is determined that AHP and GIS are two useful tools in land evaluation. The AHP technique assisted in the identification of the importance of every factor in the AMS. The GIS was used to map, display, and monitor the land capability. Furthermore, the case study offers a systematic approach to agricultural production management in the study area.

Besides the advantages, the case study also provides feedback about the limitations and key issues associated with applying the theoretical model to the actual conditions on farms. The value of the output from the operating model depends completely on the quality of the data, such as availability, reliability, precision, accuracy, competency, currency and consistency, which is entered into the system.

The following chapter will conclude the thesis with suggestions for further study.

CHAPTER 9: SUMMARY AND CONCLUSION

9.1 Introduction

This chapter summarises the findings, and highlights the outcomes from the current study, as well as providing directions for future empirical and theoretical research. It also outlines key implications for practitioners interested in land capability assessment. The chapter emphasizes major results of the study.

The chapter begins with an overview of the thesis. Next the key findings from modifying the theoretical model and the outputs from the case study implementation are presented. It then presents the contributions that this study makes to the relevant fields of knowledge, and notes limitations in the theoretical model application. Finally, the chapter provides suggestions for practitioners in the field of land evaluation and gives recommendations for further research.

9.2 Overview of the thesis

The research topic builds on past research into the integration of multi-disciplines in an agricultural management system to determine the capability of farmland. The land capability system is multi-dimensional, and is applicable to many kinds of land use type. This allows the relationships and interactions between factors impacting upon the land capability to be determined and analysed.

The general objective of the study was to develop an agricultural land capability management system (theoretical model), suitable for capability analysis at different administrative levels such as the district, commune, and farm for use in determining the efficiencies of existing farming practices. Results were based on modifying and testing the theoretical model through undertaking the case study in the Mekong Delta, Viet Nam.

Key questions in this study were: What are the major components and factors required for an effective agricultural management system (AMS) and how are these components and factors important to the farmland capability? Can a GIS based agricultural management system be developed to effectively measure the capability of farmland? Can a GIS be used effectively to map and monitor agricultural production in the study area (An Giang Province)? Prior to this research there was no integration of the biophysical, technical, environmental, and socio-economic factors into a unified system to consider the land capability. There was a similar lack of knowledge and studies based on the AMS in the study area.

Agricultural production, agricultural management, and agricultural land use all have a close relationship with the farmland capability. Hence, before the approaches and the theoretical framework for land evaluation are presented, issues relating to the agricultural sector are reviewed.

Chapter two began with a discussion on the role of the agricultural sector in socio-economic development and the negative impacts of agricultural practices. Agriculture promotes national economic development and provides opportunities and an investment environment for both the private sector and state economic organizations. It is a way of life throughout the world, with 2.5 billion of 3 billion rural people tied to agricultural activities such as food production. Moreover, agriculture contributes to social development in terms of job opportunities, income generation for rural inhabitants, hunger elimination and poverty reduction, and diet improvement as well. Specifically, agriculture is a key economic component for many developing and agriculture-based nations in Asian and African such as Thailand, Viet Nam, and Indonesia. However, agricultural practices can have negative impacts like environmental degradation to soil and water, can cause human health problems and can result in deforestation. The chapter concluded with a short introduction to agricultural land distribution at various scales, from the global, regional, national and down to the local study area context.

Chapter three discussed theories, methods, techniques, frameworks, and studies relating to land evaluation. The FAO and USDA are two core approaches commonly used to determine the land capability. Modified versions are created and applied in many parts of the world. The chapter investigated the procedures, key objectives, principles and activities associated with land evaluation. Specifically, many examples of land evaluation studies worldwide were summarised and analysed. The application of common support tools in land evaluation, such as the AHP and GIS, were also described in this chapter. The chapter demonstrated quite clearly that there is a need to structure an agricultural management system, which comprises multi-dimensional land qualities to determine the land capability.

The content of **Chapter four** related to the structure and organization of the theoretical model development. The model was built upon the knowledge gained through the literature review in Chapter 3. First, the theoretical and conceptual frameworks were clarified. The theory of systems thinking and the nature (characteristics) of systems were discussed in detail. The chapter then provided a narration relating to the development of the theoretical model that included the five activities listed below:

- Defining the proposed farming systems for farmland capability assessment;
- Determining key components in the AMS for farmland capability assessment;
- Identifying class-determining factors (required land characteristics) of each component in the AMS;
- Developing a farmland capability classification system for the proposed farming systems;
- Determining the capability of farmland for the proposed farming systems.

These activities were applied to the case study.

Chapter five introduced briefly the study area characteristics, including those of Viet Nam, the Mekong Delta, the An Giang Province, and the Cho Moi District. Information and attributes relating to agricultural management and production, agricultural land use, farming systems, soil properties, land capability, climate, and hydrology, were especially highlighted. Data presented in this chapter have a vital influence on testing the theoretical model, and are very important for explaining results from the case study implementation. The content in this chapter indicated that the Cho Moi District has diverse land use types, particularly temporary crops. Therefore, it is a suitable site to carry out the case study.

The theoretical model was converted to a practically applicable model, and then it operated in actual on-ground conditions throughout the conduct of the case study. This embodies the main content of **Chapter six**. The chapter explicitly reviewed the series of activities that were undertaken to examine the practical model, with the first task being the definition of representative land utilisation types. Next the process of creating the practical model was outlined such as the refinement of suitable components and corresponding factors in the AMS and weighting the importance of those components and factors in contributing to the land capability using the AHP technique. The chapter also reported on the field survey, on-farm investigation and data collection for testing the model (land capability assessment). Data included both primary and secondary sources, from many providers at the provincial level to the farm level. Finally, the process for current and potential land capability analysis, with supports from the AHP and GIS, were outlined in this chapter.

Chapter seven was divided into two main sections. The first section described the findings from the theoretical model modification. The three dominant farming systems i.e. rotational rice-vegetables, single rice and single vegetable, and the three rationalised administrative scales i.e. the district, commune and farm, selected to check the model design were discussed. The biophysical, technical and management, land development and environmental, and socio-economic and policy, were four key components in the AMS impacting upon the land capability and they were further investigated. The impact of each component was found to be dependent on different administrative scales. It was determined that every component above has many different corresponding factors, which influenced the land capability. These factors made various contributions to the land capability, depending on each farming system, and on each administrative scale used for land assessment. In addition, classes for the land capability classification, and the standardised capability values relevant to the capability classes for each factor were discussed in this section. The second part of this chapter outlined the output generated from the case study examination. Results of land capability analysis at three administrative scales and for three farming systems were presented and compared with the current local land capability classification. The findings determined in this chapter provided evidence for several important conclusions. First, it confirmed that the theoretical model covers acceptable components and factors required for an effective agricultural management system to determine the land capability. Evidence for this was that no other component or factor was proposed to be added into the model during its adjustment. Second, the model is highly adaptable and is applicable in many locations and for many land utilisation types. Feedback from individuals and organizations involved in the case study indicated that the model worked well in the study area context, and gave suitable results when compared with previous land evaluation studies in the local area. Third, farmland capability determination based on the AMS, as proposed in this research, is a new approach to land evaluation, and the results from this study can be useful in agricultural land use and management in particular, and agricultural production management in general.

In **Chapter eight** the discussion was based around the general research findings and their relationship to the existing relevant theories described in the literature review (Chapters 2 and 3). In this chapter the links between the results from modifying the developed model and the case study implementation presented in previous chapters were clarified. The chapter began with a discussion on the selection of suitable farming systems, administrative scales and consideration of the land capability in land assessment. Then an investigation into the nomination of effective components and corresponding factors in the AMS, and the standardising of the capability value for factors, was undertaken. A discussion on the importance of components and factors in the AMS in determining the land capability was involved in this chapter. The chapter ended with a critical discussion on feedback from the case study implementation. Along with advantages, the case study also gave feedback about the limitations and relevant issues to consider when applying the theoretical model to practical conditions. It was pointed out that the outputs from the application of the model depend completely on the quality of data and is concerned with such variables as availability, updating, accuracy and consistency in the system.

In **chapter nine**, the fundamental conclusions based on the findings and discussions above were presented. This chapter highlighted contributions that the present work made to the relevant fields of knowledge, and notes limitations in the theoretical model application. Finally, the chapter gave suggestions for practitioners in the field of land evaluation and directions for further research.

9.3 Responding to the research questions

The primary output from this research is the theoretical model (agricultural management system) for farmland capability determination. The model provides a logical and systematic determination of how the land capability is considered based on attribute data sets brought together within a spatial database that encompasses not only the biophysical factors, but also includes technical and management, land development and environmental, and socio-economic parameters. The main product from the model is a map system that indicates the land capability classes at different administrative scales, and for many land utilisation types. The theoretical model was successfully created, and it was built on a sound theoretical base. The model was effectively applied in the on-farm conditions, in the Mekong Delta, Viet Nam.

Conclusions in this section are presented in relation to the major research questions expressed at the start of the thesis.

Question 1: What are the major components required for an effective agricultural management system that contribute to farm land capability?

The current debate about land, land use and land evaluation is outlined demonstrating that the land capability assessment must be a multi-sector, multi-disciplinary procedure. The land evaluation process requires not only the input from land experts; it also needs involvement from other stakeholders such as economists, environmentalists and policy makers. Background knowledge, presented in Chapters 2 and 3, indicates that land capability is related to many aspects. Therefore in this study, many broad components were built into the theoretical model for land capability assessment, with each component containing several corresponding factors.

The study determined that the biophysical, technical and management, land improvement and environmental, and socio-economic and policy traits, are the four major components required for building an effective agricultural management system to determine the land capability. The evidence is that those components were tested and provided valid results in the case study.

The components are the major determinants in land evaluation. Every component consists of several relevant sub-components called factors. The requirements for every component in the AMS for land capability determination vary. One determinant is the land evaluation scale. For example, the land development and environmental component was considered in the AMS at the district and commune scales, but not at the farm scale.

Question 2: How are the major components in the agricultural management system important to the farmland capability?

Components in the AMS have impacted in a variety of ways upon the land capability. The variation is influenced by the administrative scale and is based on the contribution made by the corresponding factors. The importance of components is examined and indicated by their weighted value in the AMS for the land capability. At the district scale, the weight value had been calculated as 0.410, 0.369, 0.139, and 0.082 respectively for land development and environmental; socio-economic and policy; biophysical; and the technical and management components. These values show that the land development and environment component is the first contributor to the land capability, and the socio-economic component is the second. In contrast, the biophysical, and technical and management components have the least influence on the land capability.

At the commune scale, the most important contributors to the land capability were the biophysical (weight value of 0.384) and the land development and environment (0.300) components. The socio-economic and policy (0.191) and the technical and management (0.126) components were lesser contributors to the land capability. At the farm scale, the land development and environmental component was not considered in the AMS because it made no contribution to the land capability. Instead, the technical and management component (0.589) was determined to be the major contributor to the land capability. The socio-economic and policy (0.252) and the biophysical (0.159) components had a moderate influence on the land capability.

The results and feedback from the case study indicate that the importance of the major components in the AMS to the farmland capability is inconsistent. It fluctuates depending on which level the land capability is analysed at and for the kinds of land utilisation that are evaluated, as well as for the goal of every land evaluation study and the specific conditions in the study area.

Question 3: What are the key factors that impact upon the economic viability and the prosperity of farms?

To understand the impact of components and factors on the land capability in contributing to the economic viability of the land for specific land utilisation types, this study provided an analysis and understanding of the components and factors that contribute to the prosperity of farms. Findings from the theoretical model adjustment and the case study summarized in Chapter 7, have been used to distil a set of 35 class-determining factors in the AMS to be used for land assessment. A large number of these factors have impacted upon the land capability in terms of productivity and economics. Meanwhile, some others have contributed in terms of sustainability (the environment).

The selection of the key factors that impact upon the economic viability and the prosperity of farms, varied between administrative scales and between land use types. Technical factors made less contribution to the economic viability at the district and commune scales, but were very important for the economic viability at the farm scale. The case study also identified a group of 15 factors in three major components (biophysical; technical and management; and socio-economic and policy) in the AMS, which impacted upon the prosperity of farms. However, not all factors impacted upon the farm prosperity as it depended on what kind of specified land use the farm practices.

Question 4: How do the key factors relating to agricultural production impact upon the economic viability of farmland?

The economic viability of farmland relates to the economic potential that the land has when used for a specified utilisation. Therefore, the impact of factors upon the economic viability of farmland when related to agricultural production actually is concerned with the interaction between the factors and the farming systems. The role and possible impacts of factors upon the economic viability of farmland were measured by their actual value and overall weight. The actual value was obtained through farmland investigation. The overall weight was a multiplier of the weight of components and corresponding factors in the AMS. The overall weight value of each individual factor ranked the factor in the importance hierarchy in relation to the farmland capability. The higher the weight, the more important the factor. The sum of the overall weight of all factors in the AMS was 1.0 (100%).

Findings from the case study, presented in Chapter 7, clarify that every factor in the AMS has a particular degree of impact upon the economic viability of farmland. This impact was determined from the knowledge of and interpretation by local land experts. It was changed to accord with different land evaluation scales and farming systems, and the specific conditions in the research area. Five key factors contributing to the economic viability of farmland at the district level were policies used in relation to consuming agricultural products, long-term salinity (or landslip, or landslide), environmental hazards, production costs, and environmental control ability. Their shared total overall weight value was more than 60% of the overall weight value of all factors in the AMS. At the commune and farm scales, the degree of contribution of factors to the economic viability of farmland was variable as it depended on the farming system because each land use type is associated with different requirements.

The case study also revealed that the impact of factors upon the economic viability of farmland involved interactive and interdependent relationships between elements in the system. If any factor is corrected or amended it then results in change in other factors that contribute to the economic viability of farmland. This inter-relationship allows external investments to be effectively applied to improve and raise the land capability, which in turn is very significant in farmland use and management.

According to systems theory, a system comprises interacting parts and together they make up a system. In the context of this research these separate parts can be elements, factors, components or smaller systems that make up the overall system. Components in the system have particular attributes and relationships. In this research, the AMS is the highest system. It encompasses smaller systems called components such as biophysical, technical, and socio-economic and policy. These components are made up of subsystems which are interactive elements called factors. This hierarchical characteristic of the system allows the land capability to be examined systematically, from the overall observation of the general agricultural management system, to more detailed consideration at the component level of the system, and further to specific elements in the system that impact upon the land capability, these are the factors. Therefore, the land capability can be effectively measured in the AMS. This has been the key for mapping and monitoring agricultural production in the study area.

Question 5: Can a Geographic Information System (GIS) based agricultural management system be developed to effectively measure the capability of farmland in the study area?

As presented in literature review (Chapter 3), a GIS refers to a system rather than software. Basically, GIS encompasses five main functional components: hardware, software, data, procedures, and people (expertise, users) (Rossiter, 1994; ESRI, 1999; Pidwirny, 2006) for relevant information on data input, data storage and management, data manipulation and analysis, and data output (Malczewski, 2004; ESRI, 1999; Pidwirny, 2006; Maguire, 1991). Based on the nature and characteristics of GIS, the current research developed a GIS-based agricultural management system to measure the farmland capability. The land capability was examined and determined based on components and factors structured in the AMS.

In the AMS structure, a land capability classification system was designed and standardised by means of capability values, based on factors, corresponding to specific classes for every land use requirements. To evaluate the farmland capability, attribute data about land qualities were entered into a GIS to create thematic maps. These maps were then overlain, using the map overlay function of the GIS, to generate land mapping units. In this study, land mapping units are formed from the boundaries associated with the different administrative scales. Here, the actual values of the factors are matched with the land use requirements to create the land capability classes, which are then presented as land capability maps using the GIS. The current land capability can be modelled to predict the potential land capability scenarios by introducing external interventions to amend the actual value of land capability.

The case study in this research demonstrates that a GIS-based agricultural management system was a suitable and useful way to measure and predict the capability of farmland in the An Giang Province. The land capability, for dominant farming systems, was measured by analysing factors relating to agricultural production in the AMS. The results of the land capability assessment were computed immediately after the actual values of land qualities are input into the system through the different processes. With the support of GIS, these results clearly showed the capability levels and where the land capability was suited for specified land use types. Moreover, limitations to the viability of farmland were also revealed during the land capability analysis. This allows the land to be modelled and improved by raising its capability. Also, by using the GIS-based AMS, the land capability can be determined for different periods of time, and at different administrative scales, from the regional to the local and farm scales, depending on the availability of input data. Therefore, land managers can simulate future capability scenarios of the land for promising farming systems. This is significant for land use planning procedures, particularly for the An Giang Province where land use is rapidly changing.

Question 6: Can a GIS be used effectively to map and monitor agricultural production in the study area?

As discussed in Chapter 3, the purpose of land assessment is to protect and improve long-term agricultural productivity, water quality, and habitats for all organisms including people. It assists land users and managers to develop a sustainable management practice system. Land capability assessment in the current study does not in itself determine the land utilisation types in the An Giang Province, but it does provide data (results) on the basis of which such decisions can be made through examining alternative potential forms of use generated for each area of land. Such examination includes consequences, benefits and the adverse effects of such decisions. By this means the results of the land assessment in the case study allowed agricultural production patterns in the An Giang Province to be planned, distributed, mapped and monitored using the management function of the GIS. The agricultural production system can be viewed in accordance with the vertical system (regional scale to local and farm scales) and horizontal system (between regions, localities, and farms). Attributes and the spatial data, of the agricultural production systems are entered and stored in the GIS, which can easily be updated, modified and accessed for future uses.

This allows agricultural production in the An Giang Province to be effectively monitored.

9.4 Contributions of the study

In the twenty-first century, food and fibre production systems will need to meet three major requirements: (1) adequately supply safe, nutritious, and sufficient food for the world's growing population, (2) significantly reduce rural poverty by sustaining the farming-derived component of rural household incomes, and (3) reduce and reverse natural resource degradation, especially that of land (World Bank, 2006, p.2). While, land use in general, and agricultural land use in particular, are facing many emerging challenges of climate change, intensification of agricultural production, floods, drought, land degradation, soil erosion, water and soil pollution, land desertification, and exhaustion of natural resources (Tilman *et al.*, 2002; Wassmann *et al.*, 2004; Oosterberg *et al.*, 2005).

These issues, stated above, give humans a challenge in exploring ways for sustainable utilisation and exploitation of the natural resources, particularly the land resource. Land capability assessment is an extremely important component of land evaluation for sustainable use of the land resource since it is only through this type of assessment that the capability of the land can be determined. There are many studies relating to land capability and suitability evaluation (*see Chapter 3*) conducted in many parts of the world, and with different approaches.

This study applies a holistic approach developed after referring to previous studies, as well as using a literature review, to develop a theoretical model that integrates land characteristics relating to land quality to determine the capability of farmland. The study takes theoretical perspectives from systems theory as outlined by the FAO (1993; Haaf, 2002; Pidwirny, 2006a; 2006b) resulting in the guidelines that (1) an Agricultural Management System (AMS) will be structured, formed, and developed; (2) components in the AMS, which contribute to the capability of farmland and the prosperity of farms will be explored and defined, including bio-physical, technical and management, land improvement or development, conversation and environmental, policy and institutional, and socio-economic factors; (3) roles and functions of every factor in the AMS will be determined and analysed; (4) functional interactions and relationships within and between components in the AMS will be considered and evaluated; (5) modelling will involve optimal expected scenarios of the capability of farmland and the prosperity of farms; (6) the capability of farmland and the prosperity of farms (processed outputs of the AMS) will be revealed.

Hence, the broad outcome of this study is that a theoretical model for farmland capability assessment will be designed and introduced. The model will be capable of being applied widely in many regions in the world. Depending on specific circumstances, the model will be flexible enough to be adjusted and modified to adapt to local conditions. The model allows the evaluation of multidisciplinary capabilities for farmland, and during the evaluation, interrelationships and interactions between land characteristics can be considered. This allows the capability of farmland to be determined objectively and appropriately.

More importantly, in regions where land use changes are occurring, the model can determine and also predict potential farmland capability, as well as indicate solutions for farmland improvement. It satisfies the fundamental requirements for land evaluation, sustainable land use and planning.

In the Viet Nam context, for the period 1975-1985 (after Viet Nam's independence), agricultural land use in the whole of Viet Nam depended on a five-year centrally planned economy decreed and approved by the party congress (Trung, 2006). Agricultural land use was planned by local and provincial authorities, guided by the Ministry of Planning and supported by the National Institute for Agricultural Planning and Projection (Governors). Land use planning was viewed as a top-down process rather than at the place where land use decisions are made by land users and farmers. Therefore the use of farmland was imposed by a master plan of the nation and in many cases this led to an incorrect evaluation of the genuine capability of farmland.

In 1986, economic liberalization was executed through the "Doi moi-innovation" policy of the Vietnamese government. Thereby, farmers negotiated with the local authorities on long term lease contracts for land use rights and were free to decide on land use by themselves. The role of local authorities and governors was to act as overall land managers and advisors. Recently, the FAO framework for Land Evaluation has been used widely as a methodology for land use advice in Viet Nam. Also, schemes such as the Participatory Land Use Planning and the Land Use Planning and Analysis System, and others, have also been applied. However, the land evaluation activity for most approaches is only a land suitability evaluation by matching land use requirements and land characteristics in terms of land quality. Therefore, relationships and interactions between factors (or components) in a farming system (land use type) are not fully utilised.

The agricultural management system design in this research has an extremely important relevance in finding a satisfactory approach for the determination of the capability of farmland by analysing the bio-physical, the technical and management factors, the land development and environmental indicators, and the socio-economic and policy parameters. Relations and interactions between factors in the system, as well as the management techniques and limitations to land use, are considered carefully. This approach gives benefits not only for agricultural officers and managers; it also has a great potential for improving the livelihoods, and increasing the income, of the local inhabitants and farmers.

The study determines the key factors that impact upon the prosperity and viability of farmland, and the relationships and interactions between those key factors. This allows farmers to exploit and optimize the use of their land resources. The results of the study provide theoretical and empirical evidence which can be used by policy makers and rural development planners as a basis for program development and policy formulation as it relates to agriculture.

The research presents limitations associated with land characteristics and provides guidance on necessary management techniques to improve farmland capability.

Finally, the most important outcome of the study is that it builds and develops a theoretical model to be used as an overall system and a framework for farmland capability determination. This is done by integrating the results of the evaluation and analysis of related components in the agricultural management system.

9.5 Limitations of the study and further recommendations

Findings presented in Chapter 7 associated with the conclusions and outcomes in this chapter reflect the strengths of the research. Required components and corresponding factors were identified to build an effective agricultural management system for farmland capability assessment. The land capability and the prosperity of farms were considered in a multi-dimensional manner. However due to objective nature of the study there are some limitations.

- First, when testing the theoretical model, the farmland capability was analysed according to administrative units, not natural land mapping units. The case study was undertaken only in the Cho Moi District where there has been limited study of the land capability evaluation up-to-date and the current land use in the local area is mapped by land mapping units as well. Thus, in some cases, results from testing the model could not be compared with the current land use or land suitability classification in the whole case study area.

- Second, due to the case study being carried out in one district, samples for the land capability analysis at three administrative scales were not enough for a statistical analysis to be undertaken. Therefore, there has been no comparison in term of land capability for the same farming system between communes and farms.

- Finally, the theoretical model was tested on three dominant farming systems, and therefore results from the land capability analysis in the case study didn't cover all current land use types in the local area. To plan and develop a refined agricultural production management system, land managers in the Cho Moi District need to consider several common farming systems.

The findings of this research also suggest a range of fields for future research into land evaluation and agricultural management.

- The agricultural management system to determine the capability of farmland needs to be conducted according to land mapping units to cross-check the approach using administrative scales, which in turn will provide critical feedback to the theoretical model development.

- Research samples for further application of the theoretical model need to be increased to make sure that a statistical analysis can be made to compare differences in relation to the land capability between locations, for the same farming system.

- The theoretical model needs to be applied to other farming systems to test the applicability and adaptability of this research model.

- Along with the results of this study, the agricultural management system used to evaluate land capability for other common farming systems in the An Giang Province needs to be developed to provide a sufficient basis for the planning and management of agricultural production systems in the local area.

- A recommendation is that a GIS-based agricultural management system should be used to measure the capability of farmland and to map and monitor agricultural production in the An Giang Province.

The research has been successful, having been built on past research experience, and through practical experience the model has been refined to suite the local situation. It is with this assurance that the researcher recommends future studies be based on the foundation of this study.

References

Ahamed, T. R. N., Rao, K. G. and Murthy, J. S. R. 2000. GIS-based fuzzy membership model for crop-land suitability analysis. *Agricultural Systems*, 63, 75-95.

ALC. 2009. What is agricultural land? Agricultural Land Commission, Government of British Columbia, Canada (ALC). Available at http://www.alc.gov.bc.ca/alr/What_is_Ag_Land.htm. Accessed on 31/09/2009.

Alejandro Ceballos-Silva, Jorge Lopez-Blanco, 2002. Delineation of suitable areas for crops using a Multi-Criteria Evaluation approach and land use/cover mapping: a case study in Central Mexico. *Agricultural Systems*, *77,* 117-136.

An Giang Statistical Bureau. 2005. Statistical Yearbook of An Giang Province. An Giang Statistical Bureau. An Giang, Viet Nam.

An Giang Statistical Bureau. 2007. Statistical Yearbook of An Giang Province. An Giang Statistical Bureau. An Giang, Viet Nam.

An Giang Statistical Bureau. 2010. Statistical Yearbook of An Giang Province. An Giang Statistical Bureau. An Giang, Viet Nam.

Andrews, S.S., Karlen, D.L., Cambardella, C.A. 2004. The soil management assessment framework: a quantitative soil quality evaluation method with case studies. *Soil Science Society of America Journal*, 68, 1945-1962.

Anríquez, G. & López, R. 2007. Agricultural growth and poverty in an archetypical middle income country: Chile 1987-2003. *Agricultural Economics*, 36, 191-202.

Anríquez, G. & Stamoulis, K. 2007. Rural development and poverty reduction: is agriculture still the key? ESA Working Paper No. 07-02. Rome, Food and Agriculture Organization of the United Nations (FAO).

Banai, R. 1993. Fuzziness in geographic information systems: contributions from the analytic hierarchy process. *International Journal of Geographical Information Systems*, 7, 315-329.

Bandyopadhyay, S., Jaiswal, R. K., Hegde, V. S. and Jayaraman, V. 2009. Assessment of land suitability potentials for agriculture using a remote sensing and GIS based approach. *International Journal of Remote Sensing*, 30, 879-895.

Baniya, N. 2008. Land suitability evaluation using GIS for vegetable crops in Kathmandu valley /Nepal. PhD thesis. Humboldt University zu Berlin. Germany. 244p.

Batjes, N. H., Bouwman, A. F. and Sinclair, K. M. 1986. Jamaica physical land evaluation system (JAMPLES). Technical Soils Bulletin, No.3. Ministry of Agriculture, Jamaica. Available at http://library.wur.nl/isric/fulltext/ISRIC_11524.pdf. Accessed on 12/01/2010.

Beall, A. and Zeoli, L. 2008. Participatory modelling of endangered wildlife systems: Simulating the sage-grouse and land use in Central Washington. *Ecological economics*, 68, 24-33.

Beare, M. H., Reddy, M. V., Tian, G. & Srivastava, S. C. 1997. Agricultural intensification, soil biodiversity and agro-ecosystem function in the tropics: the role of decomposer biota. *Applied Soil Ecology,* 6, 87-108.

Beatty, M. T., Petersen, G. W. & Swindale, L. D. (eds). 1979. *Planning the uses and management of land.* Agronomy Monograph 21. American Society of Agronomy, Madison, WI. USA. 1028p. Available at the National Library of Australia, Canberra, Australia.

Bell, F. G. 2004. *Engineering geology and construction*. Spon Press (*an imprint of Taylor and Francis Group*). New York. 797p. Online book. Accessed on 07/01/2010.

Besley, T. & Burgess, A. R. 1998. Land reform, poverty reduction and growth: evidence from India. Discussion paper. London School of Economics, London. Available at http://sticerd.lse.ac.uk/dps/de/dedps13.pdf. Accessed on 07/01/2010.

Bhagat, R. M., Singh, S., Sood, C., Rana, R. S., Kalia, V., Pradhan, S., Immerzeel, W. and Shrestha, B. 2009. Land Suitability Analysis for Cereal Production in Himachal Pradesh (India) using Geographical Information System. *J. Indian Soc. Remote Sens*, 37, 233-240.

Bhushan, N. and Rai, K. 2004. Strategic Decision Making: Apply the Analytical Hierarchy Process. Londaon Berlin Heidelberg. Springer-Verlag (Springer Science + Business Media). 172p.

Birch-Thomsen, T. and Kristensen, S. P. 2005. Planning with complexity – how do we deal with stakeholder and spatial heterogeneity in land use planning? *Danish Journal of Geography (Geografisk Tidsskrift),* 105, 23-37.

Boehlje, M. D. and Eidman, V. R. 1984. Farm Management. New York: John Wiley & Sons.

Bon, L. T. 2010. Application of the AHP and GIS tools in farmland suitability evaluation for coconut production systems in the Mo Cay Nam District, Ben Tre Province. Bachelor thesis, Mekong Delta Development Research Institute, Can Tho University. 69 pages (in Vietnamese).

Boonyanuphap, J., Wattanachaiyingcharoen, D. & Sakurai, K. 2004. GIS-based land suitability assessment for Musa (ABB group) plantation. *J. Appl. Hort.*, 61, 3-10.

Boroushaki, S. Malczewski, J. 2010. Using the fuzzy majority approach for GIS-based multi-criteria group decision- making. *Computers and Geosciences*, article in press. 13p.

Bouma, J., Wagnet, R., Hoosbeek, M. and Hutson, J. 1993. Using expert systems and simulation modelling for land evaluation at farm level: a case study from New York State. *Soil Use and Management*, 9, 131-139.

Bouman, B. A. M., Schipper, R. A., Nieuwenhuyse, A., Hengsdijk H. & Jansen, H. G. P. 1998. Quantifying economic and biophysical sustainability trade-offs in land use exploration at the regional level: a case study for the Northern Atlantic Zone of Costa Rica. *Ecological Modelling*, 114, 95-109.

Bouman, B.A.M., Jansen, H.G.P., Schipper, R.A., Nieuwenhuyse, A.N., Hengsdijk, H. & Bouma, J. 1999. A framework for integrated biophysical and economic land use analysis at different scales. *Agriculture, Ecosystems and Environment,* 75, 55-73.

Bradstock, A. 2006. Land reform and livelihoods in South Africa's Northern Cape province. *Land Use Policy,* 23, 247-259.

Bruntland, G (ed). 1987. Our Common Future. The World Commission on Environment and Development (WCED), Oxford. Oxford University Press. (Chapter 2: Towards Sustainable Development, available at http://www.un-documents.net/ocf-02.htm. Accessed on 17/01/2010.

Bryden, J. & Geisler, C. 2007. Community-based land reform: Lessons from Scotland. *Land Use Policy,* 24, 24-34.

Burrough, P. A. 1978. Overseas national programs of land resource survey and evaluation. Canberra, Australian Government Publishing Service. 145p.

Burrough, P. A. 1992. Development of intelligent geographical information systems. *International Journal of Geographical Information Science*, 6, 1-11.

Bydekerke, L., Van Ranst, E., Vanmechelen, L. and Groenemans, R. 1998. Land suitability assessment for cherimoya in southern Ecuador using expert knowledge and GIS. *Agriculture, Ecosystems and Environment,* 69, 89-98.

Campbell, J. B. 2002. *An introduction to remote sensing.* 3rd edition. Guiford Press, New York. Online book.

Carver, S. J. 1991. Integrating multi-criteria evaluation with geographical information systems. *International Journal of Geographical Information Systems*, 5, 321-339.

Castella, J. C., Kam, S. P., Quang, D. D., Verburg, P. H. and Hoanh, C. T. 2007. Combining top-down and bottom-up modelling approaches of land use/ cover change to support public policies: Application to sustainable management of natural resources in northern Viet Nam. *Land Use Policy*, 24, 531-545.

Ceballos-Silva, A. and López-Blanco, J. 2003. Delineation of suitable areas for crops using a Multi-Criteria Evaluation approach and land use/cover mapping: a case study in Central Mexico. *Agricultural Systems*, 77, 117-136.

CEMA. 2006. Land Capability Classification System for Forest Ecosystems in the Oil Sands in Canada, Volume 1: Field Manual for Land Capability Determination. The Cumulative Environmental Management Association (CEMA), Alberta Environment, Canada. Available at www.gov.ab.ca/env/. Accessed on 11/01/2010.

Centre for hydro-meteorological forecast (CHMF) of the An Giang Province. 2006. Changes of weather and hydro-meteorology in the An Giang Province in 2006. Official final report. Internal circulated document. The CHMF of the An Giang Province.

Chan, T. O. and Williamson, I. P. 1997. Definition of GIS: the manager's perspective. *Paper presented at the International Workshop on Dynamic and Multi-Dimensional GIS*. Hong Kong, 25-26/08/1997.

Chitiga, M. & Mabugu, R. 2008. Evaluating the Impact of Land Redistribution: A CGE Micro-simulation Application to Zimbabwe. African Economies, 17, 527-549.

Cho Moi Department of Agriculture and Rural Development. 2009. Preliminary evaluation of executive plan of the agricultural sector development in the years 2008-2009. Annual report, 17 pages, the Cho Moi Department of Agriculture and Rural Development at the District level, the An Giang Province, Viet Nam.

Choudhury, K. & Jansen, L. J. M. (eds). 1998. *Terminology for integrated resource planning and management*. Rome, Food and Agriculture Organization of the United Nations (FAO). Available at http://www.mpl.ird.fr/crea/taller-colombia/FAO/AGLL/pdfdocs/landglos.pdf. Accessed on 17/07/2010.

Walter, C. & Stützel, H. 2009a. A new method for assessing the sustainability of land-use systems (I): Identifying the relevant issues. *Ecological economics*, 68, 1275-1287.

Walter, C. & Stützel, H. 2009b. A new method for assessing the sustainability of land-use systems (II): Evaluating impact indicators. *Ecological economics*, 68, 1288-1300.

Chuong, H. V. and Boehme, M. 2005. Evaluation of physical land suitability for the "Thanh Tra" pomelo crop in Hue, Viet Nam. Conference paper. Conference on International Agricultural Research for Development. October 11-13, 2005. Stuttgart-Hohenheim, Germany.

Clarke, K. C. 1998. Getting started with Geographic Information Systems. Upper Saddle River: Prentice Hall. p. 1-56. http://www.vepraskas.com/CL341/gettingstarted.pdf.

Clementi, M., Causin, R., Marzocchi, C., Mantovani, A. and Tenconi, R. 2007. A study of the impact of agricultural pesticide use on the prevalence of birth defects in northeast Italy. *Reproductive Toxicology,* 24, 1-8.

Collins, M. G., Steiner, F. R. and Rushman, M. J. 2001. Land-Use Suitability Analysis in the United States: Historical Development and Promising Technological Achievements. *Environmental Management*, 28, 611-621.

Cools, N., DePauw, E. and Deckers, J. 2003. Towards an integration of conventional land evaluation methods and farmers' soil suitability assessment: a case study in north-western Syria. *Agriculture, Ecosystems and Environment*, 95, 327-342.

Corona, P., Salvati, R., Barbati, A. and Chirici, G. 2008. Land Suitability for Short Rotation Coppices Assessed through Fuzzy Membership Functions. In Lafortezza, R. et al. (eds.). "*Patterns and Processes in Forest Landscapes"*. Springer Science+Business Media B.V. 2008.

Cowen, D. J. 1998. GIS versus CAD versus DBMS: What are the differences? American *Society for Photogrammetry and Remote Sensing*, 54, 1551-1555.

D'haeze, D., Deckers, J., Raes, D., Phong, T. A. and Loi, H. V. 2005. Environmental and socio-economic impacts of institutional reforms on the agricultural sector of Viet Nam Land suitability assessment for Robusta coffee in the Dak Gan region. *Agriculture, Ecosystems and Environment*, 105, 59-76.

Daily, G. C., Soderqvist, T., Aniyar, S., Arrow, K. J., Dasgupta, P., Ehrlich, P. R., Folke, C., Jansson, A. M., Jansson, B. O., Kautsky, N. 2000. The value of nature and the nature of value. *Science*, 289, 395-396.

DARD. 2007. Final report of agricultural activity in 2007 and plan for 2008. Department of Agricultural and Rural Development (DARD) of the An Giang Province, Viet Nam.

DARD. 2008. Preliminary evaluation of executive plan of agricultural sector development in the period 2006 - 2010. Annual report, 7 pages, Department of Agriculture and Rural Development (DARD) of the An Giang Province, Viet Nam.

Dasgupta, S., Meisner C., Wheeler, D., Lam, N. T. & Xuyen, K. 2005. Pesticide poisoning of farm workers: implications of blood test results from Viet Nam. World Bank Policy Research Working Paper 3624. Available at http://econ.worldbank.org.

Davis, B., Winters, P., Carletto, G., Covarrubias, K., Quinones, E., Zezza, A., Stamoulis, K., Bonomi, G. and Digiuseppe, S. 2007. Rural Income Generating Activities: A Cross Country Comparison. World Development Report 2008. Washington, D. C.

Davis, J. H. and Goldberg, R. A. 1957. *A Concept of Agribusiness*. Division of Research, Graduate School of Business Administration. Harvard University. Boston. p. 2.

De la Rosa D., Mayol, F., Diaz-Pereira, E., Fernandez, M., De la Rosa Jr. D. 2004. A land evaluation decision support system (MicroLEIS DSS) for agricultural soil protection with special reference to the Mediterranean region. *Environmental Modelling & Software*, 19, 929-942.

De la Rosa, D. & Sobral, R. 2008. Soil quality and Methods for its Assessments. Book chapter in Braimoh, A. K. and Vlek, P. L. G. (eds). "*Land Use and Soil Resource*". Springer Science & Business Media B. V. 2008. p.167-200.

De la Rosa, D., Anaya-Romero, M., Diaz-Pereira, E., Heredia, N. and Shahbazi, F. 2009. Soil-specific agro-ecological strategies for sustainable land use-A case study by using MicroLEIS DSS in Sevilla Province (Spain). *Land Use Policy*, 26, 1055-1065

De, N. N. 2005. Farmer activities and supporting systems in rural development: A holistic approach in the Mekong Delta, Viet Nam. PhD thesis, Mie University, Japan.

De, N. N. 2008. Rice textbook. Can Tho University. Can Tho city. 187p. Available at http://www.ctu.edu.vn/coursewares. Accessed on 16/02/2010.

Decision N^0 114/QĐ-TTg of the Prime Minister of Viet Nam. 2010. Decision N^0 114/QĐ-TTg on the functionalities, responsibilities, and powers of the Mekong River Commission of Viet Nam. Issued on 15/01/10. Hanoi, Viet Nam.

Delli, G., Martucci, A. & Sarfatti, P. 1996. Land suitability evaluation for winter wheat in Tiaret region (Algeria). In Escadafal Richard**,** Mulders, M. A., Thiombiano, L. (eds). "*Monitoring soils in the environment with remote sensing and GIS*". Paris: ORSTOM, 1996, p. 531-542. (Colloques et Séminaires).

DFID. 1999-2005. Sustainable livelihoods guidance sheets. Department For International Development (DFID). London, UK. Available at http://www.livelihoods.org/info/info_guidancesheets.html. Accessed on 17/01/2010.

Diakoulaki, D. and Grafakos, S. 2004. Multi-criteria Analysis. Final report on Work package 4. Externalities of energy: Extension of accounting framework and policy applications. National Technical University Athens, Greece. Available at http://www.externe.info/expolwp4.pdf. Accessed on 12/02/2010.

Dien, N. and Y, N. 2005. Consequences of rice-shrimp farming system: the pampas. Tuoitre newspaper, online version. Accessed on 03/03/2011 at http://phienbancu.tuoitre.vn/tianyon/Index.aspx?ArticleID=112836&ChannelID=3. Accessed on 17/07/2011.

Ding, C. 2003. Land policy reform in China: assessment and prospects. *Land Use Policy,* 20**,** 109-120.

DNRE. 2006. Adjustment of land use planning for 2010: Integrated report submitted to the People's committee of An Giang Province. 160 pages. Department of Natural Resources and Environment (DNRE) of An Giang Province, Viet Nam.

Dong, T. & Doan, T. 2008. Residues of pesticides in vegetables: It's time to feedback alarm. Binh Duong newspaper, Agency of Binh Duong Province's Viet Nam communist party. Available at http://www.baobinhduong.org.vn/detailen.aspx?Item=59006. Accessed on 27/12/2008.

Doos, Bo. R. 2002. Population growth and loss of arable land. *Global Environmental Change*, 12, 303-311.

Dung, N. H. & Dung, T. T. T. 2003. Economic and health consequences of pesticide use in paddy production in the Mekong Delta, Viet Nam. Scientific report, Economic and Environment program for Southeast Asia (EEPSEA). International Development Research Centre (IDRC), Canada. Available at http://www.idrc.ca/uploads/user-S/10536137480ACF124.pdf. Accessed on 06/11/2009.

Easa, S. and Chan, Y. 2000. Urban planning and development applications of GIS. American Society of Civil Engineers. Geographic Information Systems Committee. 283p. Online book. Accessed on 02/02/2010.

Eastman, J. R. 2006. IDRISI Andes Guide to GIS and image processing. Worcester, MA. Clark Labs. Clark University.

Egger, K. 1989. Maintenance and improvement of the soil's fertility. *Natural resource development*. 29, 106-112.

Ekanayake, G. K. & Dayawansa, N. D. K. 2003. Land suitability identification for a production forest through GIS techniques. Map India Conference 2003. GISdevelopment.net.

Mushak, E. W. and Piver, W. T. 1992. Agricultural Chemical Utilization and Human Health. *Environmental Health Perspectives*. 97, 269-274. Available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1519525/pdf/envhper00384-0251.pdf. Accessed on 15/12/2009.

EPA. 2003. Land capability assessment for onsite domestic wastewater management. Domestic wastewater management bulletin. Publication 746.1. Environment Protection Authority (EPA), Victoria, Australia.

ESCAP. 2000. Ministerial Conference on Environment and Development in Asia and the Pacific 2000. United Nations Economic and Social Commission for Asia and the Pacific (ESCAP). Kitakyushu, Japan 31 August - 5 September 2000.

ESRI. 1999. Enterprise GIS in Health and Social Service Agencies. An ESRI White Paper. Environmental Systems Research Institute (ESRI), USA. 22p.

ESRI. 2004. Getting Started with ArcGIS: ArcGIS 9. Environmental Systems Research Institute (ESRI). Redlands, CA, USA: ESRI Inc.

FACT Act. 1990. Public Law Number 101-624. Food, Agriculture, Conservation and Trade Act of 1990 (FACT Act). Congressional Record-House. USDA. Washington, D. C., USA.

Fan, S. 2002. Agricultural research and urban poverty in India. Environment and Production Technology Division Discussion Paper No. 94. Washington, D. C., International Food Policy Research Institute.

Fan, S., Zhang, X. & Rao, N. 2004. Public expenditure, growth, and poverty reduction in rural Uganda. Development Strategy and Governance Division Discussion Paper No. 4. Washington, D. C., International Food Policy Research Institute.

FAO in Viet Nam. 2008. Helping to build a world without hunger. Hanoi, Food and Agriculture Organization of the United Nations in Viet Nam. Available at http://www.fao.org.vn/. Accessed on 12/01/2010.

FAO. 1976. A framework for land evaluation. FAO Soils bulletin 32. Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO. 1980. Land evaluation for development. Natural Resources Management and Environment Department. Rome, Food and Agriculture Organization of the United Nations (FAO). Available at http://www.fao.org/docrep/u1980e/u1980e00.htm#Contents. Accessed on 12/01/2010.

FAO. 1981. Report on the agro-ecological zones project. Results for South and Central America. World Soil Resources Report 48, Volume 3. Rome, Food and Agriculture Organization of the United Nations (FAO). Online book. Accessed on 15/01/2010.

FAO. 1983. Guidelines: land evaluation for rain-fed agriculture. Soils Bulletin 52. Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO. 1984. Land evaluation for forestry. Forestry paper 48. Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO. 1985. Guidelines: Land evaluation for irrigated agriculture. FAO soils bulletin 55. ISBN 92-5-102243-7. Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO. 1991a. Guidelines: land evaluation for extensive grazing. Soils Bulletin 58. Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO. 1991b. Plan of action for people's participation in rural development, 19p. FAO Conference sess. 26. Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO. 1993. Guidelines for land-use planning, p. 96p. FAO development series 1 ISSN 1020-0819. Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO. 1995. Concepts, definitions and links. In: Planning for sustainable use of land resources: Towards a new approach. Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO. 1995. Planning for sustainable use of land resources: Towards a new approach: *Land and Water Bulletin 2*. Rome, Food and Agriculture Organisation of the United Nations (FAO). 53 p.

FAO. 1996a. Our Land Our Future. Rome and Nairobi, Food and Agriculture Organization and United Nations Environment Programme. Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO. 1996b. Agro-ecological zoning–Guidelines. Soils Bulletin 73. Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO. 1999a. Conducting a PRA Training and Modifying PRA Tools to Your Needs. An Example from a Participatory Household Food Security and Nutrition Project in Ethiopia. Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO. 1999b. The Future of our land: Facing the challenges. Rome, FAO, Rome, Rome, Food and Agriculture Organisation of the United Nations (FAO).

FAO. 2001a. Global Forest Resources Assessment 2000. Main report. FAO Forestry Paper No. 140. Rome, Food and Agriculture Organization of the United Nations (FAO). Available at www.fao.org/docrep/004/y1997e/y1997e00.htm.

FAO. 2001b. Farmer Self-Surveillance of Pesticide Poisoning Episodes: Report on One Month Pilot: August 15-Sept 15, 2000. FAO Programme for Community IPM in Asia, Field Document. Available at http://www.toxictrail.org/Documents/Vietnam-surveillance.pdf. Accessed on 05/01/2010.

FAO. 2004a. The State of Food and Agriculture 2003–04: agricultural biotechnology: meeting the needs of the poor? FAO Agriculture Series No. 35. Rome, Food and Agriculture Organization of the United Nations (FAO). Available at http://www.fao.org/docrep/006/y5160e/y5160e00.htm. Accessed on 26/12/2009.

FAO. 2004b. Socio-economic analysis and policy implications of the roles of agriculture in developing countries. Research Programme Summary Report 2004. Roles of Agriculture Project. Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO. 2006a. Global Forest Resources Assessment 2005-progress towards sustainable forest management. Forestry Paper No. 147. Rome, Food and Agriculture Organization of the United Nations (FAO). Available at www.fao.org/docrep/008/a0400e/a0400e00.htm.

FAO. 2006b. FAOSTAT Statistical Database. Rome, Food and Agriculture Organization of the United Nations (FAO). Available at http://faostat.fao.org/.

FAO. 2007a. The State of Food and Agriculture 2007: paying farmers for environmental services. FAO Agriculture Series No. 38. Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO. 2007b. Land Evaluation: towards a revised framework. *Land and water discussion paper*, 6, 124p. Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO. 2008a. The state of food and agriculture 2008 (BIOFUELS: prospects, risks and opportunities). Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO. 2008b. The state of food and agriculture in Asia and the Pacific region 2008. Rap publication. Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO. 2008c. FAOSTAT Statistical Database. Rome, Food and Agriculture Organization of the United Nations (FAO). Available at http://faostat.fao.org/.

FAO. 2009a. FAOSTAT Statistical Database. Rome, Food and Agriculture Organization of the United Nations (FAO). Available at http://faostat.fao.org/.

FAO. 2009b. Food outlook: Global market analysis. Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO. 2009c. State of the World's Forests 2009. Rome, Food and Agriculture Organization of the United Nations (FAO).

FAO/UNEP. 1997. *Negotiating a Sustainable Future for Land.* Structural and Institutional Guidelines for Land Resources Management in the 21st Century. Rome, Food and Agriculture Organization of the United Nations (FAO)/United Nations Environment Programme (UNEP).

Frank, A. U. 1989. The Geographic Information System and Its Use for Valuation. *Property Tax Journal*, 8, 85-98.

Fresco, L. O. 1991. Using land evaluation and farming systems methods for planning sustainable land use-an example from Costa Rica. In Land use planning applications. Proceedings of the FAO expert consultation 1990. World soil resources reports 68, 153-157. Interdepartmental working group on land use planning. Rome, Food and Agriculture Organization of the United Nations (FAO).

Frey, R. S. 1996. A Glossary of Agriculture, Environment, and Sustainable Development. Bulletin 661. Agricultural Experiment Station, Kansas State University. Manhattan. 24p.

Fu, B. 1988. The evaluation of land resources in China. *Scottish Geographical Journal*, 104, 41-44.

Garuti, C. and Sandoval, M. 2006. The AHP: a multi-criteria decision making methodology for shiftwork prioritizing. *Systems Engineering Society of China & Springer-Verlag*, 15, p. 189-200.

Gerdsri, N. and Kocaoglu, D. F. 2007. Applying the Analytic Hierarchy Process (AHP) to build a strategic framework for technology road-mapping. *Mathematical and Computer Modelling*, 46, 1071-1080.

Giampietro, M., Mayumi, K., Ramos-Martin, J. 2009. Multi-scale integrated analysis of societal and ecosystem metabolism (MuSIASEM): Theoretical concepts and basic rationale. *Energy*, 34, 313-322.

Giap, D. H., Yi, Y. and Yakupitiyage, A. 2005. GIS for land evaluation for shrimp farming in Haiphong of Viet Nam. *Ocean & Coastal Management*, 48, 51-63.

Gold, M. V. 2009. Sustainable agriculture: Definitions and terms. National Agricultural Library, Agricultural Research Service, U.S. Department of Agriculture. Available at http://www.nal.usda.gov/afsic/pubs/terms/srb9902.shtml#toc2. Accessed on 17/12/2009.

Gorton, M. 2001. Agricultural land reform in Moldova. *Land Use Policy,* 18, 269-279.

Goulart, F.F. Salles, P. & Saito, C.H. 2009. Assessing the Ecological Impacts of Agriculture Intensification Through Qualitative Reasoning. 23rd Annual Workshop on Qualitative Reasoning, LJUBLJANA-SLOVENIA.

Gray, D. I., Parker, W. J., and Kemp, E. 2009. Farm management research: a discussion of some of the important issue. *International Farm Management*, 5, 1-24.

Grose C. J. (ed). 1999. Land Capability Handbook. Guidelines for the Classification of Agricultural Land in Tasmania. Second Edition, Department of Primary Industries, Water and Environment, Tasmania, Australia. http://www.dpiw.tas.gov.au/inter.nsf/Attachments/TPRY-6ER6MW/$FILE/Land_Cap_Revised%20handbook.pdf. Accessed on 10/12/2009.

GSO. 2001. Statistical Yearbook 2001. General Statistics Office (GSO), Statistical Publishing House, Hanoi, Viet Nam.

GSO. 2003. Statistical Yearbook 2003. General Statistics Office (GSO), Statistical Publishing House, Hanoi, Viet Nam.

GSO. 2006. Statistical Yearbook 2006. General Statistics Office (GSO), Statistical Publishing House, Hanoi, Viet Nam.

GSO. 2007. Statistical Yearbook 2007. General Statistics Office (GSO), Statistical Publishing House, Hanoi, Viet Nam.

GSO. 2008. Statistical Yearbook 2008. General Statistics Office (GSO), Statistical Publishing House, Hanoi, Viet Nam.

Ha Linh. 2009. Ten precents of safe vegetables maintain residues of pesticides. Dan Tri newspaper. Available at http://dantri.com.vn/c7/s7-139624/10-rau-an-toan-con-ton-du-thuoc-bao-ve-thuc-vat.htm. Accessed on 12/07/2010.

Ha Yen. 2008. Agricultural production is emptying the Environment. Vietnamnet newspaper. Available at http://vietnamnet.vn/kinhte/2008/10/808951/.

Ha, T. T. L., Thanh, N. H. And Son, N. T. 2006. Land evaluation for rice, maize and soybean in LucBinh, BachThong, Bac Can province for crop pattern. *Journal of agricultural technique and science (Vie)*, 4, 139-146.

Haaf, W. T., Bikker, H. and Adriaanse, D.J (eds). 2002. Introduction to the system approach. In: Fundamentals of business engineering and management: A systems approach to people and organisations. Delft University Press. The Netherlands. p.49-81.

Habarurema, E. and Steiner, K. G. 1997. Soil suitability classification by farmers in southern Rwanda. *Geoderma*, 75, 75-87.

Hamblin, A. 2009. Policy directions for agricultural land use in Australia and other post-industrial economies. *Land Use Policy*, 26, 1195-1204.

Hang, N. T. M. 2010. Participatory agricultural land evaluation and planning in the Tan Son Commune, Tra Cu District, Tra Vinh Province. Bachelor thesis, Mekong Delta Development Research Institute, Can Tho University. 64 pages (in Vietnamese).

Hanson, L.W., Bourke, R.M., Allen, B.J. and McCarthy, T.J. 2001. Mapping land resource potential and agricultural pressure in Papua New Guinea: an outline of new methods to assist rural planning. ACIAR Technical Reports No. 50, 52 pp.

Hao, N. T. 2008. Classification of land mapping units based on soils an hydrological characteristics of Co Do district, Can Tho city. *Omonrice*, 16, 138-143.

Harker, P. T. and Vargas, L. G. 1987. The theory of ratio scale estimation: Saaty's analytical hierarchy process. *Management Science*, 33, 1383-1403.

Hashim, I. Hj., Java, I. N. S., and Gunawan, I. 2002. Evaluation of land suitability for selected land utilisation types using Geographic Information System Technology (Case Study in Bandung Basin West Java). *Trop. For. Manage. J.*, 8, 11-26.

Heeren, G. A., Tyler, J. and Mandeya, A. 2003. Agricultural chemical exposures and birth defects in the Eastern Cape Province, South Africa A case-control study. *Environmental Health*: *A Global Access Science Source*, 2, 8p. Available at http://www.ehjournal.net/content/pdf/1476-069X-2-11.pdf. Accessed on 15/11/2009.

Helms, D. 1992. *Readings in the history of the Soil Conservation Service.* Soil Conservation Service, US Government Printing Office, Washington DC. http://www.nrcs.usda.gov/about/history/pdf/Readings_in_the_History_of_001.pdf.

Hill, I. D. (ed.). 1979. Land resources of central Nigeria. Agricultural development possibilities. Land Resources Development Centre, Overseas Development Administration, Surbiton, UK.

Hill, M. J. Braaten, R. Veitch, S. M. Lees, B. G. and Sharma, S. 2005. Multi-criteria decision analysis in spatial decision support: the ASSESS analytic hierarchy process and the role of quantitative methods and spatially explicit analysis. *Environmental Modelling & Software*, 20, 955-976.

Ho Hung. 2009. Aquaculture is killing the environment. The Saigon times. Available at http://www.thesaigontimes.vn/Home/doanhnghiep/chuyenlaman/13857/.

Hong Van. 2007. Pollutants threat to the water environment in the Mekong Delta. The Sai gon times online. Available at http://www.thesaigontimes.vn/Home/thoisu/doisong/1735/.

Hoosbeck, M. R. and Bryant, R. B. 1992. Towards the quantitative modelling of pedogenesis: a review. *Geoderma*, 55, 183-210.

Hopkins, L. D. 1977. Methods for Generating Land Suitability Maps: A Comparative Evaluation. *Journal of the American Planning Association*, 43, 386-400.

Hossain, M. S. and Das, N. G. 2010. GIS-based multi-criteria evaluation to land suitability modelling for giant prawn (*Macrobrachium rosenbergii*) farming in Companigonj Upazila of Noakhali, Bangladesh. *Computers and Electronics in Agriculture*, 70, 172-186.

Hossain, M. S., Chowdhury, S. R., Das, N. G. and Moshiur Rahaman, M. 2007. Multi-criteria evaluation approach to GIS-based land-suitability classification for tilapia farming in Bangladesh. *Aquacult Int*, 15, 425-443.

Hossain, M. S., Chowdhury, S. R., Das, N. G., Sharifuzzaman, S. M., Sultana, A. 2009. Integration of GIS and multi-criteria decision analysis for urban aquaculture development in Bangladesh. *Landscape and Urban Planning*, 90, 119-133.

Hotman, E. 2005. Base reference analytical hierarchy process for engineering process selection. In Khosla et al. (eds): KES 2005, LNAI 3681, p. 184-190. Springer-Verlag Berlin Heidelberg.

http://gis.nic.in/gisprimer/introduction.html. Accessed on 29/01/2010.

http://gislounge.com/what-is-gis/. Accessed on 29/01/2010.

http://maic.jmu.edu/sic/gis/components.htm. Accessed on 07/02/2010.

http://www.baoyenbai.com.vn. Accessed on 07/07/2011.

http://www.css.cornell.edu/landeval/ales/alesprog.htm.

http://www.geog.leeds.ac.uk/courses/level2/geog2750/geog2750_landcap.doc.

http://www.nwgis.com/gisdefn.htm. Accessed on 29/01/2010.

http://www2.ag.ohio-state.edu/~mgtexcel/Function.html. Accessed on 17/04/2010.

http://www.sil.org/lingualinks/literacy/referencematerials/glossaryofliteracyterms/whatistheparticipatoryruralapp.htm. Accessed on 01/06/2011.

http://www.worldatlas.com.

Huan, H. N. 2006. Relationships between nutrient and pest management in an integrated approach "three reductions three gains" on rice. Discussion paper, Department of Agriculture and Rural Development of the An Giang Province, Viet Nam. Available at http://sonongnghiep.angiang.gov.vn/webpage_1/3giam3tang_files/moiqh3g3t.htm.

Huan, N. H. & Anh, D. T. 2002. Viet Nam promotes solutions to pesticide risks. Agro-Chemicals Report, *Vol. II, No. 1*, 21-26. Fertilizer Advisory, Development and Information Network for Asia and the Pacific (FADINAP). Economic and Social Commission for Asia and the Pacific.

Huynh Quang Tin, Nguyen Hong Cuc, Huynh Nhu Dien, Nguyen Thanh Tam. 2010. Evaluating the Community Biodiversity Development and Conservation project in the Mekong Delta: period 2006-2009. Full report on project implementation evaluation, the Mekong Delta Development Research Institute, Can Tho University.

IPSARD. 2007. Tam Nong project, 4th draft version, Institute of Policy and Strategy for Agricultural and Rural Development of Viet Nam (IPSARD), MARD, Viet Nam.

Jain, S. P. and Polman, W. 2003. A handbook for trainers on participatory local development. Bangkok, Food and Agriculture Organization of the United Nations (FAO) Regional Office for Asia and the Pacific. 2nd, p. 57.

Jaruntorn Boonyanuphap, Det Wattanachaiyingcharoen and Katsutoshi Sakurai. 2004. GIS-based land suitability assessment for Musa (ABB group) plantation. *J. Appl. Hort*, 6, 3-10. Available at http://www.horticultureresearch.net/Jaruntorn.pdf.

Jones, P. and Sysomvang, S. 2005. Participatory Land-Use Planning and Land Allocation. Technical Booklets in Improving Livelihoods in the Uplands of the Lao PDR. NAFRI, NAFES and NUOL.

Johnson, G. L. and Lard, C. F. 1961. Knowledge situations, pp. 41-54. In, Johnson, G. L., Halter, A. N., Jensen, H. R. and Thomas, D. W. (Eds.), A Study of the Managerial Processes of Midwestern Farmers. Ames, Iowa: Iowa State University Press.

Kalogirou, S. 2002. Expert systems and GIS: an application of land suitability evaluation. *Computers, Environment and Urban Systems*, 26, 89-112.

Karlen, D. L. Mausbach, M. J., Doran, J. W., Cline, R. G., Harris, R. F. and Schuman, G. E. 1997. Soil Quality: A Concept, Definition, and Framework for Evaluation. *Soil Sci. Soc. Am. J.*, 61, 4-10.

Karlen, D. L., Stott, D. E., Cambardella, C. , Tomer, M. D. and Wolf, R. R. 2007. Soil Quality Assessment in the Iowa South Fork Watershed. *Paper presented at the annual meeting of the SOIL AND WATER CONSERVATION SOCIETY, Saddlebrook Resort, Tampa, Florida*, Jul 21, 2007.

Kassam, A. H., van Velthuizen, H. H., Fischer, G. W. and Shah, M. M. 1991. Agro-ecological land resources assessment for agricultural development planning a case study of Kenya resources data base and land productivity. Technical Annex 1 (Land Resources). Land and Water Development Division Food and Agriculture Organization of the United Nations and International Institute for Applied Systems Analysis. Available at http://www.fao.org/docrep/009/t0732e/T0732E00.htm#TOC.

Kay, R. D. and Edwards, W. M. 1994. Farm Management. Third edition. New York: McGraw-Hill.

Kim, P. V. 2009. The principles on plants' disease. Electronic book, Department of Plant Protection, College of Agriculture and Applied Biology, Can Tho University, Viet Nam. Available at http://www.ctu.edu.vn/colleges/agri/gtrinh/.

Kinsey, B. H. 2004. Zimbabwe's Land Reform Program: Underinvestment in Post-Conflict Transformation. *World Development,* 32**,** 1669-1696.

Klaus, D. Songqing, J. & Vandana, Y. 2008. Impact of Land Reform on Productivity, Land Value and Human Capital Investment: Household Level Evidence from West Bengal. American Agricultural Economics Association. Annual Meeting, July 27-29, 2008, Orlando, Florida.

Klingebiel, A.A. and Montgomery, P.H. 1961. Land capability classification. Agriculture handbook no 210. Soil conservation service, Washington D.C. US Department of Agriculture (USDA).

Kurland, K. S. and Gorr, W. L. 2007. GIS Tutorial for Health. New York, ESRI Press. 320p. Online book. Accessed on 02/02/2010.

Kurttila, M. Pesonen, M. Kangas, J. and Kajanus, M. 2000. Utilizing the analytic hierarchy process AHP in SWOT analysis - a hybrid method and its application to a forest-certification case. *Forest Policy and Economics*, 1, 41-52.

Laborte A. G., Roetter R. and Hoanh. C. T. 1999. SysNet Tools: the multiple goal linear programming (MGLP) model and MapLink. IRRI Technical Bulletin No. 6. Manila (Philippines): International Rice Research Institute. 31p.

Laffan, M. 1994. A methodology for Assessing and Classifying Site Productivity and Land Suitability for Eucalypt Plantations in Tasmania. Hobart, Forestry Commission Tasmania.

Law on Government Organization. 1992. Approved by the National Assembly of Socialist Republic of Viet Nam, IXth Legislature, first session, September 30, 1992.

Le Canh Dung, Nguyen Hong Tin, Lam Huon, Nguyen Cong Toan. 2010. Study on food security policies in the Mekong Delta. Full report submitted to the World Bank. The Mekong Delta Development Research Institute, Can Tho University.

Le Huy Ba. 2000. Environment. Reference book, National HCM University Publishing house, Viet Nam (in Vietnamese).

Lee, J. E. and Chastain, E. D. 1960. The role of problem recognition in managerial adjustment. *Farm Economics*, 42, 650-659.

Lerman, Z. 2009. Land reform, farm structure, and agricultural performance in CIS countries. *China Economic Review,* 20, 316-326.

Liberation Saigon. 2008. Agriculture in the Mekong Delta: experienced lesson from practice. Saigon liberation newspaper. No. 13/04/2009. HCM city, Viet Nam.

Liengsakul, M., Mekpaiboonwatana, S., Pramojanee, P. Bronsveld, K. and Huizing, H. 1993. Use of GIS and remote sensing for soil mapping and for locating new sites for permanent cropland-A case study in the "highlands" of northern Thailand. *Geoderma,* 60, 293-307.

Lingjun, L., Zong, H., Yan, H. 2008. Study on land use suitability assessment of urban-rural planning based on remote sensing—a case study of Liangping in Chongqing. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. *Vol. 37, Part B8*, Beijing 2008.

Lipton, M. 2009. Land Reform in Developing Countries: Property Rights and Property Wrongs. Routledge, p. 384p.

Liu, Y., Lv, X., Qin, X., Guo, H., Yu, Y., Wang, J. and Mao, G. 2007. An integrated GIS-based analysis system for land-use management of lake areas in urban fringe. *Landscape and Urban Planning*, 82, 233-246.

Loc, V. T. T. 2007. Assessment of regional value chains for promoting sustainable fisheries development in the Mekong Delta. Approved proposal submitted to Sustainable Mekong Research Network. Mekong Delta Development Institute, Cantho University, Viet Nam.

Loc, V. T. T., Bush, S., Sinh, L. X., Navy, H. & Khiem, N. T. 2009. Value chains for sustainable Mekong fisheries: the case of *Pangasius hypopthalmus* and *Henicorhynchus/Labiobarbus* spp. in Viet Nam and Cambodia. Scientific report submitted to the Sustainable Mekong Research Network (SUMERNET), Chulalongkorn, Thailand.

Long, H. H., Nga, T. T. T., Hoang, T., Thao, N. D. N. and Ho, T. H. 2008. Mekong Delta: a key position in export. The Mekong Delta economic co-operation. MDEC An Giang, Viet Nam. Available at http://www.mdec.vn/index.php?cgi==wGZBJ0RuBXY9UTbmgXMTRXaaVXU9QTbmMneRJGNstWS9MTbmgDMwADdn1jMtZCbpFGdlR2av9mYf1TMtZSbh5Gdllmd9ATb.

López, R. 2007. Agricultural growth and poverty reduction. In Bresciani, F. & Valdés, A. (eds). Beyond food production: the role of agriculture in poverty reduction. Cheltenham, UK, Edward Elgar Publishing. (Online book).

Luning, H. A. 1991. An integration of land evaluation and farming systems analysis for land use planning. In Land use planning applications. Proceedings of the FAO expert consultation 1990. World soil resources reports 68, 147-152. Interdepartmental working group on land use planning. Rome, Food and Agriculture Organization of the United Nations (FAO).

Lyle, J. & Suiltz, F. P. 1983. Computerized Land Use Suitability Mapping. *The Cartographic Journal*, 21, 336-344.

Lyon, J. G. and McCarthy, J. 1995. Wetland and environmental applications of GIS. New York, CRC Press LLC (Lewis Publishers). 373p. Online book. Accessed on 02/02/2010.

MacDougall, E. B. 1975. The accuracy of map overlays. *Landscape Planning*, 2, 23-30.

MAF and ME. 1983. Land capability classification for agriculture in British Columbia. Ministry of Agriculture and Food and Ministry of Environment (MAF and ME). MOE Manual 1. Kelowna, British Columbia, Canada.

MAFF. 1998. Agricultural Land Classification of England and Wales. Revised guidelines and criteria for grading the quality of agricultural land. Ministry of Agriculture, Fisheries and Food, England (MAFF), England.

Maguire, D. J. 1991. An overview and definition of GIS. In Maguire, D. J., Goodchild, M. F. and Rhind, D. W. (eds), *Geographical Information Systems Principles: and Applications*. New York, Longman Scientific and Technical, 1, 9-20. Available at http://www.wiley.com/legacy/wileychi/gis/Volume1/BB1v1_ch1.pdf. Accessed on 29/01/2010.

Mai, V. 1995. The progress and problems in IPM practice in Viet Nam. 19 Session of APPPC, 27 Nov.- 1 Dec 1995, Los Baños, Philippines.

Malczewski, J. 1999. GIS and Multi-criteria Decision Analysis. Wiley & Sons, New York. 363p. Online book. Accessed on 27/02/2010.

Malczewski, J. 2004. GIS-based land –use suitability analysis: a critical overview. *Progress in Planning*, 62, 3-65.

Malczewski, J. 2006. Ordered weighted averaging with fuzzy quantifiers: GIS-based multi-criteria evaluation for land-use suitability analysis. International Journal of Applied Earth Observation and Geo-information, 8, 270-277.

Malkina-Pykh, I. G. and Pykh, Y.A. 2004. Sustainable food and agriculture. Book chapter. *Agricultural Systems*, 80, 303-306.

Manna, P., Basile, A., Bonfante, A., Mascellis, R. D. and Terribile, F. 2009. Comparative Land Evaluation approaches: An itinerary from FAO framework to simulation modelling. *Geoderma*, 150, 367-378.

MARD. 2008. Viet Nam Agriculture in 2007 and further perspective. Annual report. Information centre for agriculture and rural development. Ministry of Agriculture and Rural Development of Viet Nam (MARD), Viet Nam.

MARD. 2009. News for production and marketing on August. News page for trade promotion. Ministry of Agriculture and Rural Development of Viet Nam (MARD), Viet Nam.

Martin, D. and Saha, S. K. 2009. Land evaluation by integrating remote sensing and GIS for cropping system analysis in a watershed. *Current Science*, 96, 569-575.

Maticic, B. 1999. The impact of agriculture on ground water quality in Slovenia: standards and strategy. *Agricultural Water Management,* 40, 235-247.

Matson, P., Parton, W., Power, A. and Swift, M. 1997. Agricultural intensification and ecosystem properties. *Science*, 277, 504-509.

Mauricio, P. F. F., Rosa, M. O. F. & Patrício, A. S. C. 2009. Land suitability, water balance and agricultural technology as a Geographic-Technological Index to support regional planning and economic studies. *Land Use Policy*, 26, 589-598.

May, H. & Lahiff, E. 2007. Land reform in Namaqualand, 1994-2005: A review. *Journal of Arid Environments,* 70, 782-798.

Mbatani, B, N. 2000. Determining the rain-fed arable production potential of climatically marginal land in the Northwest Province using the CYSLAMB land evaluation model. Master thesis. The University of Pretoria, South Africa.

McRae, T., Smith, C. A. S. and Gregorich, L. J. (eds). 2000. Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project. A Summary. Agriculture and Agri-Food Canada, Ottawa, Ont.

Messing, I., Fagerstro, M. H. H., Chen, L. and Fu, B. 2003. Criteria for land suitability evaluation in a small catchment on the Loess Plateau in China. *Catena*, 54, 215-234.

Michael D. Dukes, P.E. and Robert O. Evans, P.E. 2006. Impact of Agriculture on Water Quality in the North Carolina Middle Coastal Plain. *Irrigation and Drainage Engineering*, 132, 250-262.

Nielson, J. (1961). Improved managerial processes for farmers. *Farm Economics*, 43, 1250-1261.

Miller, H. J. and Shaw, S. L. 2001. Geographic information systems for transportation: principles and applications. New York, Oxford University Press, Inc. Online book. Accessed on 02/02/2010. 474p.

Minh, L. Q. 2002. Transboundary cause-effects of upstream development to environment and livelihoods in the Mekong Delta, Viet Nam. Paper presented at: Mekong Dialogue Workshop International transfer of river basin development experience: Australia and the Mekong Region, 2nd September 2002.

Minh, V, Q. 1995. Use of soil and agro-hydrological characteristics in developing technology extrapolation methodology: a case study of the Mekong Delta, Viet Nam. Master thesis. University of the Philippines at Los Banõs. 157p.

Minh, V. Q., Tri, L. Q. and and Yamada, R. 2003a. Development A Methodology for Land Evaluation and Land Use Planning in The Mekong Delta Using GIS as A Tool. http://www.ctu.edu.vn/institutes/mdi/jircas/JIRCAS/research/workshop/pro03/F2-FS2(Mr.Minh).pdf. Accessed on 15/02/2010.

Minh, V. Q., Tri, L. Q. and Yamada, R. 2003b. Delineation and incorporation of socio-infrastructure database into GIS for land use planning: A case study of Tan Phu Thanh village, ChauThanh District, Cantho Province. Map Asia Conference 2003. http://www.gisdevelopment.net/application/urban/overview/ma03012pf.htm.

MLWISW. 2008. Suggesting poverty reduction policies for 60 poorest districts. Presentation report at workshop on sustainable poverty reduction in poor districts. Ministry of Labour, War Invalids and Social Welfare of Viet Nam (MLWISW), (21/3/2008) in the Khanh Hoa Province, Viet Nam.

Mohamedl, A. A., Sharifil, M. A., And Keulenz, H. V. 2000. An integrated agro-economic and agro-ecological methodology for land use planning and policy analysis. *JAG*, 2, 87-103.

Mongkolsawat, C., Thirangoon, P. and Kuptawutinan, P. 1997. A Physical Evaluation of Land Suitability for Rice: A Methodological Study using GIS. Available at http://www.gisdevelopment.net/aars/acrs/1997/ts11/ts11004.asp. Accessed 15/11/2009.

Moss, M.R. 1978. Concept and theory in land evaluation for rural land use planning. Occasional Publication No. 6. Birmingham, Department of Geography, University of Birmingham.

Moss, M.R. 1985. Land processes and land classification. *Journal of Environmental Management*, 20, 295-319.

Murphy, B. W., Murphy, C., Wilson, B.R., Emery, K. A., Lawrie, J., Bowman, G., Lawrie, R. and Erskine, W. 2004. A revised land and soil capability classification for New South Wales. 13th International Soil Conservation Organisation Conference-Brisbane, July 2004.

Murthy, R. S., Venkataratnam, L. and Saxena, R. K. 1983. Application of remote sensing techniques for land evaluation and classification for agriculture. *Proc. Indian Acad. Sci. (Engg. Sci.)*, 6, 177-188.

Nam, V. T. B. 2007. Using geo-spatial analysis for water use and management in the flooding area in the Mekong Delta, Viet Nam. Presentation paper in Applied Geomatics Workshop on November 23, 2007. Nong Lam University, Ho Chi Minh City, Viet Nam.

Nancy, L. J., Liljab, N. and Ashbyc, J. A. 2003. Measuring the impact of user participation in agricultural and natural resource management research. *Agricultural Systems*, 78, 287-306.

NASA. Undated. Available at http://gislounge.com/what-is-gis/. Accessed on 21/01/2010.

NEDECO. 1993. Master plan for the Mekong Delta in Viet Nam, A perspective for sustainable development of land and water resources. Government of Viet Nam, State Planning Committee, Work Bank, Mekong Secretariat, United Nations Development Programme.

Ngoc Lam. 2009. Every day, there are more than two million people consume unsafe vegetables. Tien Phong Newspaper. Available at http://www.tienphong.vn/Tianyon/Index.aspx?ArticleID=169925&ChannelID=2.

Nguyen, H. D. 2008. The current status of cultivation and improvement of soil fertility, triple rice yield inside dyke at the Cho Moi District, An Giang Province. Master thesis. College of Agriculture and Applied Biology, Can Tho University, 61 pages.

Ni, D. V. 1993. Land evaluation of rain-fed lowland rice areas in the Mekong Delta of Viet Nam. Master thesis. University of the Philippines at Los Banõs. 72p.

Nikolaidis, C., Mandalos, P. & Vantarakis, A. 2008. Impact of intensive agricultural practices on drinking water quality in the EVROS Region (NE GREECE) by GIS analysis. *Environ Monit Assess*, 143, 43–50.

Nydick, R. L. and Hill, R. P. 1992. Using the Analytic Hierarchy Process to Structure the Supplier Selection Procedure. *International Journal of Purchasing and Materials Management*, 28, 31-36.

ODTGAUS. 2009. State Policy on the Protection of Agricultural Land 2009. Official Directory of the Tasmanian Government, Australia (ODTGAUS) http://www.dpac.tas.gov.au/__data/assets/pdf_file/0004/82714/State_Policy_on_the_Protection_of_Agricultural_Land_2009.pdf. Accessed on 31/09/2009.

Oosterberg, W., Drimmelen, C. V., Vlist, M. V. D. 2005. Strategies to harmonize urbanization and flood risk management in Delta's. Water Affairs (DGW) of the Dutch Ministry of Transport, Public Works and Water Management (V&W), Holand. Available at http://www-sre.wu-wien.ac.at/ersa/ersaconfs/ersa05/papers/174.pdf. Accessed on 25/08/2009.

PANUPS. 1995. Evidence Mounts Questioning Insecticide use in Tropical Rice. Pesticide Action Network North America Updates Service (PANUPS). March 7, 1995. Infopubs. http://www.sare.org/sanet-mg/archives/html-home/7-html/0147.html.

Paul Smith, John Lawrie, Alan Welch, and Daniel Wiecek. 2004. Developing a land capability system for the Western Plains of New South Wales. SuperSoil 2004: 3rd Australian New Zealand Soils Conference, 5-9 December 2004, University of Sydney, Australia.

People's Committee of An Giang Province. 2009. General introduction to An Giang Province. Available at http://www.An Giang.gov.vn. Accessed on 17/07/2010.

Pereira, José M. C. and Duckstein, Lucien. 1993. A multiple criteria decision-making approach to GIS based land suitability evaluation. *International Journal of Geographical Information Science*, 7, 407-424.

Perfecto, I. and Vandermeer, J. 2008. Biodiversity Conservation in Tropical Agro-ecosystems A New Conservation Paradigm. *New York Academy of Sciences*, 1134, 173-200.

Peter, J. T. 1996. Land Capability Assessment for the Wellington-Blackwood Survey Resource Management Technical Report No. 162. Government of Western Australia.

Pidwirny, M. (2006a). "Definitions of Systems and Models". Fundamentals of Physical Geography, 2nd Edition. Accessed on 27/12/2009 at http://www.physicalgeography.net/fundamentals/4b.html.

Pidwirny, M. (2006b). "Structure of Systems". Fundamentals of Physical Geography, 2nd Edition. Accessed on 27/12/2009 at http://www.physicalgeography.net/fundamentals/4c.html.

Pidwirny, M. 2006c. Maps, Remote Sensing, and GIS. In "*Fundamentals of Physical Geography, 2nd Edition*". Available at http://www.physicalgeography.net/fundamentals/chapter2.html. Accessed on 27/12/2009.

Pierce, F. J. and Clay, D. E. 2007. GIS applications in agriculture. Florida, Taylor & Francis Group (CRC Press), LLC. 203p.

Pierce, F. J., Larson, W. E., Dowdy, R. H. & Graham, W. A. P. 1983. Productivity of soils: assessing long-term changes due to erosion. *Journal of Soil and Water Conservation*, 38, 39-44.

Pioram, J. J. 1997. Agricultural systems in transition. *Agricultural Systems*, 2, 33-45.

Poisot, A. S., Speedy, A. and Kueneman, E. 2007. Good Agricultural Practices-a working concept: Background paper for the FAO Internal Workshop on Good Agricultural Practices (Rome, Italy 27-29 October 2004). Rome, Food and Agriculture Organization of the United Nations (FAO). 31p.

Population Reference Bureau. 2008. World Population Highlights: Key Findings From PRB's 2008 World Population Data Sheet. *Population bulletin*, 63, Washington, D. C., (www.prb.org).

Population Reference Bureau. 2009. World Population Highlights: Key Findings From PRB's 2009 World Population Data Sheet. *Population bulletin*, 64, Washington, D. C., (www.prb.org).

Prakash, T. N. 2003. Land suitability analysis for agricultural crops: A fuzzy multi-criteria decision making approach. Master thesis. International Institute for Geo-information Science and Earth Observation. Netherlands. 57p.

Rahimi Lake, H., Taghizadeh Mehrjardi, R, Akbarzadeh, A. and Ramezanpour, H. 2009. Qualitative and Quantitative Land Suitability Evaluation for Olive (*Olea europaea* L.) Production in Roodbar Region, Iran. *Agricultural Journal*, 4, 52-62.

Ravallion, M. & Chen, S. 2004. "How Have the World's Poorest Fared Since the Early 1980's?" *World Bank Research Observer* 19, 2, 141-170.

Ravallion, M. & Chen, S. 2007. "China's (Uneven) Progress Against Poverty." *Development Economics*, 82, 1-42.

Reinhardt, I. W. 2000. Principles and Application of Geographic Information Systems and Internet/Intranet Technology. Paper presented at the RTO IST Symposium on "*New Information Processing Techniques for Military Systems*", Istanbul, Turkey, 9-11/10/2000. Available at http://ftp.rta.nato.int/public/PubFulltext/RTO/MP/RTO-MP-049/MP-049-10.pdf. Accessed on 02/02/2010.

Reshmidevi, T. V., Eldho, T. I. & Jana, R. 2009. A GIS-integrated fuzzy rule-based inference system for land suitability evaluation in agricultural watersheds. *Agricultural systems*, 101, 101-109.

Ritter, W. F. 2001. Pesticides and water quality impacts. In Ritter, W. F. & Shirmohammadi, A. (eds). Agricultural non-point source pollution: Watershed management and hydrology. Lewis Publishers, Boca Raton, London, New York, Washington, D. C.

Ritter, W. F. and Shirmohammadi, A. 2001. Agricultural non-point source pollution: Watershed Management and Hydrology. Washington, D.C., Lewis publishers, CRC Press LLC.

Ritung, S., Wahyunto, Agus, F., Hidayat, H. 2007. Land Suitability Evaluation with a case map of Aceh Barat District. Indonesian Soil Research Institute and World Agroforestry Centre, Bogor, Indonesia.

Robinson, N. J., Reynard, K. A., Sheffield, K. J. & Bluml, M. R. 2004. Ararat Rural City Land Capability Pilot Project, Volume 1: Soil-landform units, land capability analyses and lands hazards. *Research report No. 55*. Department of Primary Industries. The State of Victoria, Australia.

Rojas, E. & Meganck, R. A. 1987. Land distribution and land development in the Eastern Caribbean. *Land use policy*, 4, 157-167.

Rojas, E. 1984. Agricultural land in the Eastern Caribbean: From resources for survival to resources for development. *Land use policy*, 1, 39-54.

Rossiter, D. and Van Wambeke, A. 1997. Automated Land Evaluation System: ALES Version 4.65 User's Manual. Ithaca, New York, Cornell University.

Rossiter, D. G. 1994. Land Evaluation Course NotesPart 2: Geographical Information Systems. College of Agriculture & Life Sciences, Cornell University. 31p.

Rossiter, D. G. 1995. Economic land evaluation: Why & How. *Soil use & Management*, 11, 132-140.

Rossiter, D. G. 1996. A theoretical framework for land evaluation. Discussion paper. *Geoderma*, 72, 165-190.

Rossiter, D.G. & Van Wambeke, A. R. 1997. Automated Land Evaluation System ALES Version 4.65 User's Manual. Department of Soil, Crop & Atmospheric Sciences, Cornell University, Ithaca, New York.

Rotter, R. P., Hoanh, C. T., Laborte, A. G., Keulen, H. V., Van Ittersum, M. K., Dreiser, C., Van Diepen, C. A., De Ridder, N. and Van Laar, H. H. 2005. Integration of Systems Network (SysNet) tool for regional land use scenario analysis in Asia. *Environmental Modelling & Software*, 20, 291-307.

Rowe, J. S. 1980. The common denominator of land classification in Canada: an ecological approach to mapping. *The Forestry Chronicle*, 56, 19-20.

Rowe, J. S. 1981. Ecological Land Classification: A Survey Approach. *Environmental Management*, 5, 451-464.

Rowe, R. K., Howe. D. F. and Alley. N. F. 1981. Guidelines for land capability assessment in Victoria. Soil conservation authority. Victoria, Australia.

Saaty, T. L and Vargas, L. G. (eds). 2001. Models, methods, concepts & applications of analytical hierarchy process. International Series in Operations Research and Management sciences. Massachusetts, Kluwer Academic Publishers. Online book. Accessed on 15/02/2010. 333p.

Saaty, T. L and Vargas, L. G. (eds). 2001. Models, methods, concepts & applications of analytical hierarchy process. International Series in Operations Research and Management sciences. Massachusetts, Kluwer Academic Publishers. Online book. Accessed on 15/02/2010. 333p.

Saaty, T. L. 2002. Decision making with the analytic hierarchy process. *Scientia Iranica*, 9, 215-229.

Saaty, T. L. 2008a. Relative Measurement and Its Generalization in Decision Making Why Pairwise Comparisons are Central in Mathematics for the Measurement of Intangible Factors The Analytic Hierarchy/Network Process. *Rev. R. Acad. Cien. Serie A. Mat.*, 102, 251–318.

Saaty, T. L. 2008b. Decision making with the analytic hierarchy process. *Int. J. Services Sciences*, 1, 83-98.

Salam, M. A., Ross, L. G., Lindsay, G. and Beveridge, M. C. M. 2002. Evaluation of land suitability for crab culture: a methodological study using GIS. Proceedings of Map Asia 2002. August 07-09, 2002. Bangkok, Thailand.

Samranpong, C., Ekasingh, B. and Ekasingh, M. 2009. Economic land evaluation for agricultural resource management in Northern Thailand. *Environmental Modelling & Software*, 24, 1381-1390.

Sanchez, P. A., Couto, W. & Buol, S.W. 1982. The fertility capability soil classification system: interpretation, applicability, and modification. *Geoderma*, 27, 283–309.

Sanchez, P.A., Palm, C.A. & Buol, S.W. 2003. Fertility capability soil classification: a tool to help assess soil quality in the tropics. *Geoderma*, 114, 157-185.

Sands, G. R., Podmore, T. H. 2000. A generalized environmental sustainability index for agricultural systems. *Agriculture, Ecosystems and Environment*, 79, 29–41.

Sanh, N. V., Xuan, V. T. and Phong, T. A. 1998. History and future of farming systems in the Mekong Delta. In: Development of farming systems in the Mekong Delta of Viet Nam, Xuan, V. T. and Matsui, S. (editors), Ho Chi Minh city Publishing House. p17-80.

Santé-Riveira, I., Crecente-Maseda, R. and Miranda-Barrós, D. 2008. GIS-based planning support system for rural land-use allocation. *Computer and electronics in agricultural*, 63, 257-273.

Scholten, H. J. and Lepper, M. J. C. de. 1995. An introduction to geographical information systems. In Lepper, M. J. C. de et al. (eds.), *The Added Value of Geographical Information Systems in Public and Environmental Health, Kluwer Academic Publishers, Netherlands,* 53-70.

Scott Frey, R. 1996. A glossary of agriculture, environment, and sustainable development. Bulletin 661. Agricultural Experiment Station, Kansas State University. Manhattan.

Sequi, P. 1999. Impact of agriculture on the environment. CIHEAM - Options Mediterraneennes. Available at http://ressources.ciheam.org/om/pdf/c37/99600020.pdf. Accessed on 07/01/2010.

Seybold, C.A., M.J. Mausbach, D.L. Karlen, and H.H. Rogers. 1998. Quantification of soil quality. p. 387-404. In: R. Lal, J.M. Kimble, R.F. Follett, and B.A. Stewart (eds.) Soil processes and the carbon cycle. CRC Press, BocaRaton.

Shamsi, U. M. 2005. GIS applications for water, wastewater, and stormwater systems. Florida, CRC Press. 413p. Online book. Accessed on 02/02/2010.

Shim, J. P., Warkentin, M., Courtney, J. F., Power, D. J., Sharda, R. and Carlsson, C. 2002. Past, present and future of decision support technology. *Decision Support Systems*, 33, 111-126.

Shoup, W. D. 2004. Agricultural Systems: A Managerial Overview. Book chapter in Agricultural systems management: optimizing efficiency and performance. Marceld Ekker, Inc. New York.

Sicat, R. S., Carranza, E. J. M. and Nidumolu, U. B. 2005. Fuzzy modelling of farmers' knowledge for land suitability classification. *Agricultural Systems*, 83, 49-75.

Siderius, W. (ed.) 1986. Land evaluation for land use planning and conservation in sloping areas. ILRI Publication 40. International Institute for Land Reclamation and Improvement (ILRI), Wageningen. The Netherlands.

Simmons, S. R., Oelke, E. A. and Anderson, P. M. 1995. Growth and Development Guide for Spring Wheat. University of Minnesota, Agricultural Extension, F0-02547. Available at http://www.extension.umn.edu/distribution/cropsystems/DC2547.html. Accessed on 17/01/2010.

Smyth, A. J. & Dumanski, J. 1995. A framework for evaluating sustainable land management. *Canadian Journal of Soil Science,* 75, 401-406.

Smyth, A. J., Dumanski, J., Spendjian, G., Swift, M. J. & Thornton, P. K. 1993. FESLM: an international framework for evaluating sustainable land management. *World Soil Resources Report*, 73. Rome, Food and Agriculture Organization of the United Nations (FAO).

Smyth, C. R. and Bittman, K. 1998. Pre-and Post-Mining Land Capability Assessment at Quintette Operating Corporation. *Proceedings of the 22nd Annual British Columbia Mine Reclamation Symposium* in Penticton, BC, 1998. The Technical and Research Committee on Reclamation.

SoilQuality.org. 2009. Soil Functions: Services Provided by Soil Resources. Available at http://soilquality.org/functions.html.

Sombroek, W. G. 1996. Land resources evaluation and the role of land–related indicators. In: Land quality indicators and their use in sustainable agriculture and rural development. Rome, Food and Agriculture Organization of the United Nations (FAO). Available at http://www.fao.org/docrep/W4745E/w4745e05.htm. Accessed on 24/04/2010.

Son, D. K., Que, N. N., Dieu, P. Q., Trang, T. T. T., And Beresford, M. 2006. Policy reform and the transformation of Vietnamese agriculture. In Rapid growth of selected Asian economies Lessons and implications for agriculture and food security Republic of Korea, Thailand and Viet Nam. Bangkok, Food and Agriculture Organization of the United Nations.

Son, N. T., Hieu, T. V., Shrestha, R. P., Trieu, N. T., Kien, N. V., Anh, V. T., Dung, P. A., Duc, H. N., Du, N. M. and Niem, N. X. 2008. Integrated land-use planning for sustainable agriculture and natural resources management in the Vietnamese Mekong delta. *AEJ*, 6, 307-324.

Son, N.T. 2005. GIS Aided Land Evaluation for Sustainable Agricultural Development in the Tri Ton District, An Giang, Viet Nam. Master Thesis No.NR-05-06. Asian Institute of Technology, 2005. Bangkok: Asian Institute of Technology.

Steiner, F. 1987. Agricultural Land Evaluation and Site Assessment in the United States: An Introduction. *Environmental Management*, 11, 375-377.

Steinitz, C., Parker, P. and Jordan, L. 1976. Hand-drawn overlays: their history and prospective uses. *Landscape Architect*, 9, 444-455.

Store, R. and Kangas, J. 2001. Integrating spatial Multi-Criteria Evaluation and Expert knowledge for GIS-based habitat suitability modelling. Landscape and Urban Planning, 55, 79-93.

Swinnen, J. F. M. 2002. Land reform in Russia: constraints and policy implications. *Economic Systems,* 26, 159-162.

Thanh, D. N. 2002. Comparative socio-economic analysis of selected farming systems in the coastal areas of the Mekong Delta, Viet Nam. Doctor Thesis in Rural development, Faculty of the Institute of Graduate Studies, Central Luzon State University, Science City of Munoz, Nueva Ecija, Philippines.

Thanh, H. H. 2001. Investigation and survey on the current status of the pattern of two and three rice cropping seasons per year at the Cho Moi District, An Giang Province (1999-2000). Master thesis. College of Agriculture and Applied Biology, Can Tho University, 83 pages (in Vietnamsese).

Thao, N. H. 2008. Classification of land mapping units based on soils as hydrological characteristics in the Co Do District, Can Tho City. *Omonrice*, 16, 138-143.

Thapa, R. B. and Murayama, Y. 2008. Land evaluation for peri-urban agriculture using analytical hierarchical process and geographic information system techniques: A case study of Hanoi. *Land Use Policy*, 25, 225-239.

The ACT Parliamentary Counsel. 1999. Land capability assessment guidelines. Available at http://www.legislation.act.gov.au/. Accessed on 27/12/2009.

The State Planning Commission. 1989. Land capability assessment for local rural strategies. Guidelines. Department of agriculture in conjunction with the State Planning Commission. Western Australia.

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R and Polasky, S. 2002. Agricultural sustainability and intensive production practices. Insight review articles. *Nature*, 418, 671-677.

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, WH., Simberloff, D., Swackhamer, D. 2001. Forecasting agriculturally driven global environmental change. *Science*, 292, 281-284.

Tin, H. N. 2005.The informal seed supply system in the Mekong Delta. Final report on the Community Biodiversity Development and Conservation project. Southeast Asia Regional Initiatives for Community Empowerment. Philippines.

Tri, L. Q. and Tri, V. P. D. 2005. Land evaluation and farming system analysis (LEFSA) for land use planning at Song Phu commune, Tan Binh district, Vinh Long province. *Journal of science and technology (Vie)*, 21, 84-90. Available at http://www.vista.gov.vn/english/. Accessed on 06/01/2010.

Tri, L. Q., Nhan, N. V., Huizing, H. G. J. and van Mensvoort, M. E. F. 1993. Present land use as basis for land evaluation in two Mekong Delta districts. In Dent, D. L. and van Mensvoort, M. E. F. (eds). "*Selected Papers of the Ho Chi Minh City Symposium on Acid Sulphate Soils*". International Institute for Land Reclamation and Improvement. Wageningen, The Netherlands.

Trung, N.H., Le Quang Tri,, Mensvoort, M.E.F. van, and Bregt, A.K. 2004. GIS for participatory land use planning in the Mekong Delta, Viet Nam. In: Proceedings AFITA/WCCA Joint Congress on IT in Agriculture, Bangkok, 9-12 September 2004. Bangkok: National Science and Technology Agency, 2004.

Trung. N. H. 2006. Comparing land use planning approaches in the Mekong Delta. PhD thesis. Wageningen University, Netherlands.

Tsoumakas, G., Vlahavas, I. 2001. Land Evaluation-An Artificial Intelligence Approach. In Rautenstrauch, C. and Patig, S. (eds.). "*Environmental Information Systems in Industry and Public Administration*". Ch. 9, p. 158-166. Idea Group Publishing. Online book.

Tuc, V. P., Wangsuphachart, V., Tasanapradit, P., Fungladda, W., Trong, P. V. & Nhung, N. T. 2007. Impacts of pesticide use on semen characteristics among rice farmers in the Kienxuong District, Thaibinh Province, Viet Nam. *Southeast Asian J. Trop. Med. Public Health*, 38, 569-575.

Turner, B. L. 1997. The sustainability principle in global agendas: implications for understanding land use/cover change. *Geographical Journal*, 163, 133-140.

U. S. Census Bureau. 1997. North American Industry Classification System (NASICS). Available at http://www.census.gov/epcd/naics/naics3dx.htm#N11.

UNEP. 2000. Global environment outlook 2000 (overview). Division of Environmental Information, Assessment and Early Warning (DEIA&EW). United Nations Environment Programme (UNEP), Nairobi, Kenya.

UNEP. 2002. Global Environment Outlook 3: Past, present and future perspectives. United Nations Environment Programme (UNEP), Nairobi, Kenya.

UNEP/GRID-Arendal. 2007. Agriculture land use distribution-croplands and pasture land, *UNEP/GRID-Arendal Maps and Graphics Library*. http://maps.grida.no/go/graphic/agriculture-land-use-distribution-croplands-and-pasture-land1. Accessed on 12/12/2009.

UNESCAP. 2007. Achieving the millennium development goals in the Asian and Pacific region: regional road map to 2015, Paper presented by the Secretariat to the Sixty-third Session of the Economic and Social Commission for Asia and the Pacific. United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP).

UNFPA. 2001. Footprints and Milestones: Population and Environmental Change - The State of World Population 2001. New York, United Nations Population Fund (http://www.unfpa.org/upload/lib_pub_file/471_filename_swp2001_eng.pdf).

United States Geological Survey. 2007. What is GIS? Available at http://webgis.wr.usgs.gov/globalgis/tutorials/what_is_gis.htm. Accessed on 29/01/2010.

USDA. 2001a. Guidelines for Soil Quality Assessment in Conservation Planning. United States Department of Agriculture (USDA). Washington, DC, 38p.

USDA. 2001b. User Manual for LESA-CALES: Computer-Assisted Land Evaluation System. Natural Resources Conservation Service. Office of Farmland Protection and Community Planning. United States Department of Agriculture (USDA). Washington, DC.

USDA. 2005. Agricultural Land Evaluation and Site Assessment (LESA). Natural Resources Conservation Service. United States Department of Agriculture (USDA). Washington, DC.

USDA. 2008. Critical Loads Glossary (last modified on 08/19/2008). United States Department of Agriculture (USDA). Forest services. Available at http://www.nrs.fs.fed.us/clean_air_water/clean_water/critical_loads/glossary/. Accessed on 27/05/2010.

USDA. 2009. National Soil Survey Handbook, title 430-VI. U.S. Department of Agriculture (USDA), Natural Resources Conservation Service. Available online at: http://soils.usda.gov/technical/handbook/ accessed [12/27/2009].

USDA. 2010a. National Soil Survey Handbook, title 430-VI. U.S. Department of Agriculture (USDA), Natural Resources Conservation Service. Available online at: http://soils.usda.gov/technical/handbook/. Accessed on 07/01/2010.

USDA. 2010b. Soil Quality Assessment. Natural Resources Conservation Service. Available at http://soils.usda.gov/sqi/assessment/assessment.html. Accessed on 07/01/2010.

USDA. 2010c. Soil Quality: Improving how your soil works. Natural Resources Conservation Service. Available at http://soils.usda.gov/sqi/. Accessed on 07/01/2010.

Usongo, L. and Nagahuedi, J. 2008. Participatory land-use planning for priority landscapes of the Congo Basin. In *Unasylva*, 230, p. 17-24. Rome, Food and Agriculture Organization of the United Nations (FAO).

Uy, P. D. and Nakagoshi, N. 2008. Application of land suitability analysis and landscape ecology to urban green-space planning in Hanoi, Viet Nam. *Urban Forestry & Urban Greening*, 7, 25-40.

Valente, C. 2009. The Food (In) Security Impact of Land Redistribution in South Africa: Micro-econometric Evidence from National Data. *World Development,* 37, 1540-1553.

Van Diepen, C. A., Van Keulen, H.. Wolf J. and Berkhout, J. A. A. 1991. Land evaluation: from intuition to quantification. In Stewart B. A. (ed), Advances In Soil Science. Springer, New York. pp. 139-204.

Van Ittersum, M. K., Rotter, R. P., Keulen, H. V., Ridder, N. D., Hoanh, C. T., Laborte, A. G., Aggarwal, P. K., Ismail, A. B. and Tawang, A. 2004. A systems network (SysNet) approach for interactively evaluating strategic land use options at sub-national scale in South and South-East Asia. *Land Use Policy*, 21, 101-113.

Van Mensvoort, M. E. F., Nhan, N. V., Tinh, T. K. Tri, L. Q. 1993. Coarse land evaluation of the acid sulphate soil areas in the Mekong delta based on farmers' experience. In Dent, D. L. and van Mensvoort, M. E. F (eds). "*Selected Papers of the Ho Chi Minh City Symposium on Acid Sulphate Soils*". International Institute for Land Reclamation and Improvement. Wageningen, The Netherlands. p. 321-339.

Vandermeer, J. and Perfecto, I. 2005. The future of farming and conservation. *Science*, 308, 1257-1258.

Vandermeulen, V., Gellynck, X., Huylenbroeck, G. V., Orshoven, J. V. and Bomans, K. 2009. Farmland for tomorrow in densely populated areas. *Land Use Policy*, 26, 859–868.

Veldkamp, A. and Fresco, L. O. 1996. CLUE: A conceptual model to study the conversion of land use and its effects. *Ecological Modelling*, 85, 253 - 270.

Verheye, W. H. 1996. Advanced Course on Land Evaluation and Land Use Planning. Sierra Leone, 4-16 July 1996. FAO & Government of Sierra Leone Land Use Committee. FAO, Rome.

Vietnamese labour newspaper. 2008. Water farming causes environmental pollution in the Mekong River Delta. Available at http://www.laodong.com.vn/Home/Nuoc-canh-tac-gay-o-nhiem-moi-truong-Dong-bang-song-Cuu-Long/200811/114240.laodong.

VNA. 2007. Aquaculture: Abuse of chemicals, pollutants. Viet Nam News Agency (VNA).

Voogd, H. 1983. Multi-criteria Evaluation for Urban and Regional Planning. Pion Limited, London, 367p. Online book. Accessed on 07/02/2010.

Wandahwa, P. and van Ranst, E. 1996. Qualitative land suitability assessment for pyrethrum cultivation in west Kenya based upon computer-captured expert knowledge and GIS. *Agriculture, Ecosystem and Environment*, 56, 187-202.

Wassmann, R., Hien, N. X., Hoanh, C. T and Tuong, T. P. 2004. Sea level rise affecting the Vietnamese Mekong Delta: Water elevation in the flood season and implications for rice production. *Climatic Change*, 66, 89-107.

Webster, R. 1994. The development of pedometrics. *Geoderma*, 62, 1-15.

Wescott, K. and Brandon, R. J. 2000. Practical applications of GIS for archaeologists: a predictive modelling toolkit. London, Taylor & Francis. 160p. Online book. Accessed on 02/02/2010.

Womach, J. 2005. Agriculture: A Glossary of Terms, Programs, and Laws, 2005 Edition. CRS Report for Congress (Order Code 97-905). 270p. Available at http://ncseonline.org/NLE/CRSreports/05jun/97-905.pdf. Accessed on 21/02/2010.

World Bank. 2006a. Sustainable land management: Challenges, opportunities, and trade-offs. Washington, D. C., World Bank. 89p.

World Bank. 2006b. *World Development Indicators*. Washington, D. C., World Bank.

World Bank. 2007a. Micro-finance: Breaking the cycle of poverty. North American Affairs newsletter. July, Issue 6. Washington, D. C., World Bank.

World Bank. 2007b. World Development Indicators 2007. Washington, D. C., World Bank. Online book, 121-125. Available at http://www.scribd.com/doc/16060172/World-Development-Indicators-2007-. Accessed on 17/07/11.

World Bank. 2008a. Agriculture for Development 2008. World Development Report 2008. Washington, D. C., World Bank. 352 pages. Available at http://siteresources.worldbank.org/INTWDR2008/Resources/WDR_00_book.pdf.

World Bank. 2008b. Climate Change Response Strategies for Agriculture: Challenges and Opportunities for the 21st Century. Discussion Paper 42, Agriculture & Rural Development Department, World Bank. Washington, D. C., World Bank.

WRI. 2008. World Resources 2008: Roots of Resilience-Growing the Wealth of the Poor. World Resources Institute in collaboration with United Nations Development Programme, United Nations Environment Programme, and World Bank (WRI). Washington, D. C., World Bank.

Wright I. A., Birnie R. V., Malcolm A., Towers, W. and McKeen, M. 2006. The Potential Use of the Land Capability for Agriculture Classification for Determining Support to Disadvantaged Areas of Scotland. Macaulay Institute Craigiebuckler Aberdeen AB15 8QH. UK.

www.data.geocomm.com

www.Gcmd.gsfc.nasa.gov/ceosidn

www.geographynetwork.com

www.nsdi.usgs.gov

Xuan, V. T. and Matsui, S. (eds). 1998. Development of farming systems in the Mekong Delta of Viet Nam. Ho Chi Minh Publishing house. Viet Nam.

Zalidis, G., Stamatiadis, S., Takavakoglou, V., Eskridge, K. & Misopolinos, N. 2002. Impacts of agricultural practices on soil and water quality in the Mediterranean region and proposed assessment methodology. *Agriculture, Ecosystems & Environment,* 88, p. 137-146.

APPENDIX 1: TERMINOLOGIES

The following definitions of terminologies exclude the interpretation and explanation presented in Appendix 8

1. Common terminologies

Agribusiness refers to the sum total of all operations involved in the manufacture and distribution of farm supplies; production operations on the farm; and the storage, processing and distribution of farm commodities and items made from them (Davis and Goldberg, 1957).

Analytical Hierarchy Process (AHP) refers to a decision-making theory developed by Saaty (the University of Pennsylvania), while directing the research project in the U.S Arms Control and Disarmament Agency (Bhushan and Rai, 2004). It is widely applied in the process of multi-criteria decision analysis as a comprehensive framework designed to deal with the intuitive, the rational, and the irrational when decision makers make multi-objective, multi-criterion and multi-factor decisions with or without certainty about any number of alternatives (Harker and Vargas, 1987). The AHP offers a methodology to rank alternative courses of action based on the decision makers' judgments concerning the importance of the criteria and the extent to which they are met by individual alternatives (Nydick and Hill, 1992).

Benefit-cost ratio refers to the present value of the benefits from an enterprise (farm, forest, etc.) divided by the present value of its costs (FAO, 1993).

Class-determining factors refer to variables affecting agronomic, management, land development, conservation, the environment, or socioeconomic conditions that has an influence on the outputs and inputs of a specified kind of land use, and which is used to assess the suitability class in which a land unit should be placed for that use (FAO, 1985). In the current study, class-determining factors mean factors involved in the Agricultural Management System (AMS) for farmland capability assessment.

Components refer to broad groups of class-determining factors in the agricultural management system that, directly impact upon the capability of farmland for a specific use (in the current study, they include main components such as the biophysical, technical and management, land development or improvement, socio-economic, institutional and policy).

Degrees of limitation refer to the scaling of a single factor (land use requirement, land quality/land characteristic) according to its adverse effects on a specified land utilisation type (FAO, 1985).

Farming system (FS) refers to a class consisting of all farms with similar land use, environment and economy; comprising the farm household, its land and the systems of cropping or livestock production for consumption or sale. A farming system is a decision-making unit and a land-use system based on agriculture (FAO, 1993).

Geographic information system (GIS) refers to a system for capturing, storing, checking, integrating, manipulating, analysing and displaying data which is spatially referenced to the earth (FAO, 1996b *et al.*; Choudhury and Jansen, 1998).

Input materials refer to the internal natural, physical, and human resources within the community including external inputs or resources brought on or introduced in a particular area to achieve agriculture production goals (Thanh, 2002, p. 64).

Land capability refers to the ability of land to sustain a specified land use without resulting in significant onsite or offsite degradation or damage to the land resources (FAO, 1976 and 1993; Rowe *et al.*, 1981; The ACT Parliamentary Counsel, 1999; USDA, 2010a).

Land characteristic refers to an attribute of land that can be measured or estimated in a routine survey in any operational sense (FAO, 1976), including by remote sensing, census and natural resource survey (FAO, 2007b).

Land evaluation (assessment) refers to the process of assessment of land performance when used for specified purposes involving the execution and interpretation of surveys and studies of all aspects of land (see above) in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation (FAO, 1976).

Land improvement refers to an alteration in the qualities of land that improves its potential for land use (see major land improvement, minor land improvement) (FAO, 1976). It is an activity that causes beneficial changes in the qualities of the land itself (FAO, 2007b).

Land mapping unit (LMU) refers to an area of land demarcated on a map and possessing specified land characteristics or qualities (FAO, 1976).

Land quality (LQ) refers to a complex attribute of land that acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for a specified kind of use. LQs refer to the ability of the land to fulfil specific requirements for a LUT (FAO, 1976).

Land suitability refers to the applicability of a given type of land for a specific land use (Choudhury & Jansen 1998; FAO, 2007b). The fitness of land for a specified kind of use (FAO, 1993)

Land survey/investigation refers to laboratory analysis and field activities for data collection on land characteristics, based on land use requirements of a specific land use type.

Land use refers to the management of land to meet human needs. This includes rural land use and also urban and industrial use (FAO, 1993).

Land use requirement (LUR) refers to a condition of the land necessary for successful and sustained implementation of a specific LUT. Each LUT is defined by a set of LURs that specify its demands on the land (FAO 1983, 1985, 2007b).

Land use type (land utilization type, LUT**)** refers to a use of land defined in terms of a product, or products, the inputs and operations required to produce these products, and the socio-economic setting in which production is carried out (FAO, 1976). In the strict meaning of the term, describes a synthetic, simplified, representative land-use type for the purpose of land suitability evaluation. It is necessary to distinguish between the LUT, described above, and an actual, or real land use observed and described in the field. In the context of rain-fed agriculture the LUT refers to a crop, crop combination or cropping system within a specified technical and socio-economic setting. In the context of irrigated agriculture, irrigation and management methods are specified. A LUT in forestry consists of technical specifications in a given physical, economic and social setting. A LUT such as nature reserve or water-supply catchment would have technical, size and location specifications (FAO, 2007b, p. 66).

Land/farmland capability analysis refers to comparison between found land characteristics and land use requirements in order to classify capability levels for a specific land use type.

Limiting factor (limitation) refers to a land quality, or land characteristic, which adversely affects the potential of land for a specified kind of use, e.g. salinity, drought, floods (FAO, 1993).

Management process (agricultural management/farm management): management process has originally developed by Johnson *et al.* (1961), Lee and Chastain (1960), and Nielson (1961). Johnson *et al.* (1961) stated the management process has six functions problem recognition/definition, observation, analysis, decision, action, responsibility bearing. This process has dominated farm management theory for the last forty years (Gray *et al.*, 2009, p. 4) although the model was simplified during this time from six to three functions: planning, implementation and control (Boehlje and Eidman, 1984; Kay and Edwards, 1994). Gray *et al.* (2009) compared many theories on the management process and the divergence of farm management theory into three different views (management process, decision making process and problem solving process) of management practice that has limited the development of theory. Brief results show that there is no a universal theory on the management process although it involves key functions e.g. planning, implementation and control. The management process in this study based on agricultural production management, which encompasses 4 key functions mentioned in Chapter 4: planning, organising, directing, and monitoring.

Matching refers to the process of mutual adaptation and adjustment of the descriptions of land utilisation types and the increasingly known land qualities (FAO, 1976; 2007b).

Modelling refers to the construction of physical, conceptual or mathematical simulations of the real world. Models help to show relationships between processes (physical, economic or social) and may be used to predict the effects of changes in land use (FAO, 1993).

Natural resources refer to the resources of the land relevant to its potential for land use, e.g. climate, water, soils, pastures, forests (FAO, 1993).

Proposed farming systems (PFS) refer to farming systems (farmland use types) proposed for land/farmland capability determination in this research.

System refers to a functional arrangement of components that process inputs into outputs, for example a farm. Systems display properties which result from the interaction of their components (FAO, 1993).

Participatory Rural Appraisal (PRA) is one of the techniques used for gathering information on community resources and needs for use in literacy and community development programs. The techniques include the use of transect walks, maps, calendars, matrices, and diagrams using locally available materials (http://www.sil.org/lingualinks/literacy/referencematerials/glossaryofliteracyterms/whatisthepa rticipatoryruralapp.htm, accessed on 01/06/2011), FAO (1991b, 1999a).

2. Terminologies in the theoretical model (Agricultural Management System)

2.1 Bio-physical factors

Alkalinity refers to the sodicity that used to describe the condition of a sodic (alkali) soil (FAO, 1985).

Annual average temperature (AAT) (^{0}C) refers to the temperature regime or temperature condition, which/where impacts upon the proposed farming system/s (PFS) by limiting or stimulating the growth and development of crops. The AAT is calculated based on the total temperature of measurement times in a year and (divided by) number of measurements in a year.

Annual average rainfall (AAR) (mm) refers to water supply capacity for farmland use requirements (farming systems). The AAR is calculated based on the total rainfall of measurement times in a year and (divided by) number of measurements in a year.

Annual average relative humidity (AARH) (%) refers to the percentage of water vapor in (how much of it) the air that can impact upon the growth of plants (PFS). The AARH is calculated based on the total relative humidity of measurement times in a year and (divided by) number of measurements in a year.

Base saturation (%) refers to a way of measuring the base cations are available to plants. Base saturation is given as the percentage of potential cation exchange sites that actually have exchangeable base cations on them. It is expressed as a percentage of the total cation exchange capacity (USDA, 2008).

Cation exchange capacity (CEC, cmol/kg) refers to the total quantity of cations which a soil can adsorb by cation exchange usually expressed in milliequivalents per 100 grams. Measured values of cation exchange capacity depend somewhat on the method used for the determination (FAO, 1985).

Coarse material (%) refers to the texture modifier that is determined by the percentage of pebbles, gravels or stones in every soil layer. The classes are: few: <15%, plenty: 15-35%, abundant: 35-60%, and dominant: >60% (Ritung *et al.*, 2007).

C-organic refers to components of organic matter (%) in soils.

Depth of sulfidic (cm) refers to existence/presence of sulfidic toxicity in soils.

Erosion hazard refers to surface soil loss, categorised by levels below (Ritung *et al.*, 2007, p.8):

Classes	Class surface soil loss cm/yr
Very low	< 0.15
Low	0.15 - 0.9
Moderate	0.9 - 1.8
High	1.8 - 4.8
Very high	> 4.8

ESP stands for the exchangeable sodium percentage, calculated by the following equation (Ritung *et al.*, 2007; FAO, 1985):

$$ESP = \frac{\text{Exchangeable Na x 100}}{\text{Soil CEC}}$$

Growing period refers to a continuous period of the year during which temperature and soil water availability, are sufficiently high to permit plant growth. In most of the tropics, the growing period is determined by water availability within rooting depth- in the soil. In the temperate zone, low temperature is often limiting. In areas with bimodal rainfall distribution there may be two growing periods each year. The term applies primarily to annual crops, since deep-rooted trees can continue to grow when the top 2 m or more of soil is dry (FAO, 1993).

Humidity refers to a measure of water vapor in the air, where/which impacts upon the PFS by limiting or stimulating the growth and development of crops.

Radiation refers to the process by which energy is propagated and absorbed through plantation systems.

Salinity (ds/m) refers to degree of saltness in water.

Slope (%) refers to the degree of deviation of a soil surface from the horizontal plane, measured in a percent.

Soil depth refers to the rooting condition for growth of crops under the PFS, divided into four levels (Ritung *et al.*, 2007): very shallow, shallow, moderately deep, and deep.

Soil/water pH refers to the acidity of fields (in soil/water) of the PFS, classified as slight acidity, medium acidity, heavy acidity (Thanh, 2002, p. 65):

Slight acidity: pH = 5.5 to 6.5

Medium acidity: pH = 4.5 to 5.5

Heavy acidity: pH = less than 4.5

Soil texture refers to the percentage of sand, silt and clay particles of soil in fields of proposed farming systems, classified as clay, clay-loam, loam, sandy-loam and sandy (Thanh, 2002, p. 65).

Storm, wind, and hoarfrost refer to natural disasters/limitations, limiting the growth and development of the PFS.

Water quality refers to the quality of water bodies, which are affected by water generated by or associated with development.

Biological oxygen demand (BOD) is a descriptor of effluent content. It is the amount of oxygen required to completely oxidize a quantity of organic matter by biological processes.

Dissolved oxygen (DO) refers to the volume of oxygen that is contained in water. Oxygen enters the water by photosynthesis of aquatic biota and by the transfer of oxygen across the air-water interface.

2.2 Technical and management factors

Cropping calendar refers to seasonally crop distribution in a year.

Cropping index refers to the number of crops harvested in relation to the years in the cropping cycle (FAO, 1985).

Fertilizer refers to total chemical fertilizer used consisting of nitrogen, phosphorus, and potash.

Land clearing refers to the clearance of plants/crops on the PSF's fields.

Land grading/physical, chemical, organic aids and amendments refer to methods/techniques applied to increase the soil fertility.

Leaching refers to the process of removal of soluble material by passage of water through soil.

Pesticides refer to the total amount of insecticides, fungicides and herbicides used for the PFS, expressed in liters/kilograms per hectare.

Pilot design refers to methods/techniques to design fields of the PFS.

Potential of yield refers to the ability to generate productivity of crop varieties.

Stocking/snowing density refers to amount of seed planted per a hectare.

2.3 Land development and improvement factors

Ground/ surface water hazard refers to environmental hazards can take place and exist on ground or surface water.

Long-term erosion hazard refers to erosion hazards impact upon the environment for a long time.

2.4 Socio-economic factors

Age refers to the age of head or members of household (farmer), expressed in number of years.

Education standard refers to the highest educational attainment of household head and members of household, expressed in number of years.

Ethnic group refers to nationality of farmland users/farmers.

Household size refers to the number of family members and non-family members staying with the respondents.

Sex refers to the gender of farmland users/farmers.

Social class refers to the economic position of farmland users/farmers in the locality, indicated by their net income, and classified by local authorities.

2.5 Policy/institutional factors

Land use planning policies refers to trends, plans of local authorities in land use.

Rights/duties of land users refer to responsibilities/rights of farmers/farmland users on their farmland, according to local land laws/regulations.

Taxation for farmland refers to laws/policies on tax for farmland users/farmers.

APPENDIX 2: GUIDELINE (1)

FOR A FOCUS GROUP DISCUSSION IN THE AN GIANG AGRICULTURAL EXTENSION CENTRE

(the Participatory Rural Appraisal[28] approach is applied,

participants are senior extension officers)

Hello, I am a PhD student at the RMIT University. As part of my studies, I am conducting research entitled "An Agricultural Management System Designed to Determine the Capability of Farmland at the District, Commune, Hamlet, and Farm level in the An Giang Province, Viet Nam". Today, I am pleased to meet you and discuss on the above-stated topic. Please feel free to collaborate and share your knowledge/experiences. It is guaranteed that the information you provide will be private and used for research purpose only.

Date of interview: Place of interview:

Notes: LUT: Land Utilisation/Use Type = FS: Farming System; PFS: proposed farming system

The purpose of this guideline is to identify dominant farming systems (in the research area, An Giang Province) for determining the capability of farmland and to collect data.

1. General information on interviewee

No	Name	Sex	Position	Come from	Contact detail	Qualifications	Experience/age	Fields	Code
1									1.1
2									1.2
3									1.3
Etc									1.n

2. Information on the current farming systems in the local area

2.1 What are popular farming systems?	2.11 2.12
2.2 Which is the most important/dominant farming system(s)? 2.3 Why?	2.21 2.22

3. Information on the future farming systems in the local area

3.1 What farming systems will be mainly practiced?	
3.2 Which will be the most important farming system(s)? 3.3 Why?	3.31 3.32
Based on above stated-information (items 2 and 3), Which is/are the proposed FS(s) for determining the capability of farmland in the local area? And why?	

[28] *FAO. 1999. Conducting a PRA Training and Modifying PRA Tools to Your Needs. An Example from a Participatory Household Food Security and Nutrition Project in Ethiopia. Rome, Food and Agriculture Organization of the United Nations (FAO).*

4. Information on the capability of farmland in the local area

4.1 Please evaluate/identify the capability of farmland and its utilisation (Strengths, Weaknesses, Opportunities, Threats, SWOT)	
4.1.1. Strengths (S)	4.1.1.1 4.1.1.2
4.1.2. Weaknesses (W)	4.1.2.1 4.1.2.2
4.1.3. Opportunities (O)	4.1.3.1 4.1.3.2
4.1.4. Threats (T)	4.1.4.1 4.1.4.2
4.2 Is the present farmland utilisation matched to its capability? If no, please specify reasons?	4.2.1 4.2.2
4.3 Solutions proposed for increasing/improving the capability of farmland?	4.3.1 4.3.2

5. Additional information on the farming systems in the local area

5.1 Please describe and draw a cropping calendar of the PFS? What kinds of cultivar are planted? What are key their agronomic characteristics?	5.1.1 5.1.2
5.2 What are the present consumption markets? How much are they worth? Please simply draw the value chain of the products?	5.2.1 5.2.2
5.3 What are the water supply systems and irrigation methods? How much are they worth?	5.3.1 5.3.2
5.4 What is the value of capital investment and recurring costs per ha?	5.4.1 5.4.2
5.5 What are the common kinds of labor hired? (Family, daily hire, permanent etc)? How much are they worth?	5.5.1 5.5.2
5.6 Please evaluate the technical skills and attitudes of farmers? (Good, fair, poor etc and how much worth for each?)	5.6.1 5.6.2
5.7 What are the popular kinds of use of power for production (animal, human tractor etc)?	5.7.1 5.7.2
5.8 How are mechanization and farm operations applied?	5.8.1 5.8.2
5.9 What is the size and shape of the farm (by land use types, fragmentation of holdings, rain-fed and irrigated)	5.9.1 5.9.2
5.10 Please evaluate (SWOT) material inputs and outputs	5.10.1 5.10.2
5.11 How much yield, production costs and profits per ha per year?	5.11.1 5.11.2
5.12 Please list of environmental impacts from that FS?	5.12.1 5.12.2
5.13 Please describe market prices, input costs and availabilities, subsidies, credit forms in the local area?	5.13.1 5.13.2

Note: *depending on specific circumstances, where necessary, some questions will be more developed and used*

APPENDIX 3: GUIDELINE (2)

FOR EXPERT INTERVIEW AT THE MEKONG DELTA DEVELOPMENT RESEARCH INSTITUTE, CAN THO UNIVERSITY

Hello, I am a PhD student at the RMIT University. As part of my studies, I am conducting research entitled "An Agricultural Management System Designed to Determine the Capability of Farmland at the District, Commune, Hamlet, and Farm level in the An Giang Province, Viet Nam". Today, I am pleased to meet you and discuss on the above-stated topic. Please feel free to collaborate and share your knowledge/experiences. It is guaranteed that the information you provide will be private and used for research purpose only.

Date of interview: Place of interview:

Note: *AMS stands for agricultural management system; MDI stands for Mekong Delta Development Research Institute, AEC stands for Agricultural Extension Centre. The purpose of this guideline is to adjust the theoretical designed-model to suit the research area context. Participants are selected experts at the MDI and An Giang AEC.*

1. General information on interviewee

Table 1: Information relating to interviewee

No	Name	Sex	Position	Contact detail	Qualifications	Experience/age	Fields	Code
1								1.1
2								1.2
3								1.3
Etc								1.n

2. Adjustment of components and factors in the AMS

Here are components and factors in the AMS designed (theoretical model) for determining the capability of farmland at various administrative scales/levels (province, district, commune, hamlet, and farm). The theoretical model design is based on a literature review (global context). According to your practical experiences and knowledge, please feel free to adjust the theoretical model to suit the Viet Nam Mekong Delta, and the An Giang Province context (rules for the adjustment and modification are based on significant impacts of those factors upon the capability of farmland, especially for rotational rice-vegetables, single rice, and single vegetable systems).

2.1 What components/factors below should be involved in the AMS?

2.2 Otherwise, What other components/factors need to be more added?

2.3 Which administrative scales/levels are suitable for determining the capability of farmland? Why?

2.4 Do you have/offer any other recommendations/suggestions on the theoretical model?

Note: *depending on specific circumstances, where necessary, some questions will be ignored or more developed and used; (1), (2), (3), (…), and (n) in column (IV) of the table 2 are explanations for why some factors should be/or not considered in the AMS. Faming systems nominated for considering the capability of farmland are rotational rice-vegetables, single rice, and single vegetable systems.*

Table 2: Components/factors in the AMS designed for determining the capability of farmland

(I)	(II)	(III)	(IV)				
		Components/Factors in the AMS	**Adjustments and comments**				
		1. Bio-Physical factors	(1)	(2)	(3)	…	(n)
		Temperature					
1	☐	Annual average temperature					
2	☐	Solar radiation					
		Hydrology and humidity					
3	☐	Annual average rainfall					
4	☐	Annual dry/drought period					
5	☐	Water quality					
6	☐	Irrigation systems					
7	☐	Annual average humidity					
		Oxygen availability					
8	☐	Drainage systems					
		Rooting conditions					
9	☐	Soil texture (surface)					
10	☐	Coarse material					
11	☐	Soil depth					
12	☐	Aeration condition					
		Nutrient retention and pH					
13	☐	CEC-clay					
14	☐	Base saturation					
15	☐	C-organic					
16	☐	Macro-nutrients availability (NPK)					
17	☐	Micro-nutrients availability					
18	☐	Soil pH					
19	☐	Water pH					
		Toxicity					
20	☐	Salinity					
21	☐	Alkalinity/ESP					
22	☐	Depth of sulphuric					
23	☐	Hoarfrost (salt fog)					
		Erosion, flood and other hazards					
24	☐	Slope					
25	☐	Erosion hazards					
26	☐	Duration of floods					
27	☐	Depth of floods					
28	☐	Annual inundation period					
29	☐	Storm					
30	☐	Wind					
		Other bio-physical factors					
31	☐	Growing period of crops					
32	☐	Insect (common pest)					
33	☐	Disease (common pest)					
34	☐	Weed (common pest)					
35	☐	Distance from the house to farms					
36	☐	Road transport system					
37	☐	Waterway transport system					
38	☐	Availability of transport facilities					
39	☐	Communication media systems					

Table 2: Components/factors in the AMS designed for determining the capability of farmland (continued)

(I)	(II)	(III)	(IV)				
		2. Technical and management factors					
		Technique					
40	☐	Land preparation technique					
41	☐	Planting technique					
42	☐	Seed sector (supply and distribution systems)					
43	☐	Seed quality for cultivation					
44	☐	Yield potential of variety					
45	☐	Pre-processing technique					
46	☐	Storing technique					
47	☐	Drying technique					
48	☐	Applied ability of mechanization					
49	☐	Cropping index					
		Farm management					
50	☐	Pilot/field design					
51	☐	Cropping calendar distribution					
52	☐	Stocking/sowing density					
53	☐	Fertilizer and insecticide use management					
54	☐	Water and pest management					
55	☐	Farm size					
		3. Land development or improvement					
56	☐	Land clearing					
57	☐	Flood controls					
58	☐	Land grading					
59	☐	Physical, chemical, organic aids and amendments					
60	☐	Leaching					
61	☐	Reclamation period					
62	☐	Irrigation engineering (construction)					
		4. Conservation and environmental factors					
63	☐	Long-term salinity, landslip					
64	☐	Ground or surface water hazards					
65	☐	Long-term erosion hazards					
66	☐	Environmental hazards					
67	☐	Environmental control ability					

Table 2: Components/factors in the AMS designed for determining the capability of farmland (continued)

(I)	(II)	(III)	(IV)				
		5. Socio-economic factors					
68	☐	Average age of farmers (land users)					
69	☐	Sex of farmers					
70	☐	Education standard of farmers					
71	☐	Ethnic group of farmers					
72	☐	Social class of farmers					
73	☐	Household size of farmers					
74	☐	Membership of social organizations, if any					
75	☐	Farming experience/skills of farmers					
76	☐	Livelihood opportunities for farmers					
77	☐	Labour force in the local area					
78	☐	Skills of labour force in the local area					
79	☐	Production costs					
80	☐	Farmers' credit sources accessibility					
81	☐	Credit allowance for farmers					
82	☐	Farmers' market accessibility (input/output)					
83	☐	Farmers' accessibility to support agencies					
84	☐	Farmers' accessibility to agricultural services					
85	☐	Farmers' accessibility to market information					
		6. Policy/institutional factors					
86	☐	Taxation applied for farmland					
87	☐	Farmers' rights/duties for use of the land					
88	☐	Laws for natural resource management					
89	☐	Land use planning policies					
90	☐	Loan policies					

Note: *Where necessary, some additional questions are formed and used*

APPENDIX 4: GUIDELINE (3)

FOR A KEY INFORMANT PANEL INTERVIEW

IN THE AN GIANG PROVINCE

Hello, I am a PhD student at the RMIT University. As part of my studies, I am conducting research entitled "An Agricultural Management System Designed to Determine the Capability of Farmland at the District, Commune, Hamlet, and Farm level in the An Giang Province, Viet Nam". Today, I am pleased to meet you and discuss on the above-stated topic. Please feel free to collaborate and share your knowledge/experiences. It is guaranteed that the information you provide will be private and used for research purpose only.

Date of interview:……./……./……. District name:…………..../An Giang

Code:……………..…..

1. General information on interviewee

No	Name	Sex	Position	Contact detail	Qualifications	Experience/age	Fields
1							
2							
Etc							

2. Information on land attributes at the district scale

No	1. Bio-Physical factors	Actual value	Notes
1	Common pests (%)		
2	Annual dry/drought period (month/year)		
3	Annual inundation period (month/year)		
4	Irrigation and drainage system		
5	Flood hazards (m)		
6	Transport systems		
	2. Technical and management factors		
7	Seed sector (%)		
8	Applied ability of mechanization		
9	Water and pest management		
	3. Land development and environmental factors		
10	Flood control ability		
11	Long-term salinity, landslip, landslide (dangerous degree)		
12	Environmental hazards		
13	Environmental control ability		
	4. Socio-economic and policy factors		
14	Livelihood opportunities for farmers in the local area		
15	Production costs (USD/ha)		
16	Laws for natural resource management (ha/household)		
17	Policies used for agricultural production consumption		

Note: *Where necessary, some additional questions are formed and used*

APPENDIX 5: GUIDELINE (4)

FOR A FOCUS GROUP DISCUSSION (COMMUNE LEVEL)

IN THE AN GIANG PROVINCE

Hello, I am a PhD student at the RMIT University. As part of my studies, I am conducting research entitled "An Agricultural Management System Designed to Determine the Capability of Farmland at the District, Commune, Hamlet, and Farm level in the An Giang Province, Viet Nam". Today, I am pleased to meet you and discuss on the above-stated topic. Please feel free to collaborate and share your knowledge/experiences. It is guaranteed that the information you provide will be private and used for research purpose only.

Date of interview:.../..../... Commune ....…. District:.............

Code:..........…

1. General information on interviewee

No	Name	Sex	Position	Contact detail	Qualifications	Experience/age	Fields
1							
2							
Etc							

2. Information on land attributes at the communal scale

No	1. Bio-Physical factors	LUT1		LUT2		LUT3	
		AV	**Ns**	**AV**	**Ns**	**AV**	**Ns**
1	Common pests (%)						
2	Irrigation and drainage system						
3	Aeration condition						
4	Available nutrients						
5	Availability of transport facilities						
	2. Technical and management factors						
6	Seed sector (%)						
7	Applied ability of mechanization (%)						
8	Water and pest management						
	3. Land development and environmental factors						
9	Flood control ability (years)						
10	Irrigation engineering (construction)/(stations)						
11	Environmental control ability						
	4. Socio-economic and policy factors						
12	Livelihood opportunities for farmers (%)						
13	Labour force (for farming activities) in the local area						
14	Production costs (USD/ha)						
15	Farmers' accessibility to agricultural services						
16	Credit allowance for farmers (USD/ha)						

Notes: *LUT1: Rotational rice-vegetables system, LUT2: rice system, and LUT3: vegetable system; AV: actual value, Ns: additional notes. Where necessary, some additional questions are formed and used.*

APPENDIX 6: GUIDELINE (5)

FOR FARMER'S INDIVIDUAL INTERVIEWS

IN THE AN GIANG PROVINCE

Hello, I am a PhD student at the RMIT University. As part of my studies, I am conducting research entitled "An Agricultural Management System Designed to Determine the Capability of Farmland at the District, Commune, Hamlet, and Farm level in the An Giang Province, Viet Nam". Today, I am pleased to meet you and discuss on the above-stated topic. Please feel free to collaborate and share your knowledge/experiences. It is guaranteed that the information you provide will be private and used for research purpose only.

Date of interview:…/…./….Hamlet name:……………../Commune name……………

Code:……

1. General information on interviewee

Name	………..	Experience	………..	Areas for this FS	………..
Sex	………..	Contact detail	………..	Production costs/ha	………..
Age	………..	Total land areas	………..	Net profit/ha	………..
Education	………..	Farming system (FS)	………..	Social class	………..

2. Information on land attributes at the farm scale

No	1. Bio-Physical factors	LUT1		LUT2		LUT3	
		AV	Ns	AV	Ns	AV	Ns
1	Irrigation and drainage system						
2	Availability of transport facilities						
3	Transport system						
4	Distance from the house of farmers to their farms (km)						
	2. Technical and management factors						
5	Seed quality for cultivation						
6	Land preparation technique						
7	Planting technique						
8	Pre-processing technique						
9	Storing technique						
10	Drying technique						
11	Fertilizer and insecticide use management						
12	Farm size (ha)						
	3. Socio-economic factors						
13	Membership of any social organizations						
14	Farming experience (years)/skills of farmers						
15	Farmers' accessibility to agricultural services						

Notes: *LUT1: Rotational rice-vegetables system, LUT2: rice system, and LUT3: vegetable system; AV: actual value, Ns: additional notes. Where necessary, some additional questions are formed and used.*

Appendix 7: Factors not considered in the practical model

(I) No	(II) Factors not considered	(I) No	(II) Factors not considered
	1. Bio-Physical		**3. Land development or improvement**
1	Annual average temperature	**29**	Land clearing
2	Solar radiation	**30**	Land grading
3	Growing period of crops	**31**	Physical, chemical, organic aids and amendments
4	Annual average rainfall	**32**	Leaching
5	Annual average humidity	**33**	Reclamation period
6	Water quality		**4. Conservation and environmental**
7	Soil texture (surface)	**34**	Ground or surface water hazards
8	Coarse material	**35**	Long-term erosion hazard
9	Soil depth		**5. Socio-economic**
10	CEC-clay	**36**	Average age of farmers (land users)
11	Base saturation	**37**	Sex of farmers
12	Soil pH	**38**	Education standard of farmers
13	Water pH	**39**	Ethnic group of farmers
14	C-organic	**40**	Social class of farmers
15	Salinity	**41**	Household size of farmers
16	Alkalinity/ESP	**42**	Skills of labour force in the local area
17	Depth of sulphuric acid		**6. Policy/institutional**
18	Slope	**43**	Taxation applied for farmland
19	Erosion hazards	**44**	Farmers' rights/duties for use of the land
20	Storm	**45**	Land use planning policies
21	Wind	**46**	Loan policies
22	Hoarfrost (salt fog)		
23	Communication media system		
	2. Technical and management		
24	Yield potential of variety		
25	Cropping index		
26	Pilot/field design		
27	Cropping calendar distribution		
28	Stocking/sowing density		

- Factors were considered by every requirement. If a certain factor did not meet only one requirement, then it did not need to be considered for the next requirements. Refer to requirements (1), (2), and (3) for considering factors in item 7.2.5 in Chapter 5.

Appendix 8: The interpretation of measurable indicators/units for factors in the AMS for farmland capability determination

No	Factors in the AMS	Interpretation/explanation (particularly based on the research area context)
	1. Bio-Physical component	
1	Common pests (%)	Refer to some serious pests in the local area such as insects, disease, snails, rats and other animals, which can cause loss, or reduction in the productivity of crops. This factor is measured by % of planted areas (of crops) that are infected or attacked (by pests).
2	Annual dry/drought period (months/year)	Refers to the dried/drought months that the fields undergo annually (drought/without rain). This factor is considered at the district scale.
3	Annual inundation period (months/year)	Refers to inundated months that the fields undergo annually. This factor is considered at the district scale.
4	Irrigation and drainage system	Irrigation system refers to systems of controlled applications of water to supplement the proposed farming system (FAO, 1985). Particularly, drainage system refers to the oxygen availability management, indicated by the speed of water infiltration or the soil condition describing the duration and level of water saturation and inundation (Ritung *et al.*, 2007, p.5). In this study, irrigation and drainage system refers to infrastructure/facility systems or conditions for water supply and sewage (for fields) in the local area. At the district and commune scales, it is defined through the qualitative evaluation and mainly based on farmland areas in the local area, which having complete irrigation and drainage system. *Very well: more than 80% of (farmland areas having the complete irrigation and drainage system)* *Well: 60-79%;* *Moderate: 40-59%;* *Rain-fed: less than 40%;* At the farm scale, it is defined based on the costs that land users have to pay for water supply and sewage (water management expenses) when cultivating crops: *Very well: water supply and sewage is operated based on the natural tidal regime, farmers have not to pay any costs for water management;* *Well: associated with the natural tidal regime, water supply and sewage is operated based on the use of electricity, farmers have to pay costs for water management;* *Moderate: water supply and sewage is operated based on the use of fuel engines, farmers have to pay costs for water management and these costs are always higher than using electricity;* *Rain-fed: water supply and sewage is operated based on the natural rain regime.*

5	Aeration condition	Refers to the water sewage capacity of the soil after any short inundation periods that are caused by a heavy rain, or floods. This factor is considered at the commune scale, and it is defined through the qualitative evaluation and mainly based on the knowledge of local agricultural land experts.
6	Available nutrients	Refer to the soil fertility (micro and macro-nutrients), the availability of nutrients in soil supplying crop's requirements. This factor is considered at the commune scale, and it is defined through the qualitative evaluation, usually based on the comparison between the actual yield of crops and the expected/theoretical yield of crops when these crops are planted in the locally actual conditions. Local farmland experts reveal the capability classes of this factor below: *Very fertile: the average actual yield of crops in the commune can reach 90% of the expected/theoretical yield or higher;* *Fertile: 70-89%;* *Moderate: 50-69%;* *Poor: 30-49%;* *Very poor: less than 30%*
7	Flood hazards	Refer to the depth of floods (m) that relates to the increase in the water level when floods occurred, compared with the regular water level on fields. This factor is considered at the district scale and measured by meter.
8	Availability of transport facilities	Refers to facilities (trucks, vans, cars, animal power) used for transporting the agricultural products. At the commune scale, it is defined through the qualitative evaluation and based on the knowledge of local authorities. *Readily available: transport facilities can be found and rented rightly in the commune where farming systems are practising;* *Available: transport facilities can be found and rented somewhere in the district;* *Seasonal: transport facilities can be found and rented somewhere in the district in the period of cropping season;* *Not available: transport facilities can be found and rented somewhere outside the district;* At the farm scale, the availability of transport facilities is defined through categories below: *Readily availability: transport facilities are available at the household (farmer)* *Availability: transport facilities are available (can be found and rented) somewhere in the hamlet*

		Fairly availability: transport facilities are available (can be found and rented) somewhere (other hamlets) in the commune; *Not availability: transport facilities are only available (can be found and rented) somewhere (other communes) in the district.*
9	Transport system	Refers to road and waterway transport systems in the local area that facilitate convenient conditions for transporting the agricultural products. It is defined through the qualitative evaluation and based on the knowledge of local authorities (Department of Industry and Trade at the district level). At the farm scale, it is the internal transport systems on the farm of farmers: *Very well: farmers build concrete/cement roads on their fields for transporting input (fertilizers, seeds, insecticides) and output materials (agricultural products);* *Well: farmers build dykes on their fields that have both functions of flood protection and transporting input and output materials;* *Moderate: farmers build small banks on their fields to retain water for the field, besides these banks allow small transport facilities to transport on.*
10	Distance from the house of farmers to their farms	Refers to the average distance (be estimated) between the house of farmers to their farms (km). This factor is considered at the farm scale.
	2. Technical & management component	
11	Seed sector	Refers to seed production systems (formal and informal), seed supply and distribution ability in the local area. It is measured by % of planted land area that used the certified seeds (seeds are certified by professional function organisations in the local area) for cultivating.
12	Seed quality for cultivation	Refers to the planting quality of seeds that used for cultivating, and the seeds are certified by professional function organisations in the local area. This factor is considered at the farm scale. *Very well: Foundation seeds are used for cultivating;* *Well: Certified seeds are used;* *Moderate: Farm' saved seeds are used;* *Poor: Free seed sources (free seedling) are used.*
13	Land preparation technique	Refers to land preparation conditions for farming. This factor is considered at the farm scale. *Very well: land is done (ploughing, harrowing, levelling land surface) completely and by mechanisation;* *Well: land is done completely and by human/animal power;*

		Moderate: land is done partially; *Poor: land is not done.*
14	Planting technique	Refers to what kind of planting techniques that are applied for farming. This factor is considered at the farm scale. *Very well: Transplanting technique is applied;* *Well: Drum seeders are applied;* *Moderate: Hand sowing is applied, with an amount of seeds is ≤ 120kg/hectare;* *Poor: Hand sowing is applied, with an amount of seeds is > 120kg/hectare.*
15	Pre-processing technique	Refers to skills and knowledge of farmers in terms of pre-processing their agricultural products rightly after harvesting. This factor is considered at the farm scale. *Very well: Farmers participated in Post-harvest processing technique and Farmers' Field School training courses (organised and certified by agricultural management organisations in the local area);* *Well: Farmers participated in only Post-harvest processing technique, or Farmers' Field School training course (organised and certified by agricultural management organisations in the local area);* *Moderate: Farmers participated in other training courses relating to agricultural practices (otherwise Post-harvest and FFS);* *Poor: Farmers did not participate in any training courses relating to agricultural practices.*
16	Storing technique	As above
17	Drying technique	Refers to drying conditions/facilities used for drying agricultural products. This factor is considered at the farm scale and measured by spatial land area that used for drying (drying yard, m^3)
18	Fertilizer and insecticide use management	Refers to farmers' management functions such as planning, organizing, directing, and monitoring the application of fertilizers and insecticides for their fields with the best efficiency. This factor is considered at the farm scale. *Very well: Farmers participated in Integrated Pest Management and Farmers' Field School training courses (organised by agricultural management organisations in the local area);* *Well: Farmers participated in Integrated Pest Management, or Farmers' Field School training course only;* *Moderate: Farmers participated in other training courses relating to agricultural practices (otherwise IPM and FFS);* *Poor: Farmers did not participate in any training courses relating to agricultural practices.*
19	Applied ability of mechanization	Refers to applied ability of mechanization for farming activities in order to reduce the production costs.

		At the district scale, it is defined through the qualitative evaluation and based on the knowledge of local agricultural extension officers and experts at the Department of Industry and Trade at the district level. At the commune scale, it is measured by the estimated percentage of farmers in the commune who are applying mechanization for their farming activities, particularly for harvesting.
20	Water and pest management	Refers to the effective use of water resource irrigating the field, as well as predicting ability and proposing solutions to cope with pests. This factor is defined through the qualitative evaluation and based on the knowledge of local agricultural managers.
21	Farm size	Refers to the total land areas (ha) used for farming. This factor is considered at the farm scale.
	3. Land development and environmental component	
22	Flood control ability	Refers to the dyke systems to protect the flood as well as approaches to control the flood such as ignoring the third cropping season to protect the dyke systems through balancing the flooding water level between inside and outside the dams/dykes. At the district scale, it is defined through the qualitative evaluation and based on the knowledge of local agricultural managers. At the commune scale, it is measured by the number of years that ignoring the third cropping season.
23	Irrigation engineering (construction) (stations)	Refers to engineering, technologies or construction are used for irrigating. This factor is considered at the commune scale and measured by the number of electric irrigation stations/commune (water supply capacity by using electricity), with capacity is ≥ $4000m^3/h$/station. For the vegetables system, it is defined through the qualitative evaluation and based on technologies that farmers used for irrigating e.g. automatic-irrigating systems, stream-irrigating systems.
24	Long-term salinity, landslip, landslide	Refers to risks and danger of salinity, landslip or landslide. This factor is considered at the district scale and defined through the qualitative evaluation that revealed by the Provincial Department of Environment and Natural Resources (DENR).
25	Environmental hazards	Refer to soil and water environment hazards caused by the application of chemical fertilizers and pesticides. This factor is considered at the district scale and defined through the qualitative evaluation that revealed by the DENR.
26	Environmental control ability	Refers to the ability to manage and control the use of chemical fertilizers and pesticides. This factor is defined through the qualitative evaluation revealed by the DENR.

	4. Socio-economic and policy factors	
27	Livelihood opportunities for farmers	Refer to other job opportunities for farmers in the local area otherwise farming activities. At the district scale, this factor is defined through the qualitative evaluation that revealed by the local authorities at the Department of Labour, Invalids and Social Affairs, at the district level. At the commune scale, this factor is measured by the estimated percentage of farmers in the commune who can employ jobs otherwise farming activities.
28	Labour force for farming activities in the local area	Refers to labour-force in the local area that can be availably rented for farming activities. This factor is considered at the commune scale and defined through the qualitative evaluation that revealed by the local authorities at the Department of Labour, Invalids and Social Affairs, at the district level. *Readily available (very easy to rent): workers can be rented rightly in the commune;* *Available (easy to rent): workers can be rented in somewhere in the district;* *Seasonal: (moderate to rent): workers can be rented in somewhere in the district, in the period of cropping season;* *Not available (hard to rent): workers can be rented outside the district.*
29	Production costs	Refer to the total production costs/ha, USD/ha at the current exchange rate from Vietnamese currency. 1 USD ≈ 20 VND in 2010.
30	Membership of any social organizations	Refers to the farmers are/or not member of any social organizations (e.g. Youth Union, Women Union, Farmers' Association, Extension Clubs) in the local area at differently administrative scales such as province, district, commune. This factor is considered at the farm scale.
31	Farming experience/skills of farmers	Refers to number of years that farmers have experienced on farming activities. This factor is considered at the farm scale.
32	Farmers' accessibility to agricultural services in the local area	Refers to the farmers' conditions and accessibility (agricultural purposes only) to the credit sources, inputs and outputs (market), market information, support agencies, and other agricultural services. This factor is defined through the qualitative evaluation that revealed by the local authorities. *Very easy: farmers can access services rightly in their hamlet;* *Easy: farmers can access services rightly in their commune;* *Moderate: farmers can access services rightly in their district;* *Hard: farmers can only access services outside their district;* *Very hard: farmers can only access services outside their province.*

33	Credit allowance for farmers (USD/ha)	Refers to the maximum amount of funds that farmers can be loaned from the banks or any other bankers in the local area (USD/ha at the current exchange rate from Vietnamese currency). This factor is considered at the commune scale.
34	Laws for natural resource management (ha/household)	Refer to the maximum land areas that farmers can collect or own e.g. land area allows to de-fragment (ha/household) promulgated in the land law, or the local orders/rules. This factor is considered at the district scale.
35	Policies used for agricultural production consumption	Refer to policies (issued by local authorities) used to help farmers in consuming their agricultural products. This factor is considered at the district scale and defined through the qualitative evaluation that revealed by the local agricultural managers.

Appendix 9: Weighting selected components in the AMS at administrative scales

District scale					
	(1)	**(2)**	**(3)**	**(4)**	**Weight**
(1). Bio-physical	1	3	1/4	1/4	0.139
(2). Technical and management		1	1/5	1/3	0.082
(3). Land development and environmental			1	1	0.410
(4). Socio-economic and policy				1	0.369
Consistency Ratio (CR) = 0.073					

Communal scale					
	(1)	**(2)**	**(3)**	**(4)**	**Weight**
(1). Bio-physical	1	2	2	2	0.384
(2). Technical and management		1	1/3	1/2	0.126
(3). Land development and environmental			1	2	0.300
(4). Socio-economic and policy				1	0.190
Consistency Ratio (CR) = 0.054					

Farm scale				
	(1)	**(2)**	**(3)**	**Weight**
(1). Bio-physical	1	1/3	1/2	0.159
(2). Technical and management		1	3	0.589
(3). Socio-economic and policy			1	0.252
Consistency Ratio (CR) = 0.052				

Appendix 10: District level - Weighting selected factors in the AMS for general agricultural production systems

Bio-physical	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**W1**	**W2,**	**Rank**
(1). Common pests	1	3	2	1	1	4	0.250	0.035	11
(2). Annual dry/drought period		1	1	1/3	1	3	0.123	0.017	14
(3). Annual inundation period			1	1/3	1	2	0.119	0.017	15
(4). Irrigation & drainage system				1	3	3	0.303	0.042	9
(5). Flood level					1	2	0.139	0.019	13
(6). Transport system						1	0.065	0.009	17
Consistency Ratio (CR) = 0.032									
Technical and management	**(1)**	**(2)**	**(3)**						
(1). Seed sector	1	2	2				0.491	0.040	10
(2). Applied ability of mechanization		1	1/2				0.198	0.016	16
(3). Water & pest management			1				0.312	0.026	12
Consistency Ratio (CR) = 0.052									
Land development and environmental	**(1)**	**(2)**	**(3)**	**(4)**					
(1). Flood control ability	1	1/3	1/2	1/3			0.115	0.047	7
(2). Long-term salinity, landslip, landslide		1	1	2			0.349	0.143	2
(3). Environmental hazards			1	2			0.321	0.132	3
(4). Environmental control ability				1			0.216	0.089	5
Consistency Ratio (CR) = 0.045									
Socio-economic and policy	**(1)**	**(2)**	**(3)**	**(4)**					
(1). Livelihood opportunities for farmers	1	1/3	2	1/3			0.156	0.058	6
(2). Production costs		1	2	1/2			0.285	0.105	4
(3). Laws for natural resource management			1	1/3			0.119	0.044	8
(4). Policies used for agricultural production consumption				1			0.440	0.162	1
Consistency Ratio (CR) = 0.054									

Appendix 11: Commune level - Weighting selected factors in the AMS for the rotational rice-vegetables system

Bio-physical	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**W1**	**W2, Rank**	
(1). Common pests	1	2	2	2	2	0.320	0.123	2
(2). Irrigation and drainage system		1	2	2	2	0.243	0.093	4
(3). Aeration condition			1	2	1	0.158	0.061	6
(4). Available nutrients				1	1/3	0.102	0.039	13
(5). Availability of transport facilities					1	0.178	0.068	5
Consistency Ratio (CR) = 0.046								
Technical and management	**(1)**		**(2)**		**(3)**			
(1). Seed sector	1		2		1	0.387	0.049	10
(2). Applied ability of mechanization			1		1/3	0.170	0.021	15
(3). Water and pest management					1	0.443	0.056	7
Consistency Ratio (CR) = 0.018								
Land development and environmental	**(1)**		**(2)**		**(3)**			
(1). Food control ability	1		1/3		1/3	0.142	0.043	11
(2). Irrigation engineering (construction)			1		1/2	0.334	0.100	3
(3). Environmental control ability					1	0.525	0.157	1
Consistency Ratio (CR) = 0.052								
Socio-economic and policy	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**			
(1). Livelihood opportunities for farmers	1	1/3	1/3	1/2	1/3	0.080	0.015	16
(2). Labour-force in the local area		1	1	1/3	1/2	0.171	0.033	14
(3). Production costs			1	2	1	0.258	0.049	9
(4). Farmers' accessibility to agricultural services in the local area				1	1/2	0.206	0.039	12
(5). Credit allowance for farmers (amount)					1	0.285	0.054	8
Consistency Ratio (CR) = 0.076								

Appendix 12: Commune level - Weighting selected factors in the AMS for the rice system

Bio-physical	**(1)**	**(2)**	**(3)**	**W1**	**W2, Rank**	
(1). Common pests	1	2	3	0.539	0.207	1
(2). Irrigation and drainage system		1	2	0.297	0.114	3
(3). Availability of transport facilities			1	0.164	0.063	7
Consistency Ratio (CR) = 0.009						
Technical and management	**(1)**	**(2)**	**(3)**			
(1). Seed sector	1	1/2	2	0.312	0.039	10
(2). Applied ability of mechanization		1	2	0.491	0.062	8
(3). Water and pest management			1	0.198	0.025	12
Consistency Ratio (CR) = 0.052						
Land development and environmental	**(1)**	**(2)**	**(3)**			
(1). Food control ability	1	1	1/3	0.211	0.063	6
(2). Irrigation engineering (construction)		1	1/2	0.241	0.072	5
(3). Environmental control ability			1	0.549	0.165	2
Consistency Ratio (CR) = 0.018						
Socio-economic and policy	**(1)**	**(2)**	**(3)**			
(1). Livelihood opportunities for farmers	1	1/3	2	0.252	0.048	9
(2). Labour-force in the local area		1	3	0.589	0.112	4
(3). Farmers' accessibility to agricultural services in the local area			1	0.159	0.030	11
Consistency Ratio (CR) = 0.052						

Appendix 13: Commune level - Weighting selected factors in the AMS for the vegetables system

Bio-physical	(1)	(2)	(3)	W1	W2, Rank	
(1). Irrigation and drainage system	1	1/3	1/2	0.170	0.065	6
(2). Aeration condition		1	1	0.443	0.170	1
(3). Available nutrients			1	0.387	0.149	3
Consistency Ratio (CR) = 0.018						
Technical and management	**(1)**	**(2)**	**(3)**			
(1). Seed sector	1	2	1/2	0.312	0.039	10
(2). Applied ability of mechanization		1	1/2	0.198	0.025	12
(3). Water and pest management			1	0.491	0.062	7
Consistency Ratio (CR) = 0.052						
Land development and environmental	**(1)**	**(2)**	**(3)**			
(1). Food control ability	1	3	1/2	0.334	0.100	4
(2). Irrigation engineering (construction)		1	1/3	0.142	0.043	9
(3). Environmental control ability			1	0.525	0.157	2
Consistency Ratio (CR) = 0.052						
Socio-economic and policy	**(1)**	**(2)**	**(3)**			
(1). Production costs	1	2	1/2	0.312	0.059	8
(2). Farmers' accessibility to agricultural services in the local area		1	1/2	0.198	0.038	11
(3). Credit allowance for farmers (amount)			1	0.491	0.094	5
Consistency Ratio (CR) = 0.052						

Appendix 14: Farm level - Weighting selected factors in the AMS for the rotational rice-vegetables system

Bio-physical	**(1)**	**(2)**	**(3)**	**(4)**	**W1**	**W2, Rank**	
(1). Irrigation and drainage system	1	3	2	1	0.358	0.057	7
(2). Availability of transport facilities		1	2	1/2	0.181	0.029	13
(3). Transport system			1	1/2	0.141	0.022	15
(4). Distance from the house to farms				1	0.320	0.051	8
Consistency Ratio (CR) = 0.045							

Technical and management	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**			
(1). Seed quality	1	1/2	2	2	2	2	1	2	0.156	0.092	4
(2). Land preparation		1	2	3	3	3	2	2	0.235	0.139	2
(3). Planting technique			1	2	2	2	1	1	0.121	0.071	5
(4). Pre-processing technique				1	2	2	1/3	1	0.085	0.050	10
(5). Storing technique					1	1/4	1/3	1	0.058	0.034	12
(6). Drying technique						1	1/3	1	0.086	0.051	9
(7). Fertilizer & insecticide use management							1	3	0.177	0.104	3
(8). Farm size								1	0.082	0.049	11
Consistency Ratio (CR) = 0.045											

Socio-economic	**(1)**	**(2)**	**(3)**			
(1). Membership of any organisations	1	1/5	1/3	0.106	0.027	14
(2). Farming experience/skills of farmers		1	3	0.633	0.160	1
(3). Farmers' accessibility to agricultural services in the local area			1	0.261	0.066	6
Consistency Ratio (CR) = 0.037						

Appendix 15: Farm level - Weighting selected factors in the AMS for the rice system

Bio-physical	(1)	(2)	(3)	W1	W2, Rank	
(1). Irrigation and drainage system	1	2	1/2	0.297	0.047	9
(2). Availability of transport facilities		1	1/3	0.164	0.026	14
(3). Distance from the house to farms			1	0.539	0.086	6
Consistency Ratio (CR) = 0.009						

Technical and management	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)			
(1). Seed quality	1	4	1/2	1	3	3	3	2	0.204	0.120	1
(2). Land preparation		1	1/3	1/4	1	1	1/3	1	0.058	0.034	13
(3). Planting technique			1	1	3	3	1	2	0.195	0.115	2
(4). Pre-processing technique				1	2	2	1/2	2	0.155	0.091	5
(5). Storing technique					1	1	1/2	1	0.067	0.040	11
(6). Drying technique						1	1/4	1	0.063	0.037	12
(7). Fertilizer & insecticide use management							1	3	0.186	0.110	3
(8). Farm size								1	0.072	0.042	10
Consistency Ratio (CR) = 0.037											

Socio-economic	(1)	(2)	(3)			
(1). Membership of any social organisations	1	1	1/2	0.261	0.066	8
(2). Farming experience/skills of farmers		1	1	0.328	0.083	7
(3). Farmers' accessibility to agricultural services in the local area			1	0.411	0.104	4
Consistency Ratio (CR) = 0.052						

Appendix 16: Farm level - Weighting selected factors in the AMS for the vegetables system

Bio-physical	(1)	(2)	(3)	**W1**	**W2, Rank**	
(1). Irrigation and drainage system	1	1/3	1	0.211	0.034	8
(2). Availability of transport facilities		1	2	0.549	0.087	4
(3). Transport system			1	0.241	0.038	7
Consistency Ratio (CR) = 0.018						

Technical and management	(1)	(2)	(3)			
(1). Seed quality	1	1/3	1/3	0.142	0.083	5
(2). Land preparation technique		1	1/2	0.334	0.197	2
(3). Fertilizer & insecticide use management			1	0.525	0.309	1
Consistency Ratio (CR) = 0.052						

Socio-economic	(1)	(2)	(3)			
(1). Membership of any social organisations	1	1/5	1/3	0.110	0.028	9
(2). Farming experience/skills of farmers		1	2	0.581	0.146	3
(3). Farmers' accessibility to agricultural services in the local area			1	0.309	0.078	6
Consistency Ratio (CR) = 0.004						

Appendix 17: District level - The present capability index (Ci) of factors in the AMS for general agricultural production systems

No	Land characteristics	Investigated districts										
1. Bio-Physical		**TS**	**TPL**	**CT**	**TT**	**TB**	**CP**	**CM**	**CD**	**PT**	**TC**	**AP**
1	Common pests	0.17	0.10	0.24	0.17	0.17	0.17	0.17	0.10	0.17	0.17	0.17
2	Annual dry/drought period	0.12	0.12	0.12	0.09	0.09	0.12	0.12	0.12	0.12	0.12	0.12
3	Annual inundation period	0.15	0.12	0.15	0.08	0.08	0.12	0.12	0.08	0.12	0.12	0.12
4	Irrigation and drainage system	0.38	0.21	0.21	0.13	0.13	0.30	0.30	0.21	0.30	0.30	0.30
5	Flood level	0.10	0.10	0.10	0.10	0.10	0.10	0.06	0.10	0.06	0.06	0.06
6	Transport system	0.08	0.08	0.06	0.08	0.08	0.05	0.08	0.08	0.08	0.05	0.05
2. Technical and management												
7	Seed sector	0.36	0.28	0.36	0.28	0.28	0.36	0.36	0.28	0.36	0.28	0.28
8	Applied ability of mechanization	0.11	0.08	0.15	0.15	0.11	0.11	0.11	0.08	0.11	0.11	0.08
9	Water and pest management	0.18	0.13	0.13	0.13	0.13	0.13	0.18	0.18	0.18	0.18	0.13
3. Land development and environmental												
10	Flood control ability	0.42	0.33	0.14	0.14	0.14	0.23	0.42	0.42	0.42	0.33	0.23
11	Long-term salinity, landslip, landslide	1.00	1.00	1.00	1.00	1.00	0.71	1.00	1.00	1.00	0.71	0.71
12	Environmental hazards	0.92	1.18	0.66	0.92	0.66	0.92	0.66	1.18	0.66	0.92	0.66
13	Environmental control ability	0.62	0.80	0.44	0.62	0.44	0.62	0.80	0.44	0.62	0.44	0.62
4. Socio-economic and policy												
14	Livelihood opportunities for farmers	0.29	0.40	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
15	Production costs	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
16	Laws for natural resource management	0.39	0.22	0.31	0.39	0.39	0.31	0.22	0.31	0.31	0.31	0.31
17	Policies for product consumption	1.13	1.46	1.13	0.81	0.81	0.81	1.46	0.81	1.46	0.81	1.13
Overall capability index		**7.17**	**7.35**	**6.23**	**6.12**	**5.64**	**6.08**	**7.08**	**6.43**	**6.99**	**5.93**	**5.99**

Appendix 18: Commune level - The present capability index (Ci) of factors in the AMS for the rotational rice-vegetables system

No	Land characteristics	Investigated communes																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Bio-Physical																			
1	Common pests	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
2	Irrigation and drainage	0.65	0.65	0.84	0.47	0.65	0.84	0.65	0.84	0.65	0.65	0.65	0.47	0.65	0.65	0.65	0.84	0.84	0.84
3	Aeration condition	0.42	0.55	0.55	0.42	0.42	0.42	0.55	0.55	0.42	0.42	0.55	0.42	0.42	0.42	0.42	0.42	0.55	0.42
4	Available nutrients	0.27	0.35	0.35	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.35	0.35	0.27	0.27	0.27	0.27	0.27	0.27
5	Transport facilities	0.48	0.61	0.61	0.48	0.48	0.48	0.48	0.48	0.48	0.61	0.61	0.61	0.48	0.48	0.48	0.48	0.61	0.48
2. Technical/management																			
6	Seed sector	0.44	0.44	0.34	0.24	0.24	0.34	0.24	0.34	0.34	0.34	0.34	0.34	0.44	0.34	0.34	0.44	0.34	0.44
7	Mechanization applied	0.19	0.15	0.15	0.15	0.11	0.11	0.15	0.11	0.15	0.11	0.11	0.15	0.19	0.15	0.15	0.19	0.15	0.19
8	Water and pest management	0.39	0.28	0.28	0.39	0.39	0.39	0.39	0.39	0.28	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.28	0.39
3. Development/environmental																			
9	Flood control ability	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
10	Irrigation engineering	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.30	0.90
11	Environmental control ability	1.10	1.10	1.10	1.10	1.10	1.10	0.79	1.10	1.10	1.10	1.10	0.79	1.42	1.10	1.10	1.42	1.10	1.42
4. Socio-economic/policy																			
12	Livelihood opportunities	0.11	0.14	0.14	0.11	0.11	0.14	0.11	0.11	0.11	0.14	0.11	0.11	0.11	0.11	0.11	0.11	0.14	0.11
13	Labour force	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
14	Production costs	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
15	Farmers' accessibility	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
16	Credit allowance	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
Overall capability index		**6.62**	**6.83**	**6.92**	**6.20**	**6.34**	**6.65**	**6.19**	**6.74**	**6.37**	**6.60**	**6.77**	**6.19**	**6.93**	**6.48**	**6.48**	**7.12**	**6.24**	**7.12**

Appendix 19: Commune level - The present capability index (Ci) of factors in the AMS for the rice system

No	Land characteristics	Investigated communes																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Bio-Physical																			
1	Common pests	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
2	Irrigation and drainage	0.80	0.80	1.03	0.57	0.80	1.03	0.80	1.03	0.80	0.80	0.80	0.57	0.80	0.80	0.80	1.03	1.03	1.03
3	Transport facilities	0.44	0.57	0.57	0.44	0.44	0.44	0.44	0.44	0.44	0.57	0.57	0.57	0.44	0.44	0.44	0.44	0.57	0.44
2. Technical/management																			
4	Seed sector	0.35	0.35	0.27	0.20	0.20	0.27	0.20	0.27	0.27	0.27	0.27	0.27	0.35	0.27	0.27	0.35	0.27	0.35
5	Mechanization applied	0.55	0.43	0.43	0.43	0.31	0.31	0.43	0.31	0.43	0.31	0.31	0.43	0.55	0.43	0.43	0.55	0.43	0.55
6	Water and pest management	0.17	0.12	0.12	0.17	0.17	0.17	0.17	0.17	0.12	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.12	0.17
3. Development/environmental																			
7	Flood control ability	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
8	Irrigation engineering	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.22	0.65
9	Environmental control ability	1.15	1.15	1.15	1.15	1.15	1.15	0.82	1.15	1.15	1.15	1.15	0.82	1.48	1.15	1.15	1.48	1.15	1.48
4. Socio-economic/policy																			
10	Livelihood opportunities	0.34	0.43	0.43	0.34	0.34	0.43	0.34	0.34	0.34	0.43	0.34	0.34	0.34	0.34	0.34	0.34	0.43	0.34
11	Labour force	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
12	Farmers' accessibility	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Overall capability index		**5.91**	**5.96**	**6.11**	**5.40**	**5.51**	**5.91**	**5.30**	**5.82**	**5.66**	**5.81**	**5.71**	**5.28**	**6.24**	**5.71**	**5.71**	**6.47**	**5.68**	**6.47**

Appendix 20: Commune level - The present capability index (Ci) of factors in the AMS for the vegetable system

No	Land characteristics	Investigated communes																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Bio-Physical																			
1	Irrigation and drainage	0.46	0.46	0.59	0.33	0.46	0.59	0.46	0.59	0.46	0.46	0.46	0.33	0.46	0.46	0.46	0.59	0.59	0.59
2	Aeration condition	1.19	1.53	1.53	1.19	1.19	1.19	1.53	1.53	1.19	1.19	1.53	1.19	1.19	1.19	1.19	1.19	1.53	1.19
3	Available nutrients	1.04	1.34	1.34	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.34	1.34	1.04	1.04	1.04	1.04	1.04	1.04
2. Technical/management																			
4	Seed sector	0.35	0.35	0.27	0.20	0.20	0.27	0.20	0.27	0.27	0.27	0.27	0.27	0.35	0.27	0.27	0.35	0.27	0.35
5	Mechanization applied	0.22	0.17	0.17	0.17	0.12	0.12	0.17	0.12	0.17	0.12	0.12	0.17	0.22	0.17	0.17	0.22	0.17	0.22
6	Water and pest management	0.43	0.31	0.31	0.43	0.43	0.43	0.43	0.43	0.31	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.31	0.43
3. Development/environmental																			
7	Flood control ability	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
8	Irrigation engineering	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.13	0.38
9	Environmental control ability	1.10	1.10	1.10	1.10	1.10	1.10	0.79	1.10	1.10	1.10	1.10	0.79	1.42	1.10	1.10	1.42	1.10	1.42
4. Socio-economic/policy																			
10	Production costs	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
11	Farmers' accessibility	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
12	Credit allowance	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Overall capability index		**7.07**	**7.54**	**7.59**	**6.74**	**6.82**	**7.03**	**6.89**	**7.37**	**6.82**	**6.90**	**7.53**	**6.80**	**7.39**	**6.95**	**6.95**	**7.52**	**7.04**	**7.52**

Appendix 21: Farm level - The present capability index (Ci) of factors in the AMS for the rotational rice-vegetables system

No	Land characteristics	Investigated farms									
		1	2	3	4	5	6	7	8	9	10
1. Bio-Physical											
1	Irrigation and drainage	0.40	0.29	0.40	0.40	0.51	0.40	0.40	0.51	0.40	0.17
2	Transport facilities	0.26	0.20	0.14	0.20	0.26	0.26	0.20	0.20	0.20	0.26
3	Transport system	0.16	0.16	0.11	0.16	0.20	0.16	0.11	0.16	0.16	0.16
4	Distance between the house & farms	0.46	0.36	0.25	0.15	0.05	0.15	0.15	0.25	0.25	0.25
2. Technical/management											
5	Seed quality	0.82	0.82	0.64	0.46	0.46	0.46	0.64	0.64	0.64	0.27
6	Land preparation	0.97	0.97	0.97	1.25	1.25	0.69	0.42	0.69	0.69	0.42
7	Planting technique	0.64	0.36	0.64	0.50	0.50	0.64	0.50	0.36	0.21	0.36
8	Pre-processing technique	0.45	0.45	0.35	0.25	0.15	0.15	0.25	0.25	0.25	0.15
9	Storing technique	0.31	0.24	0.24	0.17	0.17	0.10	0.17	0.17	0.17	0.24
10	Drying technique	0.35	0.25	0.25	0.35	0.15	0.05	0.15	0.25	0.15	0.05
11	Fertilizers/insecticides management	0.94	0.94	0.73	0.52	0.73	0.73	0.31	0.52	0.31	0.31
12	Farm size	0.44	0.34	0.24	0.15	0.15	0.24	0.24	0.34	0.24	0.15
3. Socio-economic/policy											
13	Membership of associations/organizations	0.08	0.08	0.13	0.13	0.19	0.13	0.13	0.08	0.08	0.08
14	Farming experience/farmers' skill	1.44	1.12	1.12	0.80	0.48	0.80	1.12	0.48	0.80	0.80
15	Farmers' accessibility to services	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
Overall capability index		**8.17**	**7.03**	**6.69**	**5.95**	**5.70**	**5.42**	**5.26**	**5.37**	**5.03**	**4.12**

Appendix 22: Farm level - The present capability index (Ci) of factors in the AMS for the rice system

No	Land characteristics	Investigated farms									
		1	2	3	4	5	6	7	8	9	10
1. Bio-Physical											
1	Irrigation and drainage	0.33	0.43	0.43	0.43	0.33	0.33	0.43	0.43	0.43	0.33
2	Transport facilities	0.18	0.23	0.23	0.18	0.18	0.18	0.18	0.13	0.18	0.23
3	Distance between house & farms	0.09	0.26	0.26	0.43	0.60	0.60	0.60	0.43	0.43	0.43
2. Technical/management											
4	Seed quality	1.08	0.84	0.84	0.84	0.60	0.84	1.08	0.84	0.60	0.84
5	Land preparation	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
6	Planting technique	0.81	0.81	0.81	0.81	1.04	1.04	1.04	0.58	0.58	0.81
7	Pre-processing technique	0.46	0.46	0.64	0.82	0.82	0.64	0.64	0.64	0.46	0.64
8	Storing technique	0.20	0.20	0.28	0.36	0.36	0.28	0.28	0.28	0.20	0.28
9	Drying technique	0.04	0.11	0.18	0.11	0.18	0.26	0.26	0.18	0.18	0.11
10	Fertilizers/insecticides management	0.33	0.55	0.77	0.55	0.33	0.55	0.55	0.77	0.33	0.33
11	Farm size	0.21	0.30	0.30	0.21	0.13	0.13	0.21	0.30	0.30	0.21
3. Socio-economic/policy											
12	Membership of associations/organizations	0.20	0.20	0.20	0.33	0.33	0.46	0.46	0.33	0.20	0.20
13	Farming experience/farmers' skill	0.58	0.58	0.74	0.74	0.58	0.74	0.58	0.74	0.58	0.74
14	Farmers' accessibility to services	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Overall capability index		**5.52**	**5.98**	**6.70**	**6.83**	**6.51**	**7.07**	**7.33**	**6.67**	**5.48**	**6.18**

Appendix 23: Farm level - The present capability index (Ci) of factors in the AMS for the vegetable system

No	Land characteristics	Investigated farms									
		1	2	3	4	5	6	7	8	9	10
1. Bio-Physical											
1	Irrigation and drainage	0.30	0.23	0.30	0.30	0.23	0.17	0.17	0.23	0.30	0.30
2	Transport facilities	0.79	0.79	0.61	0.79	0.61	0.61	0.44	0.61	0.79	0.61
3	Transport system	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
2. Technical/management											
4	Seed quality	0.42	0.58	0.58	0.42	0.58	0.42	0.58	0.58	0.58	0.42
5	Land preparation	1.77	1.38	1.38	1.38	1.77	1.38	0.98	0.59	0.98	1.38
6	Fertilizers/insecticides management	2.78	2.16	1.54	0.93	1.54	2.16	1.54	1.54	2.16	0.93
4. Socio-economic/policy											
7	Membership of associations/organizations	0.19	0.14	0.14	0.08	0.08	0.14	0.14	0.19	0.14	0.08
8	Farming experience/farmers' skill	1.02	0.73	1.02	0.73	1.32	1.02	0.73	1.02	1.02	0.44
9	Farmers' accessibility to services	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
Overall capability index		**8.09**	**6.83**	**6.39**	**5.44**	**6.96**	**6.71**	**5.40**	**5.60**	**6.79**	**4.97**

Appendix 24: Farm level - The present capability index (Ci) of components in the AMS for selected farming systems

Components	**Rotational rice-vegetables farms (F)**									
	F1	**F**2	**F**3	**F**4	**F**5	**F**6	**F**7	**F**8	**F**9	**F**10
Biophysical	8.00	6.28	5.72	5.72	6.44	6.08	5.44	7.08	6.36	5.29
Technical & management	8.36	7.42	6.91	6.19	6.03	5.21	4.56	5.48	4.54	3.30
Socioeconomic	7.84	6.58	6.79	5.52	4.47	5.52	6.79	4.04	5.31	5.31
Overall capability index	**8.17**	**7.03**	**6.69**	**5.95**	**5.70**	**5.42**	**5.26**	**5.37**	**5.03**	**4.12**
Components	**Rice farms (F)**									
	F1	**F**2	**F**3	**F**4	**F**5	**F**6	**F**7	**F**8	**F**9	**F**10
Biophysical	3.77	5.77	5.77	6.52	7.00	7.00	7.59	6.19	6.52	6.25
Technical & management	5.82	6.05	6.99	6.79	6.38	6.85	7.40	6.60	5.00	5.98
Socioeconomic	5.96	5.96	6.61	7.13	6.48	7.66	7.00	7.13	5.96	6.61
Overall capability index	**5.52**	**5.98**	**6.70**	**6.83**	**6.51**	**7.07**	**7.33**	**6.67**	**5.48**	**6.18**
Components	**Vegetable farms (F)**									
	F1	**F**2	**F**3	**F**4	**F**5	**F**6	**F**7	**F**8	**F**9	**F**10
Biophysical	8.52	8.10	7.42	8.52	7.00	6.58	5.48	7.00	8.52	7.42
Technical & management	8.43	7.00	5.95	4.62	6.62	6.72	5.28	4.62	6.33	4.62
Socioeconomic	7.00	5.62	6.78	5.40	7.72	6.78	5.62	7.00	6.78	4.24
Overall capability index	**8.09**	**6.83**	**6.39**	**5.44**	**6.96**	**6.71**	**5.40**	**5.60**	**6.79**	**4.97**

Appendix 25: Farm level - ANOVA analysis results on the average capability index between farming systems

Anova: The capability of the bio-physical component						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Rotational system	10	62.4095	6.24095	0.66407		
Rice system	10	62.36508	6.236508	1.079325		
Vegetables system	10	74.55455	7.455455	0.986746		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	9.869571	2	4.934786	5.422562	0.010478	3.354131
Within Groups	24.57127	27	0.910047			
Total	34.44084	29				
Anova: The capability of the technical & management component						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Rotational system	10	57.99132	5.799132	2.267903		
Rice system	10	63.85346	6.385346	0.481501		
Vegetables system	10	60.18701	6.018701	1.575348		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.754286	2	0.877143	0.608458	0.551483	3.354131
Within Groups	38.92277	27	1.441584			
Total	40.67705	29				
Anova: The capability of the socio-economic component						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Rotational system	10	58.16078	5.816078	1.35852		
Rice system	10	66.48889	6.648889	0.342255		
Vegetables system	10	62.939	6.2939	1.077791		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.493014	2	1.746507	1.885692	0.171169	3.354131
Within Groups	25.0071	27	0.926189			
Total	28.50011	29				
Anova: The overall capability						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Rotational system	10	58.73764	5.873764	1.32396		
Rice system	10	64.28016	6.428016	0.389279		
Vegetables system	10	63.16827	6.316827	0.905022		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.719545	2	0.859772	0.985126	0.386416	3.354131
Within Groups	23.56435	27	0.872754			
Total	25.28389	29				