Computers and Electronics in Agriculture 93 (2013) 98–110

Contents lists available at SciVerse ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Agriculture Land Suitability Evaluator (ALSE): A decision and planning support tool for tropical and subtropical crops

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ARTICLE INFO

Article history:
Received 19 April 2012
Received in revised form 20 January 2013
Accepted 5 February 2013

Keywords:
Biophysical modeling
Expert system
GIS
Land evaluation
Land use planning
Multi-criteria analysis

ABSTRACT

Agricultural land suitability evaluation for crop production is a process that requires specialized geo-environmental information and the expertise of a computer scientist to analyze and interpret the information. This paper presents ALSE, an intelligent system for assessing land suitability for different types of crops in tropical and subtropical regions (e.g. mango, banana, papaya, citrus, and guava) based on geo-environmental factors that automates the process of evaluation and illustrates the results on an attribute table. Its main features include support of GIS capabilities on the digital map of an area with the FAO-SYS framework model with some necessary modifications to suit the local environmental conditions for land evaluation, and the support of expert knowledge through on spatial tools to derive criteria weights with their relative importance. A dynamic program for calculation of eigenvalues and eigenvectors of a weighting matrix is provided. Expertise and knowledge help ensure that ALSE databases represent realistic, practicable and functional systems. It is useful for decision makers to determine the quality of land for agricultural uses and is intended as a decision and planning support. Responsibility for any decisions based partly or wholly on the output of ALSE rests with the decision maker. ALSE ensures that the results are interpreted correctly within the relevant context, and contributes by maximizing land-use planning and decision support.

1. Introduction

Land evaluation is a process of predicting land performance over time according to the specific types of use (Zonneveld, 1989; Rossiter, 1996; Lee and Yeh, 2009; Martin and Saha, 2009; Sonneveld et al., 2010). Agriculture land suitability assessment is defined as the process of assessment of land performance when used for alternative kinds of agriculture (He et al., 2011; Mu, 2006; Prakash, 2003). The principle purpose of agriculture land suitability evaluation is to predict the potential and limitation of the land for crop production (Pan and Pan, 2012).

Continuous utilization of agriculture land in past decades, regardless of land suitability has caused much more destruction than provide the resources (FAO, 1976, 1983, 2007). Hence, proper evaluation based on agriculture land use planning is essential to solve this problem. Land evaluation methodologies have shifted from broad based to specific assessment, with increasing use of quantification (Elsheik et al., 2010; Nwer, 2006). Significant amount of literature and research has been dedicated to intelligent systems for land use and management. Prominent land evaluation expert systems that have been developed and introduced in recent years are reviewed to enable comparative analysis. The land evaluation computer system (LECS) based upon the FAO framework for predicting local crop yields has been used to assess the land suitability for a variety of crops (Wood and Dent, 1983). However, the constraints of this system is simplicity and developed for areas in Sumatra (Nwer, 2006).

ALES on the other hand is an automated land evaluation system that allows land evaluators to build expert systems for land evaluation according to the method presented in the Food and Agriculture Organization Framework for land evaluation (Johnson and

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http://dx.doi.org/10.1016/j.compag.2013.02.003

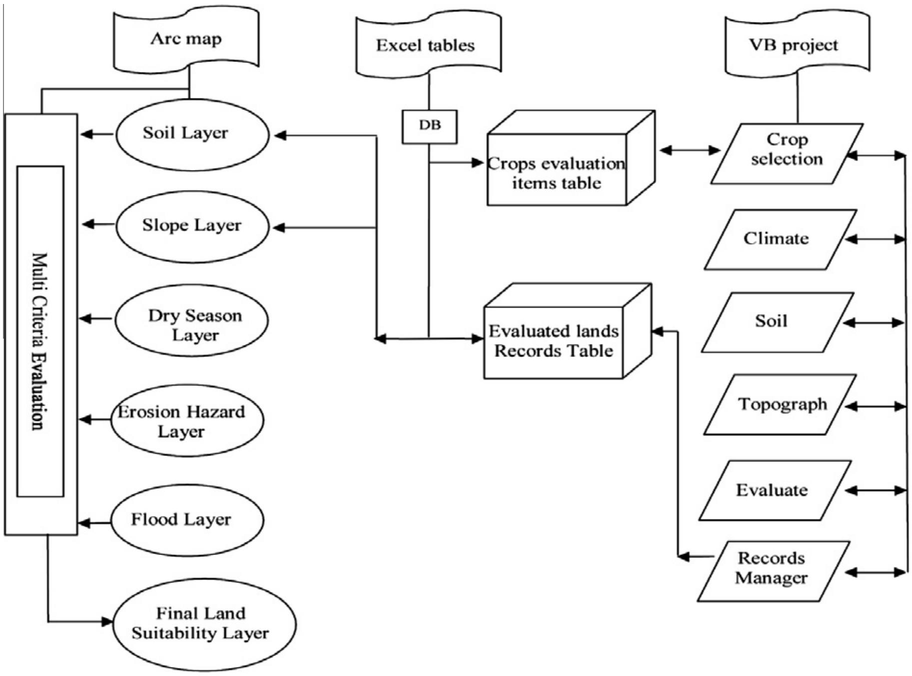

Fig. 1. Platforms structure of ALSE.

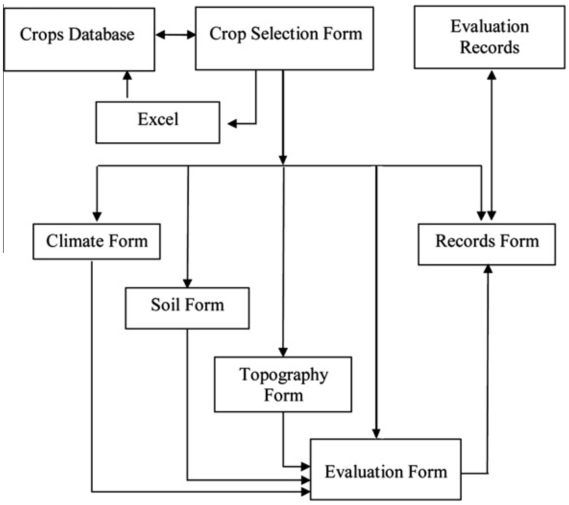

Fig. 2. System's main forms relationship in visual basic.

Cramb, 1991). This system offers the structure for a wide range of expert knowledge for a quick assessment, can be linked to socio-economic evaluation, allow the evaluator's to build their own expert system, and has no fixed list for land characteristics or land use requirements. Limitations of this system is that it cannot display maps, has no GIS functions and is not very user friendly (Rossiter, 1990; Rossiter and Wambeke, 1997).

The Micro-LEIS is an integrated system for land data transfer and agro-ecological land evaluation (Rosa et al., 1992, 2004, 2009). Currently, MicroLEIS have been integrated with GIS (Hoobler et al., 2003). Hence, this system provides a computer-based set of tools for an orderly arrangement and practical interpretation of land resources and agricultural management data. Its major components include, land evaluation using the following spatial units: place (climate), soil (site-soil), land (climate-site-soil), and field (climate-site-soil-management); data and knowledge engineering through the use of a variety of geo-referenced databases, computer programs, and boolean, statistical, expert system and neural network modeling techniques (Rosa et al., 2004, 2009). The disadvantage of this system is that it does not allow the user to build a personal expert system (Nwer, 2006).

The Intelligent System for Land Evaluation (ISLE) is knowledge based, and models the evaluation of land in accordance with the FAO-SYS model for land evaluation. The system has as input a digital map of an area and its geographical database, displays this map, evaluates the land units selected by the user and finally visualizes the results of the land units in color (Tsoumakas and Vlahavas, 1999). The constraint of this system is that it does not support a wide range of problems in land evaluation.

Another system is LIMEX, which is an integrated expert system with multimedia that was developed to assist lime growers and extension agents in the cultivation of lime for the purpose of improving their yield (Mahmoud et al., 1997). The scope of the LIMEX expert system includes assessment, irrigation, fertilization, and pest control. The expert system was augmented with multimedia capabilities by the integration of text, image, sound, video, and data which allows for a good feedback from users, assists in better understanding of the system, and allows for more flexibility in the interactive use of the system.

VEGES is another expert system developed for the diagnosis and treatment of pests, diseases and nutrient disorders of certain vegetable species (Yialouris et al., 1997). This system is simple and is based on forms of object-attribute-value (OAV) for the representation of symptoms. This method of representation easily fits into any rule based ES development tool, and thus is an advantage of the system.

Land evaluation using an Intelligent Geographical Information System (LEIGIS) is a software application resulting from research by Kalogirou (2002). LEIGIS was designed to support rural planners with the first view of the land suitability for cultivation of certain crops according to the FAO methodology. The aim of this work was to produce a physical evaluation of land capabilities and to use this to provide an economic evaluation of land for different types of agriculture. The implementation of LEIGIS includes models for

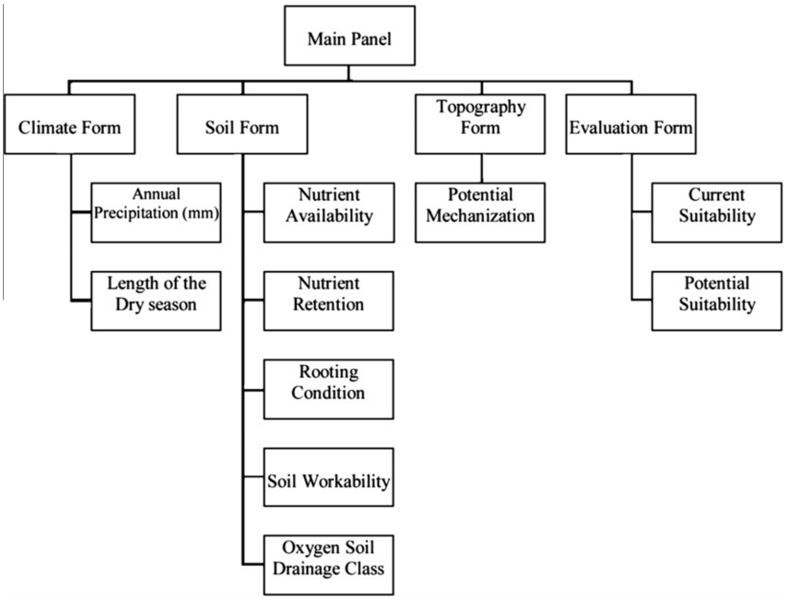

Fig. 3. Main input fields for the different forms developed in the system design.

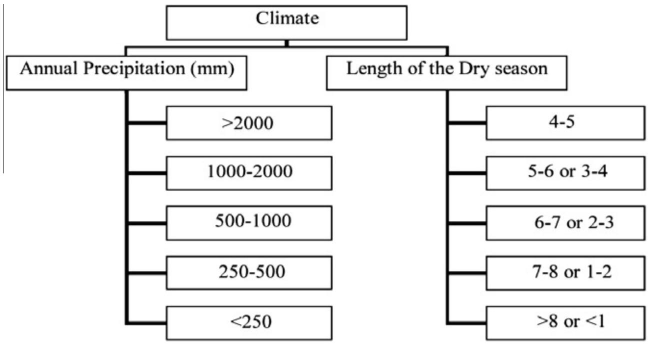

Fig. 4. Climate alternatives of the input information list for mango.

Table 1
Climate suitability evaluation for the mango in the system.

No.	Annual precipitate (mm)	Rating of suitability (%)	Suitability level
1	>2000	95	$S1$
2	1000–2000	85	$S1$
3	500–1000	60	$S2$
4	250–500	45	$S3$
5	<250	25	$N1$
6		0	$N2$

general cultivation and for specific crops (wheat, barley, maize, seed cotton, and sugar beet) (Kalogirou, 2002). This system is limited to five crops and does not include characteristics such as climate.

Model computer programs can also be implemented on the Internet through a web server, so that users can apply the models directly via a web browser. Jayasinghe and Machida (2008) developed an interactive web-based GIS online consulting system with crop-land suitability analysis, which provides information for tomato and cabbage cultivation. This system has the benefit of availability online, but is limited to two types of crop. There is a need for flexibility in the system with friendly user interface that allows the user to identify and change the requirements based on local conditions. Also the system should be able to accommodate new crops.

MultiCriteria Evaluation (MCE) this framework consists of a finite number of alternatives, explicitly known in the beginning of the solution process. Each alternative is represented by its performance in multiple criteria. The problem may be defined as finding the best alternative for a decision maker (DM), or finding a set of good alternatives. The integration of MultiCriteria Decision Analysis Approaches (MCDAs) in a Geographical Information System (GIS) provides a powerful spatial decision support system which offers the opportunity to efficiently produce these land suitability maps (Mendas and Delali, 2012). Hence, the current study harnesses recent developments in using GIS–MCE as a smart tool in supporting the decision making process for agriculture land evaluation purposes. The ALSE system was designed with specific knowledge based on GIS and multi criteria for predicting the geo-environmental suitability of land for cultivation of major crops in tropical and subtropical regions. The integration of GIS and the expert systems in ALSE enable decision making with spatial data.

The FAO (1976) framework for land suitability involves the construction of matching tables or transfer functions, and subsequent calculations of suitability. However, these processes are liable to errors. Therefore, there are a great number of benefits to be gained in automating the FAO procedures (Davidson, 1992; Rossiter, 1990). The automated procedure describes how to carry out an evaluation exercise, including how to select land uses to evaluate and prepare evaluation (map) units. It also describes what factors (land suitabilities) to consider when evaluating certain general kinds of land uses (e.g. forestry), and how to evaluate these factors (Rossiter, 1996).

The above method must however be supplemented with an analytical method, which will infer from the set of land characteristics that affect a land use to the severity levels of the land suitability. Hence, Sys et al. (1993) presented a variance of the method of matching tables, which assigns the correct severity level of the land suitability, given data values for each land characteristic (Sys et al., 1993; Sys and Riquier, 1980). The advantages of this method are that it is simple, easy-to-understand, and has a graphical presentation. However, it has the disadvantage in that it cannot account for interactions between land characteristics.

The FAO-SYS system is a land evaluation model, based on FAO's framework, with divisions of suitability classes that indicate degree of suitability. These classes are: '$S1$' = suitable, '$S2$' = moderately

Fig. 5. Soil parameters and suitability assessment for mango.

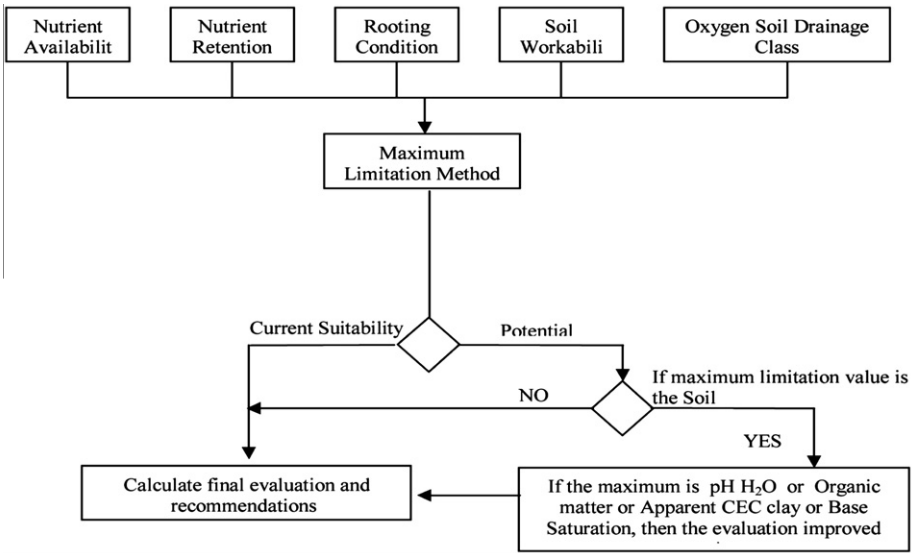

Fig. 6. Flow chart of soil suitability calculation.

suitable, '*S3*' = marginally suitable, '*N1*' = unsuitable for economic reasons but otherwise marginally suitable, '*N2*' = unsuitable for physical reasons (FAO, 1976, 1983, 2007).

2. ALSE system structure

ALSE is an intelligent system that desegregates the usefulness of a GIS with an expert system for Agriculture land evaluation. It consists of the following main parts:

1. A Visual Basic program which provides the interface to the expert system and integrated with GIS objects for judging the quality of agriculture land in selecting appropriate types of cultivation, and in planning management schemes.

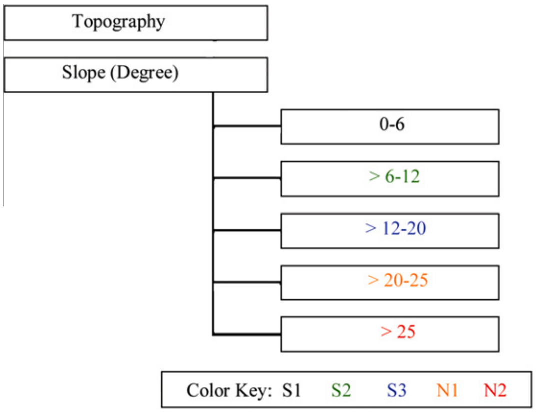

Fig. 7. Topography slopes ranges with the suitability evaluation.

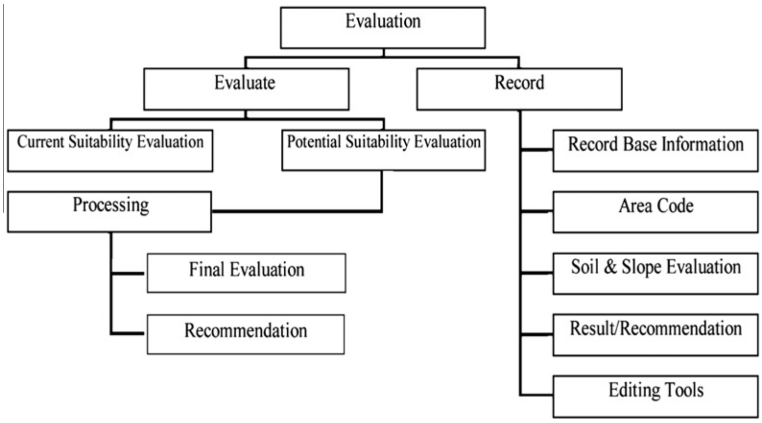

Fig. 8. Evaluation process and record information in suitability evaluation form.

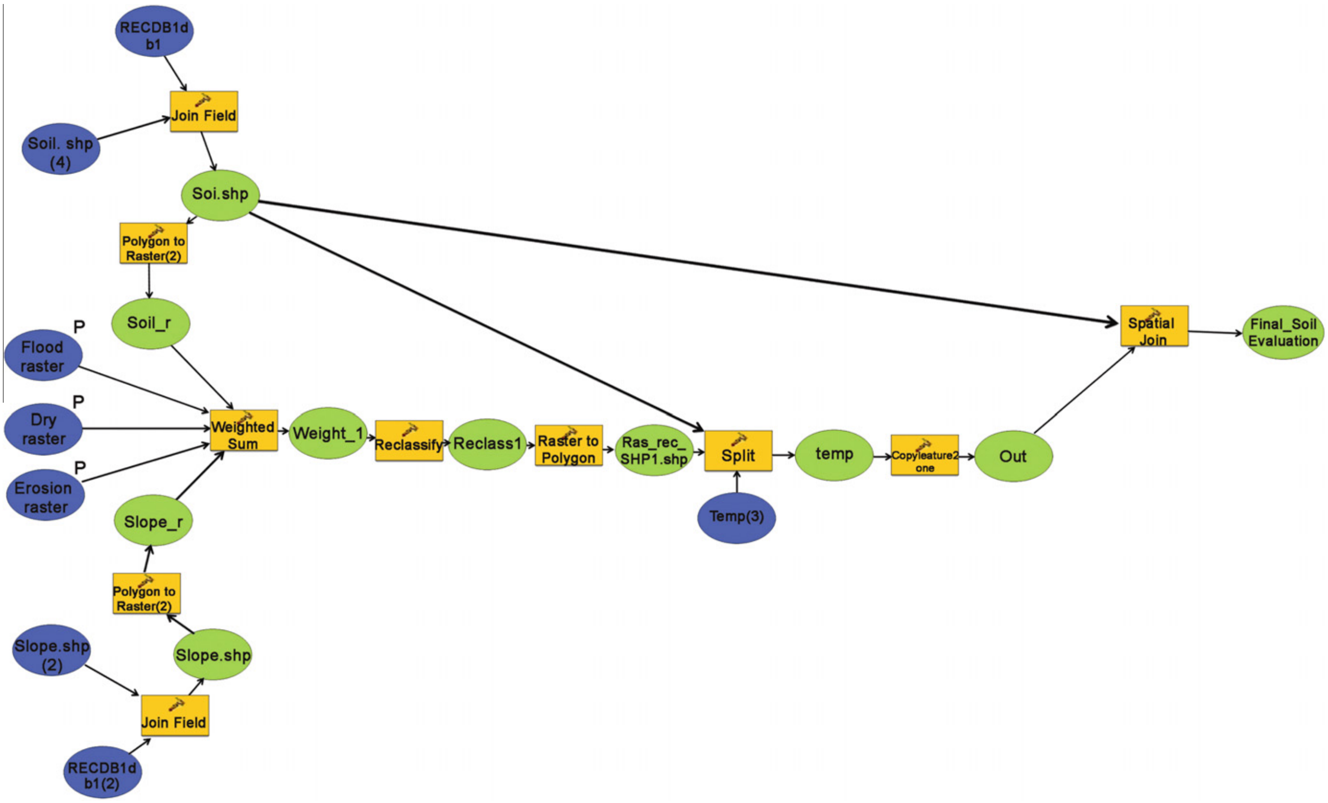

Fig. 9. The land evaluation model from the basic layers up to the final suitability layer.

Table 2
List of data sets used in the study.

Type of data	Description	Source
Soil chemical and physical values	Profile data for each type of soil	1992–2006 Department of Agriculture (DOA) Kuala Lumpur
Soil map	Soil semi detail map, scale 1: 25,000	2006 DOA Kuala Lumpur
Terrain	The terrain value extracted from the topographic map for each soil type	2006 DOA Kuala Lumpur
Landuse map	Scale 1: 50,000	2006 DOA Kuala Lumpur
Rainfall precipitation	Monthly rainfall from 34 stations during 10 years	1996–2006 Department of Irrigation and Drainage (DID)
Length of dry season map	Scale 1: 50,000	2006 DOA Kuala Lumpur
Drainage network	Scale 1:25,000	2006 DOA Kula Lumpur
Flood map	Scale 1:30,000	2008 DID

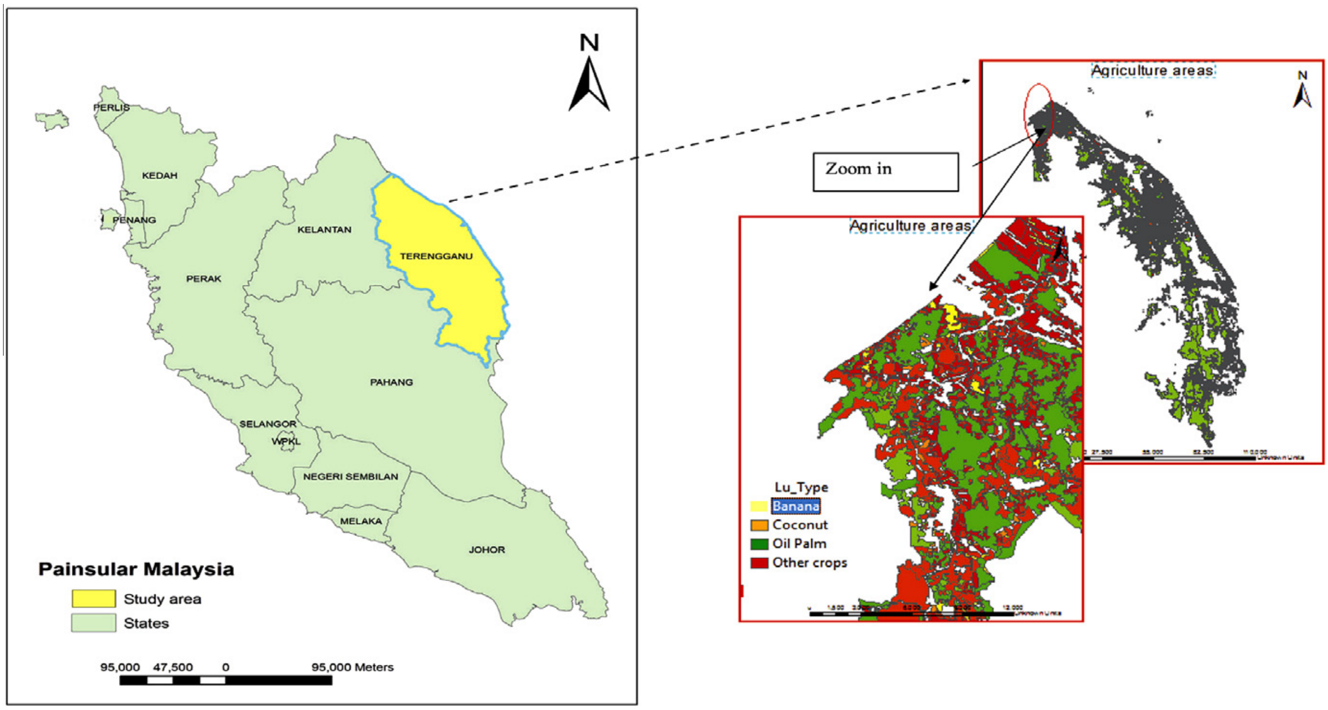

Fig. 10. Location of the study area.

2. Excel tables, which are used for selection of crop type. Adding new crop record is executed in the Excel program through the system.
3. The Arcmap Model Builder, which is used to organize and integrate spatial processes to model the land suitability. The structure of the system is illustrated in Fig. 1, while the various parts are described in the following section.

The suitability analysis for geo-environmental factors (Ceballos and Blanco, 2003; Chuong, 2008, 2007) are calculate in Visual Basic and integrated within the GIS Model Builder through linking of tables matching in ID. The input information is presented in different forms, and each form is assigned to one information type, such as climate data, soil data or topography data (Fig. 2).

The main panel is a simple platform, representing the six primary tasks: crop selection, climate, soil, topography, evaluation and records manager. The user can implement each task by clicking on the desired button, and a separate form would appear and disappear according to user preference during the evaluation process.

The main panel offers the user an opportunity to explore and switch between forms from the same platform (Fig. 3).

3. System implementation

Input information is listed in specific alternatives, and all values of the listed input information are written in a Data Base File (DBF). For each crop type, there are different values and different ranges for each criterion, organized based on the suitability of the crop type, and divided into five suitability levels: *S*1, *S*2, *S*3, *N*1 and *N*2.

3.1. Crop selection

Selection of crop type is the first step to proceed with the system. The list of the alternative inputs changes depending on the crop type. The system offers the ability to add a new type of crop by appending a new record to the crops record. Adding a new crop record is executed in the Excel program through the system, and the calculation will be based on the new crop information after the user has saved the record.

The selection of land qualities and land characteristics are pursued carefully considering the available data, texts, and literature. Therefore in this study, cultivation history and both local and worldwide knowledge, were brought together to identify the best prediction for landuse requirements. Land characteristics and their threshold values were defined considering the optimum requirements of mango (*Mangifera indica*), banana (*Musa acuminata*), papaya (*Carica papaya*), guava (*Psidium guajava*) and citrus (*Citrus medica*). The data and information on the threshold values available from literature and trials from local studies were used. The land evaluation process was carried out by matching the land characteristics with crop requirements for each polygon.

3.2. Climate

The developed system considers the climate input as a rule to the assessment process of land suitability. Climate information in the system is described by two characteristics: the annual precipitation (mm) and the length of the dry season per month. The final evaluation of the climate suitability to a specific crop will be shown in an evaluation box at the right side of the form. For a mango crop within the study area, the climate form will appear as shown in Fig. 4.

The system stores the selected input information and computes the suitability level of the annual precipitation (mm) and the length of the dry season per month. The final evaluation of climate suitability is calculated based on mango requirement (Ikisan, 2003; Table 1).

3.3. Soil

Soil suitability in the soil form consists of five main qualities: nutrient availability, nutrient retention, rooting conditions, soil workability and oxygen soil drainage class. The suitability

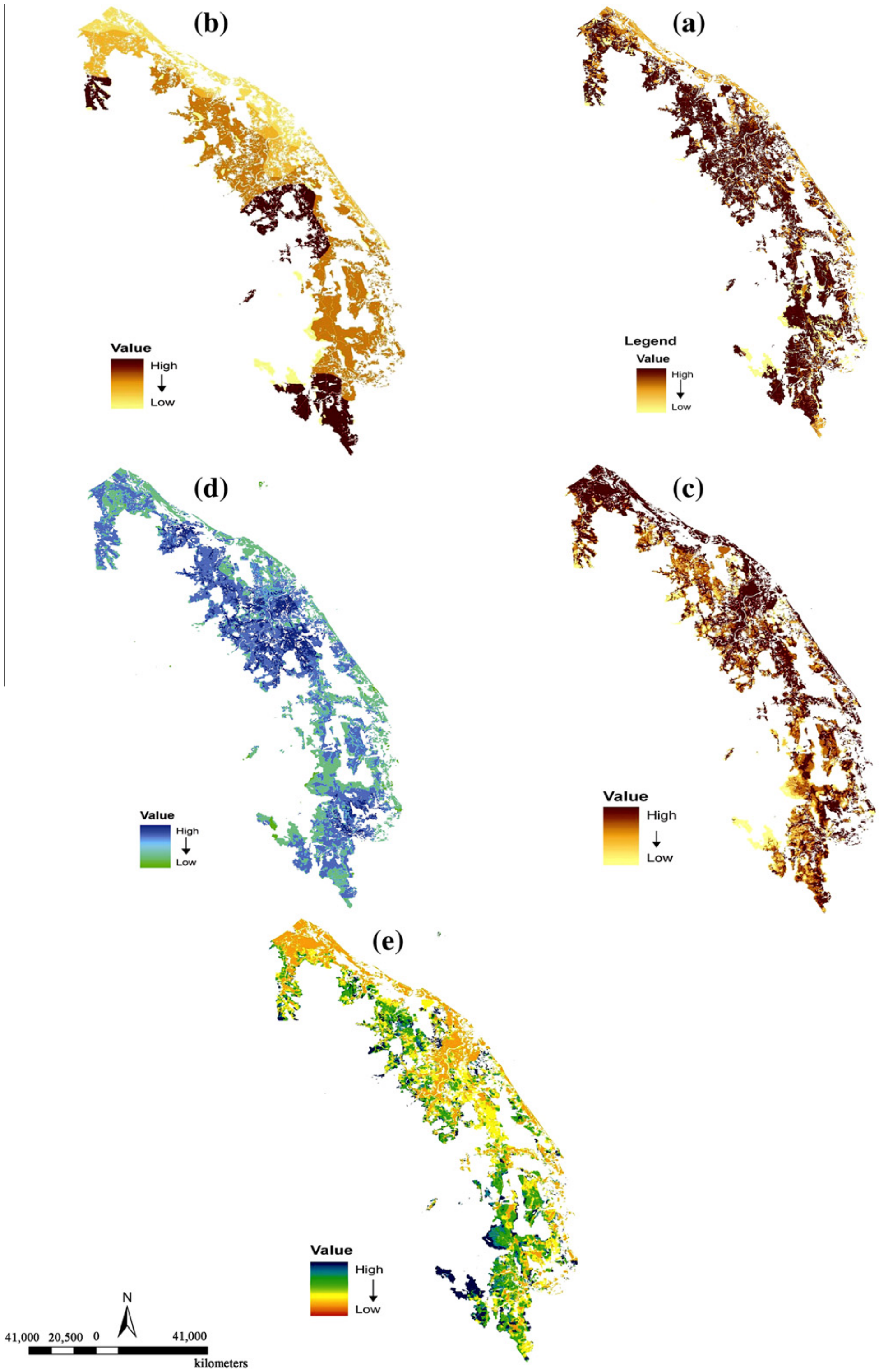

Fig. 11. ALSE tool interface of suitability map for mango cultivation based on: (a) soil parameters, (b) dry season climate, (c) slope parameter, (d) flood risk, and (e) erosion risk.

assessment process for mango is presented in Fig. 5. Each quality in the form has its evaluation results. The final result is the overall suitability for soil, computed by the maximum limitation method (Fig. 6). The user can view the result in two ways: (i) current suitability evaluation, or (ii) potential suitability evaluation. Based on the scope of suitability, there are two types of classifications in the FAO Framework (1976): Current suitability refers to the suitability for a defined use of land in its present condition, without any major improvements in it. Potential suitability is for a defined use, of land units in their condition at some future. In this research the potential suitability under the assumption of land would be modified by fertilizer.

Table 3
The result of weighting schemes for soil, slope, climate, flood and erosion scenarios.

Model run	*S*1%	*S*2%	*S*3%	*N*1%	*N*2%	Sum	Scenario
1	6	56	27	8	3	100	Soil
2	27	14	43	10	6	100	
3	12	60	22	4	2	100	
4	18	58	16	4	4	100	
5	30	48	12	5	5	100	
6	55	23	12	5	5	100	
7	63	15	12	4	6	100	
8	64	14	12	2	8	100	
9	64	14	12	2	8	100	
10	5	59	29	5	2	100	Slope
11	27	14	43	10	6	100	
12	12	67	15	4	2	100	
13	19	63	13	3	2	100	
14	28	51	15	3	3	100	
15	52	31	12	3	2	100	
16	55	28	12	3	2	100	
17	55	28	12	3	2	100	
18	55	28	12	3	2	100	
19	9	67	18	4	2	100	Climate
20	27	14	43	10	6	100	
21	9	57	29	3	2	100	
22	11	51	32	4	2	100	
23	16	43	32	5	4	100	
24	19	38	29	10	4	100	
25	19	37	26	12	6	100	
26	20	36	26	12	6	100	
27	20	36	26	12	6	100	
28	20	60	14	4	2	100	Flood
29	27	14	43	10	6	100	
30	3	54	34	7	2	100	
31	3	34	51	11	1	100	
32	1	26	45	27	1	100	
33	1	29	30	39	1	100	
34	1	31	13	52	3	100	
35	1	33	2	55	9	100	
36	0	1	34	56	9	100	
37	8	58	28	4	2	100	Erosion
38	27	14	43	10	6	100	
39	11	62	19	6	2	100	
40	17	58	15	7	3	100	
41	32	43	14	8	3	100	
42	32	43	13	9	3	100	
43	47	28	12	10	3	100	
44	47	28	12	10	3	100	
45	47	28	12	10	3	100	

3.4. Topography

Potential for mechanization indicates the topography of the area. The impact of the topography on the land suitability is measured by slope in degrees. Each crop type has a suitable range of slopes, and the system classifies different slope ranges into five categories in terms of crop suitability (Fig. 7).

3.5. Suitability evaluation

The suitability evaluation process begins after the user enters the crop name and other necessary information on climate, soil and topography of the land. There are two ways to evaluate the suitability: potential suitability or current suitability (Fig. 8).

3.6. Record manager

The final result is denoted as a new record in the database. The user is allowed to write down the primary information about the field evaluation, such as land index number, user information, record information, and other basic data. The record manager is linked to the record database directly, and allows the user to enter, explore, open, and edit the record. The record database table is the linkage between the system and the GIS program. Every land parcel has a unique code through which GIS software can relate to with the system outputs.

4. Land suitability model builder

A land suitability model was constructed using GIS capabilities and modeling functions. The GIS Model Builder was used to organize and integrate spatial processes to model the land suitability. The spatial geo-environmental factors (e.g. soil, climate, slope, erosion and flood hazard) were integrated into the GIS environment as information layers and overlaid to produce overall land suitability assessment for a particular land utilization type. The suitability analysis for geo-environmental factors is calculated in visual basic and integrated within the GIS Model Builder through linking of the two tables, considering matching in ID. The previously produced two layers for erosion (Dabral et al., 2008; Fistikoglu and Harmancioglu, 2002; Lufafa et al., 2003) and flood (Fernandez and Lutz, 2010; Meyer et al., 2009) are reclassified into five classes to produce suitability input layers. The system is designed to achieve the suitability result directly with one click. It operates specific analysis through ten different steps. Using the output tables from the Visual Basic program, the system links the suitability results to the soil and slope shape file of the same area by area index.

One script file is written in Python language to make one important step in the analysis (i.e. copy all of the parcels features to one shape file). The system operates on five layers, which are soil, flood, dry, erosion and the slope of land. Soil and slope layers are features, while the others are in raster images. The first step is to assign the suitability results, obtained by the Visual Basic system, to the soil and the slope layer using the area index code. "Join Field" is a tool used to make this step two times; one for the soil layer and another for the slope layer.

The second step in the system is to convert the joined soil and slope features to raster image to make all of the layers in raster format and allow the system to weight the overlaying layers using weights obtained by Multi Criteria Analysis. A dynamic program for the calculation of the eigenvalues and eigenvectors of a weighting matrix is provided. Weighted overlay is a technique for applying a common scale of values to diverse and dissimilar inputs to create an integrated analysis (Malczewski, 1996, 2004). The resulting layer is the suitability raster calculated from the five basic layers.

The next two steps classify the weighted overlaid raster into five classes based on suitability values, and then convert the classified raster into polygon feature layers. Each polygon has a grid code that equals to a suitability value. The suitability value refers to one of the five alternatives, 1, 2, 3, 4, and 5, where the value 1 is the most suitable and 5 is the least suitable.

The resulting polygon feature contains many scattered polygons assigned with suitability values, but without information on the area code and other land data. This polygon feature is split to the original land parcels using a split tool. The polygon features at this step are split to parcels, and the results are represented in shape files. Each file is one parcel. The parcel shape contains some polygons with different suitability values. To assemble the parcel shape files into one feature shape, a special Python script copies all of the parcels features into one shape file.

The final step in the model is to add the parcel information to each polygon within the parcel boundary. A spatial join tool is used to append parcels' information to parcel location in reference to the soil shape. The Model Builder developed for land suitability evaluation developed for a study area is presented in Fig. 9. The land suitability model is designed to accomplish a couple of spatial analyses, from the scratch layers up to the final suitability evaluation layer.

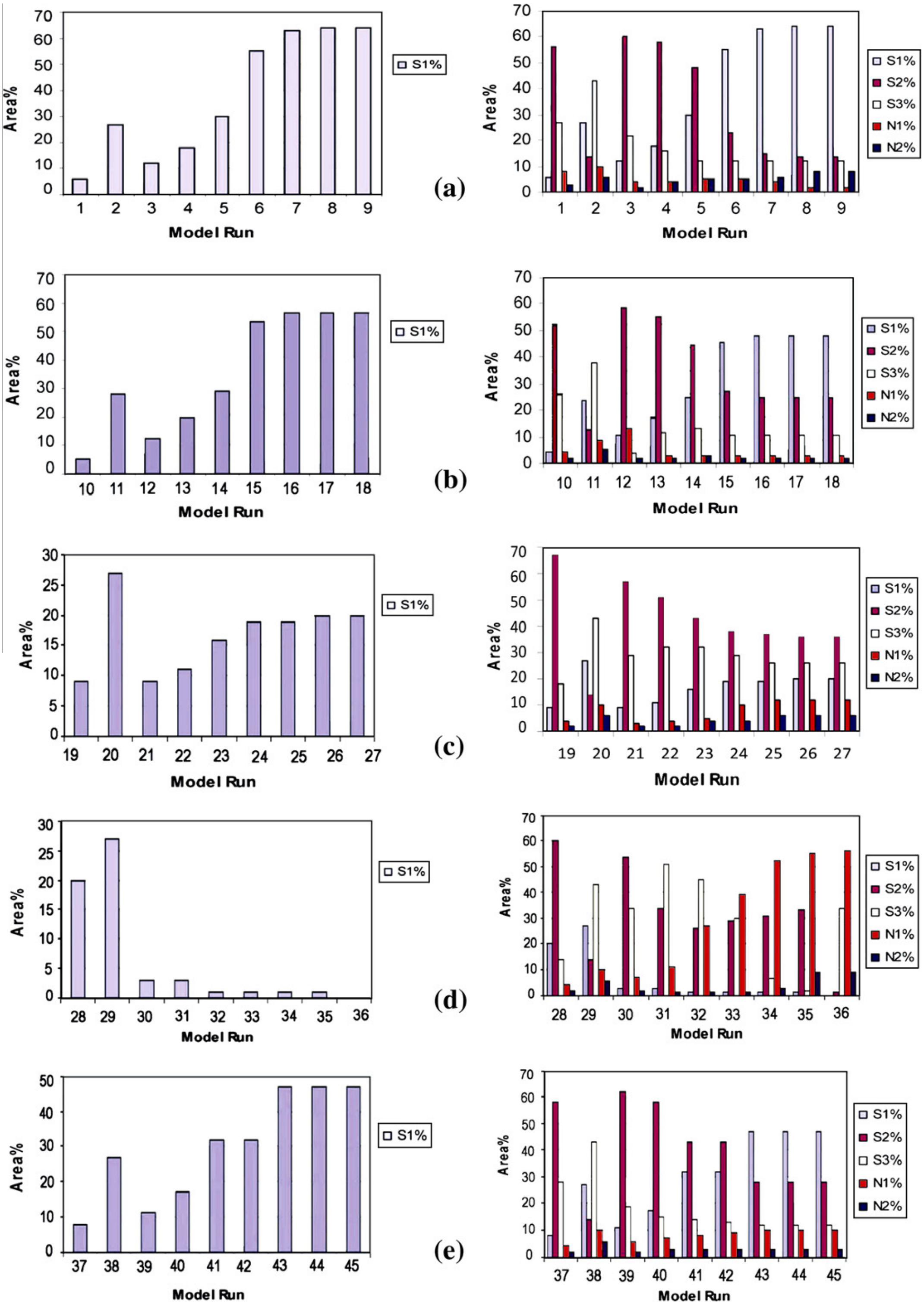

Fig. 12. The area of land suitability classes for: (a) soil, (b) slope, (c) climate, (d) flood, and (e) erosion scenario.

The integration of the information with the Visual Basic evaluation system is executed automatically through the model.

5. Sensitivity analysis

The general purpose of sensitivity analysis for the suitability criteria is to find out the influence of different criteria weights on the spatial pattern of the suitability classification. This is useful in situations where uncertainties exist in the definition of the importance of different criteria (Chen et al., 2009; Delgado and Sendra, 2004; Store and Kangas, 2001). Sensitivity analysis is used to determine the level of importance of each criterion and therefore attempts to reduce the subjectivity of weights (Feick and Hall, 2004; Field et al., 2010). S, the suitability classification for major crops is defined on R^n, where n is the number of dimensional spaces involved, i.e. it is a function of n variables:

Table 4
Weight for each parameter based on variations of function.

Criteria	*V*	Weight
Soil	88	0.275
Slope	80	0.25
Climate	47	0.146
Flood	34	0.106
Erosion	71	0.221
Total	320	1

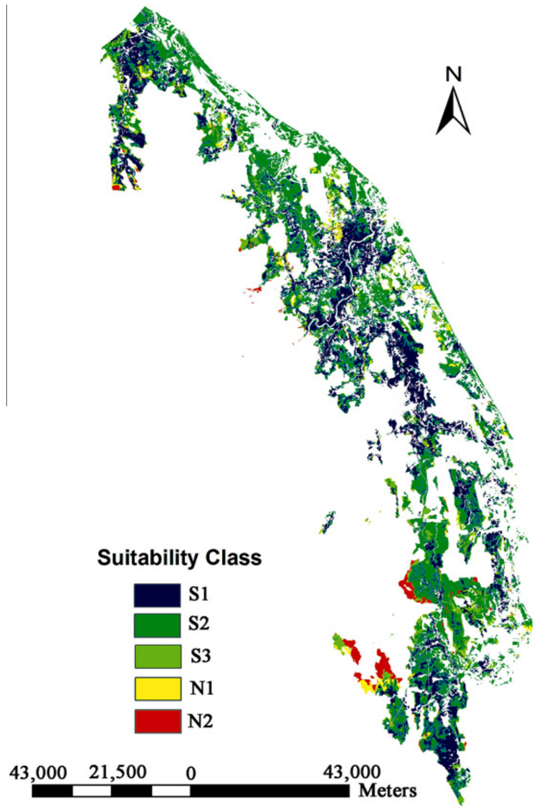

Fig. 13. Mango suitability classes.

Table 5
Comparison between the current classification and Wong classification.

Soil type	Current classification	Wong classification
BGR	*S2*	*S2*
BLN	*S2, N1*	*N1*
CPA	*S2*	*S1*
KBG	*S2, S3, N1*	*S3*
KUH	*N2*	*N2*
KYG	*S2*	*S2*
PBG	*N1*	*N1*
PBR	*S2, N1, S3*	*S2*
TBK	*S2*	*S2*
TYG	*S2*	*S2*

$$S = S(C1, C2, \dots, Cn) \tag{1}$$

where $C1$, $C2, \dots, Cn$ are the criteria (e.g. soil, slope, climate, flood, erosion, etc.).

The arguments of this function satisfy the condition:

$$R^5 = W_{1C1} + W_{2C2} + W_{3C3} + W_{4C4} + W_{5C5} = S(S1, S2, S3, S4, S5) \tag{2}$$

$$W_1 + W_2 + W_3 + \dots + W_n = 1 \tag{3}$$

where W is the level of importance (i.e. the influence of the criteria in the dimensional space). n is number of criteria; The function S takes values from 0 till 100 [$S1$: Highly Suitable; $S2$: Moderately Suitable; $S3$: Marginally Suitable; $S4$: Marginally Not Suitable; $S5$: Permanently Not Suitable].

Different scenarios will be applied for each criterion. The aim of each scenario is to identify criteria that are especially sensitive to weight changes and visualize the spatial change dynamics. Hence the level of importance for each criterion can be determined. To achieve this purpose, different weighting schemes were applied for the suitability criteria. If the first scenario is to test the sensitivity of C_1 weights on the output W_1 would refer to weight of C_1, then;

$$W_2 = W_3 = W_n = (100 - W_1)/n - 1 \tag{4}$$

In the basic computation, an equal weight was given to the Cn-1 criteria. The $[n \times (n-1) \times 2]$ weighting schemes are constructed and run using the model's implementation in ArcGIS 9.2®.

6. Variations of function

The influence of each criterion can be visualized in the spatial pattern for each scenario and the variations of function are used to test the stability of the result. The study aims to give a clear indicator for the best area for the major crops, and hence consideration will be given to the highly suitable class ($S1$ class). The equation below is used to calculate the variations in function for $S1$.

$$V_j = \sum |f(x_{i+1}) - f(x_i)| \tag{5}$$

where V is the Variation of function and j is the Number of scenario.

Example for calculate the weight of criteria (e.g. soil); after determining the variance of each criterion ($V_{1\text{soil}} = |(27-6)| + |(12-27)| + |(18-12)| + |(30-18)| + |(55-30)| + |(63-55)| + |(64-63)| + |(64-64)| = 88$; refer to data in Table 2), the weight for each criteria based on variations of function were determined by divided variance of each criteria on the total variance.

7. Combining land suitability ratings and determining final suitability

The overall suitability map was produced based on five layers of data: soil, slope, climate, flood and erosion. The weighted overlay process was used, and the weights generated from sensitivity analysis and variation of function, were applied to different thematic layers.

8. Application test

System implementation is an essential step to ensure that the system properly implements the required specifications. The application of the ALSE tool is illustrated using spatial data from a study in which multi-criteria land suitability assessment on a 12,995 km^2 scale was performed to identify the suitability of the agricultural land in Terengganu, West Malaysia (03°55′37″–05°51′06″N, 102°21′11″–103°31′28″E; Fig. 10). Agriculture remains one of the important activities with mango, banana, papaya, citrus, and guava as the main crops in production.

Selection of evaluation criteria for mango was based on the project objective, spatial scale, and in particular data availability. Five criteria and 30 alternatives were chosen including soil (nutrient availability, nutrient retention, rooting conditions, soil workability, oxygen soil drainage classes), climate, slope, erosion and flood hazard. List of data sets used in the study is given in Table 2. The results obtained from the ALSE tool developed for mango as a commercial species in the selected study area are presented in Fig. 11.

Fig. 11a shows the results of the endpoint assessment of land suitability for mango based on importance of land conditions and considering the quality of soil characteristics including pH, H_2O, depth to sulfuric horizon, CEC, base saturation, gravel and stones, effective soil depth, texture and structure and soil drainage class. The suitability classes in the map for each land characteristic were produced based on crop requirements. The overall physical suitability of land was taken from the most limiting land quality (LQ rated as the worst). The new suitability value was assigned to each soil type. Ranking method was used (Malczewski, 2004) to classify the soil in raster format. Fig. 11b illustrates the results of the suitability evaluation of mango based on the climatic parameter of dry season months. The result indicates that all of the covered areas within the metrological station points are considered highly suitable for mango based on crop requirement of annual precipitation. Therefore, dry season is deemed as the critical parameter in the current evaluation. The results of topographic parameter on mango cultivation are presented in Fig. 11c. It was clear that the most suitable area lies in the east of Terengganu State, and the suitability decreases towards the southeast direction.

Fig. 11d shows the flood risk map created based on GIS and multi criteria method. The suitable locations for mango cultivation, considering the flood parameter, are those locations of low potential flood risk. The criterion maps were combined by logical operations and criterion values were generated based on ranking method for each evaluation unit. Using pairwise compression the normalized criterion weights were calculated as 0.387, 0.198, 0.14, and 0.275, for annual rainfall, basin slope, soil type and drainage network of the river basin, respectively. The significant findings showed a Consistency Ratio (CR) value of 0.05, which fell much below the threshold value of 0.1, indicating a high level of consistency. Hence, the weights are acceptable (Jankowski, 1995; Marinoni, 2004; Saaty, 2008).

Fig. 11e shows the erosion risk map for mango cultivation in the study area calculated using the Universal Soil Loss Equation (USLE) in GIS to determine the average annual soil loss (Dabral et al., 2008; Fistikoglu and Harmancioglu, 2002). The suitable locations for mango cultivation, considering the erosion parameter, are those locations that exhibit low potential erosion risk. From the map, it was clear that the risky erosion locations are distributed in the southwestern areas where the slope was very steep.

For the purpose of sensitivity analysis, suitability maps for every weighting scheme were created in GIS. The outputs (suitability maps) were compared to assess the influence of each criterion on the overall suitability for mango. Table 3 illustrates the visual assessment of the suitability classes and the percentage area calculation of suitability classes that were conducted to interpret the output of the sensitivity analysis. From the tables, and by comparing the percentage area of the high suitability class ($S1$) for the different weighting schemes, the sensitivity of the suitability criteria was assessed. Fig. 12 shows the area of land suitability classes for the different scenarios.

Increasing the soil weighting had a dramatic effect on the suitability pattern in the study area (Table 3 and Fig. 12a). When the soil weighting was increased from 30% to 80%, the area of high suitability ($S1$) classes increased. The overall suitability classification was changed by the variation in soil weightings. The implication of these findings is that soil factors have to be given suitable weighting to reflect its importance on the suitability of mango in the study area.

Changing the weighting schemes for the slope resulted in change to the suitability outputs (Table 2 and Fig. 12b). Increasing the slope weighting had a dramatic effect on the suitability pattern in the study area. The overall suitability classification was changed by the variation in slope weighting. The change in the suitability pattern indicated sensitivity to the slope in the study area. The sensitivity analysis for climate also revealed that changing the weighting scheme changed the suitability pattern (Table 3 and Fig. 12c). However, the change was not as dramatic as in the cases of soil and slope.

The high suitability class ($S1$) increased from 9% to 27% when the climate weighting was increased from 10% to 20%, respectively. The sensitivity analysis for the flood revealed that there was only a slight change in the highly suitable class when the flood weighting was varied (Table 2 and Fig. 12d). For the erosion criterion, the results indicated that there were minor changes in the highly suitable class, but was less than the changes in the soil and slope criteria (Table 3 and Fig. 12e).

The calculations of weights for each parameter based on the results of variations of function are summarized in Table 4. The outputs of sensitivity analysis for mango indicated how the suitability patterns changed with variations in the weighting scheme (Table 4). For soil and slope criteria, there were significant changes in the highly suitable class when the weightings were changed. For erosion criterion, the results indicated that there were minor changes in the highly suitable class, which was less than the changes in the soil and slope criteria. The sensitivity analysis for the flood and climate revealed that there was only a slight change in the highly suitable class when their weightings were varied.

The overall suitability map for mango was produced based on five layers of data: soil, slope, climate, flood and erosion (Fig. 13). The weighted overlay process was used, and the weights generated from sensitivity analysis and variation of function was applied to the different layers. The results of the analysis indicated that 31% of the study area was identified as most suitable for mango (Class 1), 55% of the area as moderately suitable area (Class 2), 9% percent as marginally suitable (Class 3) and the remaining portion (5%) was not suitable for mango (Class 4 and Class 5).

9. Validation and verification

A sample area within the study area was selected for model validation and verification. The implantation of the system indicates the suitability and limitation factors for each polygon. It is noted that validation and accuracy of physical land evaluation that use a qualitative method is not possible (FAO, 1976; Rossiter, 1996). One of the methods that could be used for validation is to investigate if the selected crops were already produced in the region and then a subjective comparison could be made. If the condition exists in a region, it reflects the results in a logical and acceptable manner, and then the findings become more viable. Local experts' judgments and knowledge were consulted in the current study to validate the results of the model. There were 30 respondents in total with 20 managers and 10 officials from other fields. The model outputs for the selected crops were viewed by the local experts. The experts' opinions (DOA officials), which were based on experience in the local context, revealed that the results of the model are in agreement with what is expected of the land in the study area. The officials were satisfied with the results and they keyed in the data into the system successfully. Appendix (F) is a collection of some photographs taken during the validation was held. The classification system used by the DOA in the Ministry of Agriculture is known as the Wong classification. For further validation, Table 5 was constructed to compare between the results of the sample area based on 10 soil series type with Wong (soil–crop suitability classification for Peninsular Malaysia). From the table, it was noticed that the results were in agreement with Wong classification in term of soil suitability. The disagreement appeared when the whole factors were considered, including environmental factors. In the current classification produced by this study the same series can occur at different locations, and each location has different characteristics in terms of slope, climate and other environmental factors; which makes the results appear as *S*2 in one location and *S*3 in other location of the same soil series. This makes the current classification generally accepted since it evaluates the land by considering physical and environmental factors. Currently, the Ministry of Agriculture has started to implement this classification system in other states, and extensive training on using the system was provided during 2009–2010 to use the new classification.

10. Conclusions

The integrative aspect of ALSE was very important. It demonstrates the enormous capabilities that the end user has when more than one technology is interconnected in GIS. Thus, ALSE is a powerful system, as it provided many useful features in a single system with multidimensional fields for use in land evaluation. In general, the goal was to reach some conclusions on the quality of land, select an appropriate cultivation technique, decide on crop rotation, and plan for the management of the land. The ALSE system is based on knowledge of land use and management expertise, and uses intelligent techniques to simulate new knowledge.

The objectives and goals of this study were achieved with the aid of computer modeling, GIS, and Multi Criteria Analysis. The work highlights the need to understand land capacity to support appropriate crop cultivation. It provides optimum suitability classification considering a wide range of multi-disciplinary alternatives. It also identifies land limitations and offers alternative land management measures. The development of ALSE allows for standardizing a framework for characterizing geo-environmental conditions (e.g. climate, soil, erosion, flood and topographic) relevant for production of major crops (e.g. mango, banana, papaya, citrus, and guava). The ALSE identifies crop-specific conditions and systematically computes the spatial and temporal data with maximum potential. It would help land planners to make complex decisions within a short period taking into account sustainability. The integration of GIS and Multi Criteria enables the management of the criterion data, production of criterion layers, and calculation of attributes by means of spatial analysis, combining of decision criteria by modeling, and conducting sensitivity analyses and production of maps needed for land evaluation. Sensitivity analysis and variation of functions provided further confidence in the ALSE, and indicated priority areas for refinement. An important feature of ALSE is the capability of the system to be upgraded for each crop under all weather condition.

References

Ceballos, S.A., Blanco, J.L., 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.

Chen, Y., Yu, J., Shahbaz, K., Xevi, E., 2009. A GIS-Based Sensitivity Analysis of Multi-Criteria Weights, 18th World IMACS/MODSIM Congress. Cairns, Australia.

Chuong, H.V., 2008. Multicriteria land suitabilty evaluation for crops using GIS at community level in central Vietnam. In: International Symposium on Geoinformatics for Spatial Infrastructure Development in Earth and Allied Scie, Vietnam.

Chuong, H.V., 2007. Multi-criteria land suitability evaluation for selected fruit crops in Hilly region of central Vietnam. Humboldt University, Berlin, Germany.

Dabral, P.P., Baithuri, N., Pandey, A., 2008. Soil erosion assessment in a hilly catchment of north eastern India using USLE, GIS and Remote sensing. Water Resources Management 22, 1783–1798.

Davidson, D.A., 1992. The evaluation of land resources. Longman Group UK Ltd., London.

Delgado, M.G.m., Sendra, J.B., 2004. Sensitivity analysis in multicriteria spatial decision-making: a review. Human and Ecological Risk Assessment: An International Journal 10, 1173–1187.

Elsheik, A.R., Ahmad, N., Shariff, A., Balasundra, S., Yahaya, S., 2010. An agricultural investment map based on geographic information system and multi-criteria method. Journal of Applied Sciences 10, 1596–1602.

FAO, 1976. A framework for land evaluation. Food and Agriculture Organization of the United Nations, Soils Bulletin 32. FAO, Rome.

FAO, 1983. Guidelines: land evaluation for rainfed agriculture. Food and Agriculture Organization of the United Nations, Soils Bulletin 52. Rome, Italy.

FAO, 2007. Land Evaluation Towards a Revised Framework. Food and Agriculture Organization of the United Nations, Rome, Italy.

Feick, R., Hall, B., 2004. A method for examining the spatial dimension of multi-criteria weight sensitivity. International Journal of Geographical Information Science 18, 815–840.

Fernandez, D.S., Lutz, M.A., 2010. Urban flood hazard zoning in Tucumán Province, Argentina, using GIS and multicriteria decision analysis. Engineering Geology 111, 90–98.

Field, P., Harvey, K., Strassberg, M., 2010. Integrating mediation in land use decision making Lincoln Institute of Land Policy. Land Lines.

Fistikoglu, O., Harmancioglu, N., 2002. Integration of GIS with USLE in assessment of soil erosion. Water Resources Management 16, 447–467.

He, Y., Yao, Y., Chen, Y., Ongaro, L., 2011. Regional Land Suitability Assessment for Tree Crops Using Remote Sensing and GIS. Computer Distributed Control and Intelligent Environmental Monitoring (CDCIEM) IEEE, Changsha, pp. 354–363.

Hoobler, B.M., Vance, G.F., Hamerlinck, J.D., Munn, L.C., Hayward, J.A., 2003. Applications of land evaluation and site assessment (LESA) and a geographical information system in East Part Couny, Wyoming. Journal of Soil and Water Conservation 58, 105–112.

Ikisan, 2003. Mango Soil and Climate. <http://www.ikisan.com/crop%20specific/eng/links/ap_mangoSoils%20And%20Climate.shtml> (Retrieved March, 2003).

Jankowski, P., 1995. Integrating geographical information systems and multiple criteria decision making methods. International Journal of Geographic Information System 9, 251–273.

Jayasinghe, P.K.S., Machida, T., 2008. Web-based GIS online consulting system with crop land suitability identification. Agriculture Information Research 17, 13–19.

Johnson, A., Cramb, R., 1991. Development of a simulation based land evaluation system using crop modelling, expert systems and risk analysis. Soil Use and Management 7, 239–246.

Kalogirou, S., 2002. Expert systems and GIS: an application of land suitability evaluation. Computers, Environment and Urban Systems 26, 89–120.

Lee, T.M., Yeh, H.C., 2009. Applying remote sensing techniques to monitor shifting wetland vegetation: a case study of Danshui River estuary mangrove communities, Taiwan. Ecological Engineering 35, 487–496.

Lufafa, A., Tenywa, M.M., Isabirye, M., Majaliwa, M.J.G., Woomer, P.L., 2003. Prediction of soil erosion in a Lake Victoria basin catchment using a GIS-based Universal Soil Loss model. Agricultural Systems 76, 883–894.

Mahmoud, M., Rafeh, M., Rafea, A., 1997. LIMEX: An Integrated Multimedia Expert System for Lime Management. 5th International conference on artificial intelligence applications, Egyptian Computer Society (EGS), Cairo, Egypt, 27 February - 3 March, 1997.

Malczewski, J., 1996. A GIS-based approach to multiple criteria group decision making. International Journal of Geographical Information Systems 10, 955–971.

Malczewski, J., 2004. GIS-based land-use suitability analysis: a critical overview. Progress in Planning 62, 3–65.

Marinoni, O., 2004. Implementation of the analytical hierarchy process with VBA in ArcGIS. Computers and Geosciences 30, 637–646.

Martin, D., Saha, S.K., 2009. Land evaluation by integrating remote sensing and GIS for cropping system analysis in a watershed. Current Science 96, 1.

Mendas, A., Delali, A., 2012. Integration of MultiCriteria Decision Analysis in GIS to develop land suitability for agriculture: application to durum wheat cultivation in the region of Mleta in Algeria. Computers and Electronics in Agriculture 83, 117–126.

Meyer, V., Scheuer, S., Haase, D., 2009. A multicriteria approach for flood risk mapping exemplified at the Mulde river, Germany. Natural Hazards 48, 17–39.

Mu, Y., 2006. Developing a Suitability Index for Residential Land Use: A Case Study in Dianchi Drainage Area. University of Waterloo, Canada.

Nwer, B.A.B., 2006. The Application of Land Evaluation Technique in the North-East of Libya. Faculty of Environment. Cranfield University, Silsoe.

Pan, G., Pan, J., 2012. Research in crop land suitability analysis based on GIS. Computer and Computing Technologies in Agriculture 365, 314–325.

Prakash, T.N., 2003. Land Suitability Analysis for Agricultural Crops: A Fuzzy Multicriteria Decision Making Approach, Science in Geoinformatics. ITC, Netherlands, pp. 6–13.

Rosa, D.D.l., Moreno, J.A., Garcia, L.V., Almorza, J., 1992. MicroLEIS: a microcomputer based Mediterranean land evaluation information system. Soil Use and Management 8, 89–96.

Rosa, D.D.L., Mayol, F., Diaz-Pereira, E., Fernandez, M., 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.

Rosa, D.D.L., Anaya-Romero, M., Diaz-Pereira, E., Heredia, N., 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 6, 1055–1065.

Rossiter, D.G., 1990. ALES: a framework for land evaluation using a microcomputer. Soil Use & Management 6, 7–20.

Rossiter, D.G., 1996. A theoretical framework for land evaluation. Geoderma 72, 165–190.

Rossiter, D.G., Wambeke, A.R.V., 1997. Automated Land Evaluation System ALES Version 4.65 User's Manual. Cornell University.

Saaty, T.L., 2008. Decision making with the analytic hierarchy process. International Journal of Services Sciences 1, 83–98.

Sonneveld, M.P.W., Hack-ten Broeke, M.J.D., van Diepen, C.A., Boogaard, H.L., 2010. Thirty years of systematic land evaluation in the Netherlands. Geoderma 156, 84–92.

Store, R., Kangas, J., 2001. Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitat suitability modelling. Landscape and Urban Planning 55, 79–93.

Sys, C., Ranst, E.V., Debaveye, J., Beernaert, F., 1993. Land evaluation part III crop requirements. Agricultural publications General Administration for Development Cooperation, Belguim.

Sys, C., Riquier, J., 1980. Ratings of FAO/UNESCO Soil Units for Specific Crop Production. Food and Agriculture Organisation of the United Nation, Rome, Italy.

Tsoumakas, G., Vlahavas, I., 1999. ISLE: an intelligent system for land evaluation. Proceedings ACAI 99, 26–32.

Wood, S.R., Dent, F.J., 1983. LECS. A land evaluation computer system methodology. Bogor: Ministry of Agriculture/PNUD/FAO, Centre for Soil Research, Indonesia.

Yialouris, C., Passam, H., Sideridis, A., 1997. VEGES: a multilingual expert system for the diagnosis of pests, diseases and nutritional disorders of six greenhouse vegetables. Computers and Electronics in Agriculture 19, 55–67.

Zonneveld, I.S., 1989. The land unit – a fundamental concept in landscape ecology, and its applications. Landscape Ecology 3, 67–86.