

Application of GIS in Land-Use Planning: A Case Study in the Coastal Mekong Delta of Vietnam

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Abstract

This paper presents the applications of Geographic Information System (GIS) in three different Land Use Planning (LUP) approaches: The participatory LUP (PLUP) which strongly considers the local people perceptions for land utilizations, the guidelines for LUP by FAO enhanced with multi-criteria evaluation (FAO-MCE), and the LUP and analysis system (LUPAS) using interactive multiple-goal linear programming. GIS plays an important role in the application of these approaches. In PLUP, GIS help to integrate the acquired spatial and attribute data from farmer discussions, and to analyzes the changes not only in biophysical, land cover but also in farmers' perception on land utilizations. In FAO-MCE, GIS was used to combine biophysical and socio-economic characteristics and to perform multi-criteria evaluation. In LUPAS, an optimization model was developed. The model is linked with a GIS for data input and results presentation. The land use planners can use the model to explore different land use scenarios with different objectives and constraints, both biophysically and socio-economically.

1. Introduction

For a sustainable land use plan, nowadays, land use planning (LUP) approach requires more and more data integration, multi-disciplinary and complex analysis, and needs faster or more precise information for the participants in the LUP approaches. Certainly, Geographic Information System (GIS), which has strong capacity in data integration and analysis and visualization, becomes the main tool to support LUP approaches. The application of GIS in LUP is well documented (such as Alshuwaikhat and Nassef, 1996, Ball, 2002, Bojorquez-Tapia et al., 2001, Brazier and Greenwood, 1998, Cromley and Hanink, 1999, Fedra, 1995, Hoobler et al., 2003, Malczewski, 2004 and Trung et al., 2006). This paper presents the application of GIS in three different LUP approaches in the coastal area of the Mekong Delta, Vietnam. The participatory LUP approach (PLUP) which strongly considers the local people perceptions for land utilizations, the guidelines for LUP by FAO enhanced with multi-criteria evaluation (FAO-MCE), and the land-use planning and analysis system (LUPAS) is using interactive multiple-goal linear programming. The study was carried out in two villages south of National Road 1A: Vinh My A and Vinh Thinh. They encompass an area of approximately 9,800 ha. The study area has contrasting degrees of saltwater intrusion, and

strongly contrasting land use systems e.g. rice, vegetables, shrimp, salt, mangrove forest. The main soil related problems encountered are acidity and salinity. The main water related problems to agriculture are salinity, poor drainage and lack of fresh water. The fresh water supply of the study area completely depends on rainwater and deep groundwater. The rainy season is relatively short. The other main problem is the erratic rainfall distribution near the coast, and surface water pollution near the national road 1A (Tri et al., 2002).

2. Application of GIS in PLUP

A modified participatory rural appraisal (PRA) was used based on the toolbox designed by Ticheler et al., (2002) and on experiences from an earlier study in the same area by Feitsma et al., (2002). In this approach, groups of about 10 key informants (experienced farmers) were formed in each hamlet. In total 26 of these groups were interviewed. The PLUP was repeated twice, in 2002 and 2003. To have a thorough set of perspectives, agriculture farmers and aquaculture farmers were grouped separately. In each group, farmers participated in reviewing the hamlet's land-use history, described their land conditions and production systems, explained the reasons for land-use change, defined the socioeconomic factors that affect the change

decisions, drew a sketch map showing the land use and land constraints of their hamlets, and proposed the preferred future land use. Transect walks were also conducted to verify the farmers' resource map. During the transect walk, farmers were asked for information on the land and the land-use types they practiced. GIS was used for combining maps of hamlets and for analyzing the land use change, realization of preference, preference change and preference conflicts. The GIS operations that carried out in this approach are described in Figure 1. The hamlets' resource maps drawn by two groups of farmers were aggregated into village maps. All characteristics of the hamlets are also input into a

GIS database. In the database there are three map layers for each year: (i) a land unit layer with data on biophysical and socio-economic conditions; (ii) a land use layer which describes land use activities of the area in the year and; (iii) a farmers' preference layer. Overlaying land use maps of two year 2002 and 2003, we obtain the land use change in the study area. Similarly, overlaying farmers' preference land use we can figure the places where farmers change their preference. Combine this information with the biophysical and socio-economics condition of the study area we can find the reasons for these preference changes.

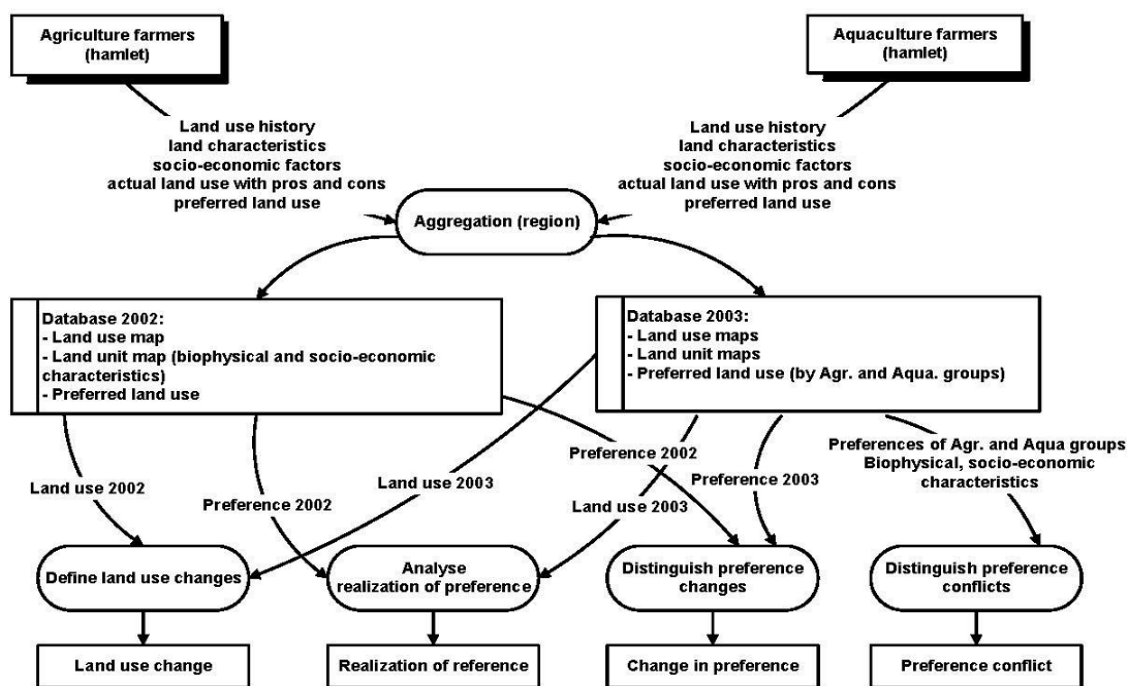


Figure 1: Application of GIS in participation land use planning (Trung et al., 2006)

To realize the conflicts in land use preference of two farmer groups (agriculture and aquaculture), the preference maps of the two groups were overlaid. The results of this analysis show the (potentially) conflict locations in the study area. This information is essential for a feasible and sustainable land use plan. The results show that land use in the study area has been very dynamic. Within one year more than half of the study area changed, agriculture was mostly replaced by aquaculture. Only half of the farmers' preferences were realized, mostly in aquaculture. The farmers' preference changed largely from agriculture to a mixture of agriculture and aquaculture, or to aquaculture alone. There was a difference in preferences between the agriculture farmers and the aquaculture farmers, caused by

differences in their biophysical and economic considerations. The farmers' land use plan is shown in Figure 2. The main limitation of this approach is the spatial accuracy of the maps drawn by farmers. However, the accuracy of the land units' boundary can be improved by transect walks together with individual interviews. Using cadastral maps can also help to increase the spatial accuracy.

3. Application of GIS in FAO-MCE

In this land use planning approach, GIS was used in all steps of the approach (Figure 3). First it was applied in land evaluation. Soil, water, terrain, and weather maps are overlaid to have land-mapping units (LMU). An LMU is a tract of land that biophysically relatively homogeneous at the scale

level concerned. Then, land use types' (LUT) requirements are compared with the LMU characteristics to have the LUT suitability. Based on the LUT suitability, the biophysical score of each LUT in each LMU is assigned. In the socio-economic assessment, LUTs' socio-economic indicators were evaluated for each LMU. The socio-economic indicators applied in this study were: gross income, investment costs, variable costs, total costs, benefit/cost ratio, labor days, accessibility,

and financial risk. Values of socio-economic indicators are called socio-economic scores. For accessibility analysis, a GIS model called the "Accessibility Analyst" developed by the CIAT; the Institute for Tropical Agriculture was used. It calculates the travel time from any given geographical location to its nearest target location. In this study these locations were the local markets where farmers could sell their products.

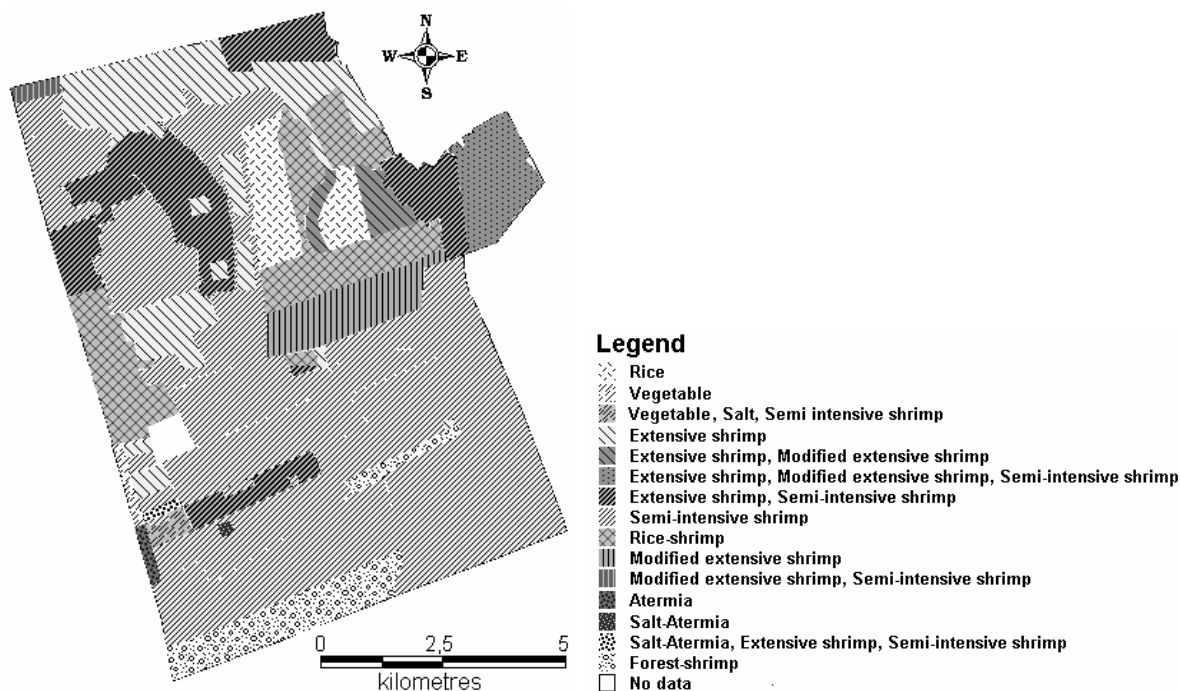


Figure 2: Farmers' land use plan

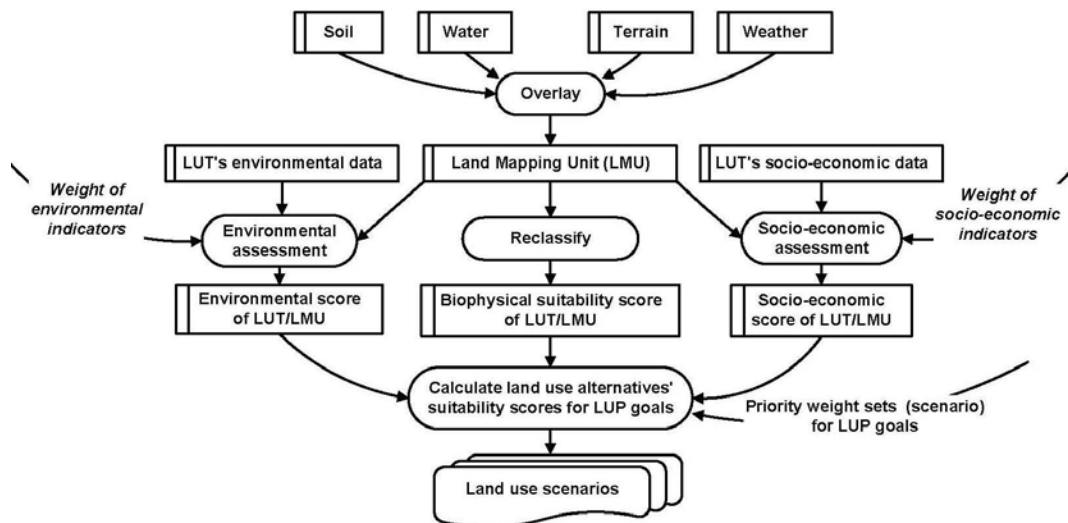


Figure 3: Using GIS in Multi Criteria Evaluation for land use planning

In the environmental assessment, the LUTs' impacts on the surrounding environment were estimated on the basis of the impact of six environmental indicators on the land. The six indicators were sedimentation, salinization, groundwater use, water pollution with organic wastes and nutrients, use of fertilizer and chemicals and (irreversible) terrain adjustments. The degree of environmental impact of each indicator is determined from the results of the farmer interviews, expert knowledge, and literature research. Values of environmental indicators are called environmental scores. The terrain adjustments were only taken into account for semi-intensive shrimp, modified extensive shrimp, and salt. The terrain adjustments needed for the development of these LUTs are the most severe. To select the most suitable LUT for each LU, the weighted linear combination (WLC) formula (Voogd, 1983) is used: In which S is the suitability score of a land use alternative for a defined LUP goal. This score is based on the standardized criterion score x and the priority weight W assigned to that criterion on basis of the chosen LUP goal. The alternative i will be judged better than alternative j if $S_i > S_j$. A land use scenario can be defined on the basis of one or more development targets. When multiple development targets are used to define a land use scenario, priority weights are assigned to the development targets (e.g. 25% weight for economic development, 75% weight for environmental conservation), and then the WLC can be applied for the alternative LUTs. For a given set of priority weights, the best alternative LUT for an LMU is the one with the highest final evaluation score. In this

study three LUP goals were considered: economic development, social security, and environmental sustainability. For each goal, criteria were chosen for analysis. Income and benefit/cost ratio were the main criteria for economic development, with income slightly more important. Four criteria were important for social security: financial risk, labor requirement, b/c ratio and environmental impact with a decreasing importance in this order. The environmental impact was used as the sole criterion for environmental sustainability. Table 1 presents the priority weighting sets that were given to the LUP goals in this study. The second and third scenarios show the results when the accent is placed on social security. They seem the same but the difference is that the second has an emphasis on job creation (high weight for Labor Day criterion) and the third has its accent on minimizing financial risk (high weight for financial risk criterion). Figure 4 presents two rather contrasting land allocation maps which resulted from scenario 5 (same priority for all goals) and scenario 6 (higher priority for economic development). The results of scenario analysis show that when a high priority was given to economic development, most of the LMUs were assigned to semi-intensive shrimp. When social security has a high priority, most land is assigned to grow rice-vegetable or single rice. When environmental sustainability has a high priority, most land is assigned for single rice. When all targets have the same priority, single rice is the main LUT. Forest-shrimp is mainly advised near the coast, rice-vegetable and rice-shrimp in the high land and near canals.

Table 1: Priority weight sets applied to the LUP goals.

	Economic development	Social security	Environmental sustainability
Scenario 1	1.0	0	0
Scenario 2	0	1.0	0
Scenario 3	0	1.0	0
Scenario 4	0.25	0	0.75
Scenario 5	0.33	0.33	0.33
Scenario 6	0.75	0.25	0
Scenario 7	0.25	0.75	0
Scenario 8	0.60	0.20	0.20

4. Application of GIS in LUPAS

The LUPAS methodology was developed under the Systems Research Network for Eco-regional Land Use Planning in Tropical Asia (SysNet) project (1996-2000). The SysNet is a systems research network in South and South-east Asia, established to develop and evaluate methodologies for enhancing

strategic land use policies. LUPAS uses the land unit (LU) as the calculation unit. LUs are obtained by the overlaying of the biophysical land mapping unit and the administration unit. The biophysical suitability of LUTs was evaluated for each LU. The socio-economic data are the input and output of LUTs in the condition of LU.

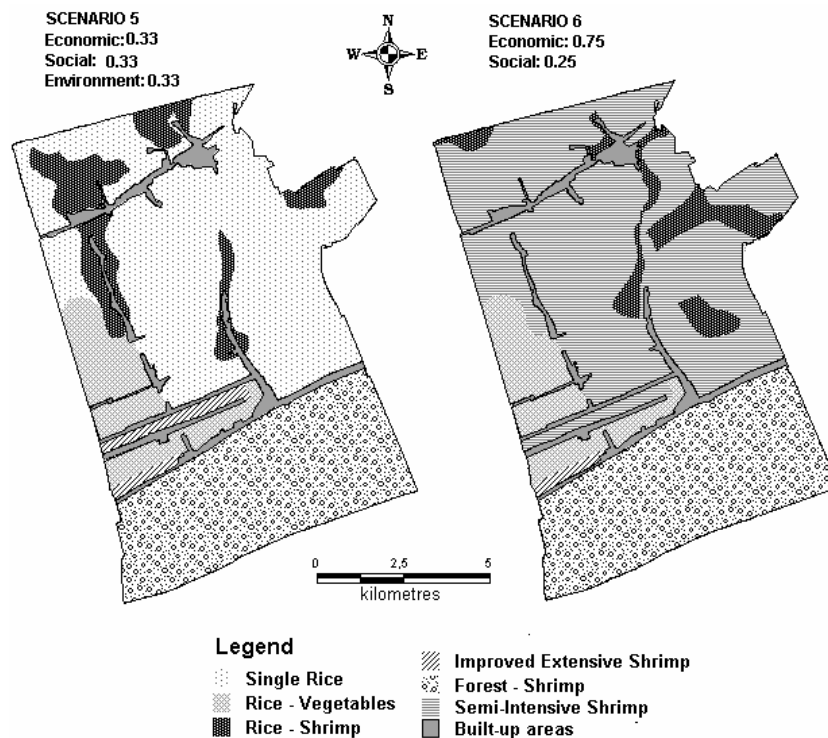


Figure 4: Land use scenario 5, same priority for all development targets, and scenario 6, more priority for economic development (Kempen, 2004)

The inputs are total input cost, water quality and quantity, labor requirement, capital, and biocides. The outputs are revenue, yield, crop residues, water table change, and biocide residues of promising LUTs. These data are exported to text files that are understood by the optimization model. The optimization models run different scenarios of resources limitation or production targets and derives the corresponding land use allocation scenarios (in text format). These files are then imported to GIS for mapping (Figure 5). In the case study, GAMS software (GAMS Development Corporation, www.gams.com) and MapInfo was used to develop the model. The model includes several modules for data input, and optimization of scenarios. Besides, a data transformation tool was built to integrate the model with GIS. In the case study, two scenarios on technical level (present technical level and improved technical level) were run. The combinations of objective function with sets of constraints and/or goal restrictions constitute a total of 16 sub-scenarios. The description of sub-scenarios is presented in Table 2. Sub-scenario 1 represents the most favorable conditions, i.e. when only land constraints occur. This is the ideal

condition, hard to achieve in reality. However, it can be used to evaluate the potential total income from agriculture and aquaculture at the actual biophysical conditions. Increases in resource constraints and goal restrictions are meant to figure out which constraints and goal restrictions most affect the overall goal, so that the trade-off between the goals can be analyzed for the more feasible and sustainable land use plan. Figure 6 presents the model results of the sub-scenario 14. In this sub-scenario all constraints are taken into account, the government's goals of rice, vegetable, salt and forest are considered, and all farmers was assumed to apply the present technical level. The scenario analysis shows that for maximizing the total income of the study area, the model assigns a high proportion of land area to shrimp LUTs. A twice-higher income can be achieved by improving cultivation technology to the existing maximum level. Capital and cultivation techniques are the main constraints. Goal restrictions (upper limit of production targets) slightly affect the total income but strongly influence land allocation. Thus, by changing goal restrictions, the risk can be reduced, for example, reducing the shrimp production target.

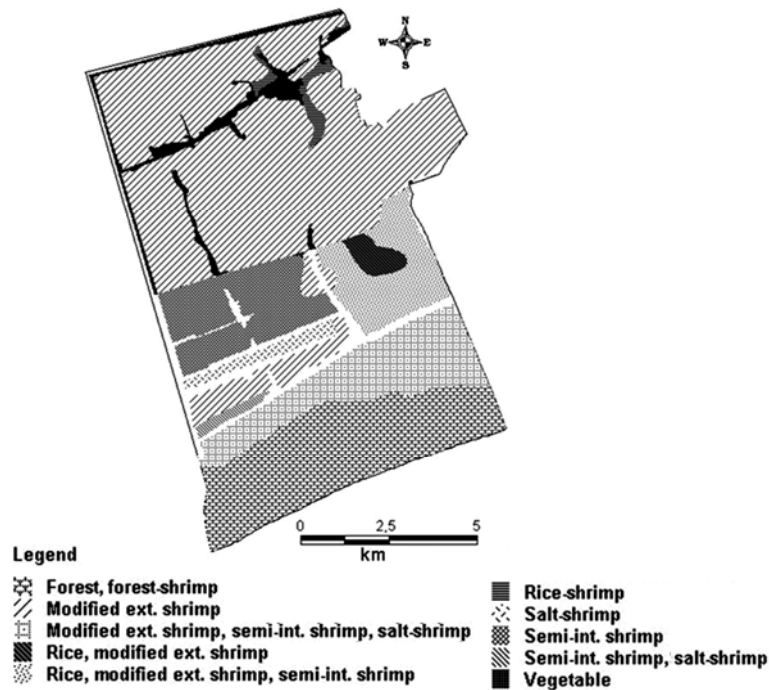


Figure 6: Land allocation map for a scenario with all constraints are taken into account, the government's goals of rice, vegetable, salt and forest are considered, and all farmers was assumed to apply the present technical level (Trung et al., 2006)

5. Conclusion

The study shows the usefulness of GIS in different steps of LUP approaches. In PLUP, GIS helps to integrate the acquired spatial and attribute data from farmer discussions and cross-section walks, and to analyses the changes in not only biophysical, land cover changes but also farmers' perception changes in land utilizations. The conflicts in resources uses, mainly between agriculture and aquaculture, were also mapped and described. In FAO-MCE, a GIS was used to combine biophysical and socio-economic characteristics for land evaluation and multi-criteria evaluation. The approach supports decision makers in trade-off among different stakeholders' interests. In LUPAS, an optimization model was linked with a GIS for data input and results presentation. By scenario analysis, the land use planners can explore different land use scenarios with different objectives and constraints, both biophysically and socio-economically. By scenario analysis, LUPAS can point out the main constraints of the development and the potential of the studied areas if those constraints are overcome. Moreover, LUPAS is used to evaluate whether development goals are feasible and if yes, how the resources should be best used to optimize goal achievements.

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