Journal of Sustainable Development in Africa (Volume 10, No.2, 2008)
ISSN: 1520-5509
Clarion University of Pennsylvania, Clarion, Pennsylvania

GIS-ASSISTED LAND EVALUATION FOR AGRICULTURAL DEVELOPMENT IN MEKONG DELTA, SOUTHERN VIETNAM

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Abstract
A study was conducted in Tri Ton district of Mekong delta in Southern Vietnam to examine the sustainability of the agricultural production system. The major objective of the study was to examine the misuse of land and suggest appropriate land-use alternatives. The data used were both spatial and socioeconomic collected through household survey. Land suitability classification for biophysical suitability and infrastructural suitability was carried out following FAO framework of land evaluation using GIS. Mapping of land misuses indicated that fair amount of current land-use practices does not match the given land quality probably due to the prevalent socioeconomic constraints that influence land use decision-making eventually resulting into lower farm household income. A land-use allocation plan is suggested based on biophysical suitability and socioeconomic preferences with an aim to restore the declining land quality and support livelihoods of the land users with reasonable income from the agriculture.

Introduction

The rapid population growth has caused increased demands for food and other agricultural products, while degradation of land quality, soil erosion and extensive deforestation continue (Fresco, 1992). Increasing unavailability of good agricultural land and ever increasing land degradation have led to cultivation of marginal land and compounded problem of food insufficiency. In South and Southeast Asia, annual economic loss from degradation ranges from under one to seven percent of agricultural gross domestic product (Scherr, 1999). Food security and environmental protection are hence today's key agendas for every developing nation. This calls for judicious planning of land resources to sustain agricultural production to meet ever increasing food demand while achieving environmental protection. Not only land-use planning in developing countries still needs to aim primarily (if not exclusively) for increased agricultural output (Fressco, 1994) but also it has become necessary for sustainable environmental management.

There are number of farming systems related studies are carried out under various natural conditions in the Mekong delta of Vietnam (Xuan and Matsui, 1998) and (Sanh *et al,* 1999). Most of the studies are limited to the classification of the rice-based farming system Ni (1993) and Minh (1995). Among few examples of ecosystem-level studies is the classification of farming systems in whole Mekong delta of Vietnam (Yamada *et al,* 1999). Cropping systems at certain areas are of low productivity and under threats of land quality degradation (VEPA, 2001). Such degradation not only causes reduction of land productivity at sites where it is taking place but also affects downstream sites where floods are present in the wet season while experiencing water shortage in dry season. Besides, under quick changes of environment and market, farmers still get to confront more and more difficulties in production (Ni and Xuan, 1998). Diversification in farming system allows farmer to lowering risk of the market and increase family's income. Risks to farming practices can be reduced if farmer can use the information of soil, hydrology, technology, market demand and household (HH) data to make farming system plan in an appropriate way (Ni and Xuan, 1998). Consequently land-use planning, i.e. what crops should be allocated on what tracts of land by what methods and in which seasons of the year, has become more important today than it has ever been for suitable cropping taken into the account of farmer's priorities and policy objectives with respect to sustainable agricultural development (Lal and Pierce, 1991), i.e. keep balancing the inherent soil resource qualities and crop requirements in an innovative soil and crop management system with emphasis on optimizing resource use and sustaining productivity over a long period in a given environmental, social, and economic context (Farshad, and Zinck, 1993).

This paper aims to identify potential land suitability for agriculture based on not only biophysical but also infrastructural preference in accordance to the framework for land evaluation developed by Food Agriculture Organization of the United Nations (FAO, 1976) using GIS, a decision support system involving the integration of spatially referenced data in a problem solving environment (Conwen, 1988); and simultaneously examine major socioeconomic factors influencing farmer's land-use decision making with respect to enabling optimum cropping for maximizing productivity while reducing environmental impacts.

The Study Area

The study area, Tri Ton district, is situated in the Mekong delta in Southern Vietnam between latitudes 10^0 12' - 10^0 57' and longitudes 104^0 46' -105^0 35' covering 59,556.5 ha. The climate is monsoon tropical semi-equatorial. The average temperature is 27.5 ^{0}C with minimum 26.3 ^{0}C and maximum 28.78 ^{0}C. Two distinct seasons are observed with the annual mean rainfall of 1,442 mm. The wet season lasts from May to November constituting approximately 80 percent of the total rainfall and causing soil erosion in certain uplands[1] while the dry season (December to April) is

[1] None-rice or rice-based upland-crop production system.

characterized by water scarcity for farming. In particular in the lowland[2], farming is frequently vulnerable from flooding each year (Adam, 2003).

The elevation of the study area ranges from under 1 to 700 m above sea level. More than three quarters of the area is plateaus. Thionic Fluvisols, Thionic Gleysols, and Albic Plinthosols are the major soil groups, occupying about 62 percent of the area. Out of the total area irrigated rice was the dominant crop (61.1 percent) (Figure 1). The rest was shared for other crops, such as cassava (2.6 percent), upland crops e.g. watermelon and legumes (7.0 percent). More than three quarters population engaged in agriculture. Despite a low population density (99 inhabitants/ km^2) in the study area compared to the national average (253 inhabitants/ km^2), there is an increasing risk of land quality decline due to inappropriate land uses (Son, 2005).
Majority population has low educational levels (illiterate-14.2; primary school-42.7; and secondary school-30.7 percent) in the area. Large farmers (land holding size > 2 ha) and medium farmers (1 - 2 ha) generally had higher educational attainment than that of small farmers (< 1 ha) in all cases. Similarly average total income of large farmers (about 2,225.7 USD/yr) is about four times higher than that of small farmers (567.6 USD/yr) and half time compared to medium farmers (975 USD/yr). Rice cultivation was a key income source, making up 85 percent of the total HH income while upland-crop production (5.3 percent), animal husbandry (4.9 percent), and off-farm activities (4.9 percent). Large and medium farmers were highly dependant on their own farms with 96 and 78 percent involving agricultural farming practices while for small farmers rice farming constituted 65 percent of the total income, and 45 percent from other sources, such as animal husbandry, off-farm activities, upland-crop production (Son, 2005).

[2] Irrigated rice or irrigated rice based upland-crop production system.

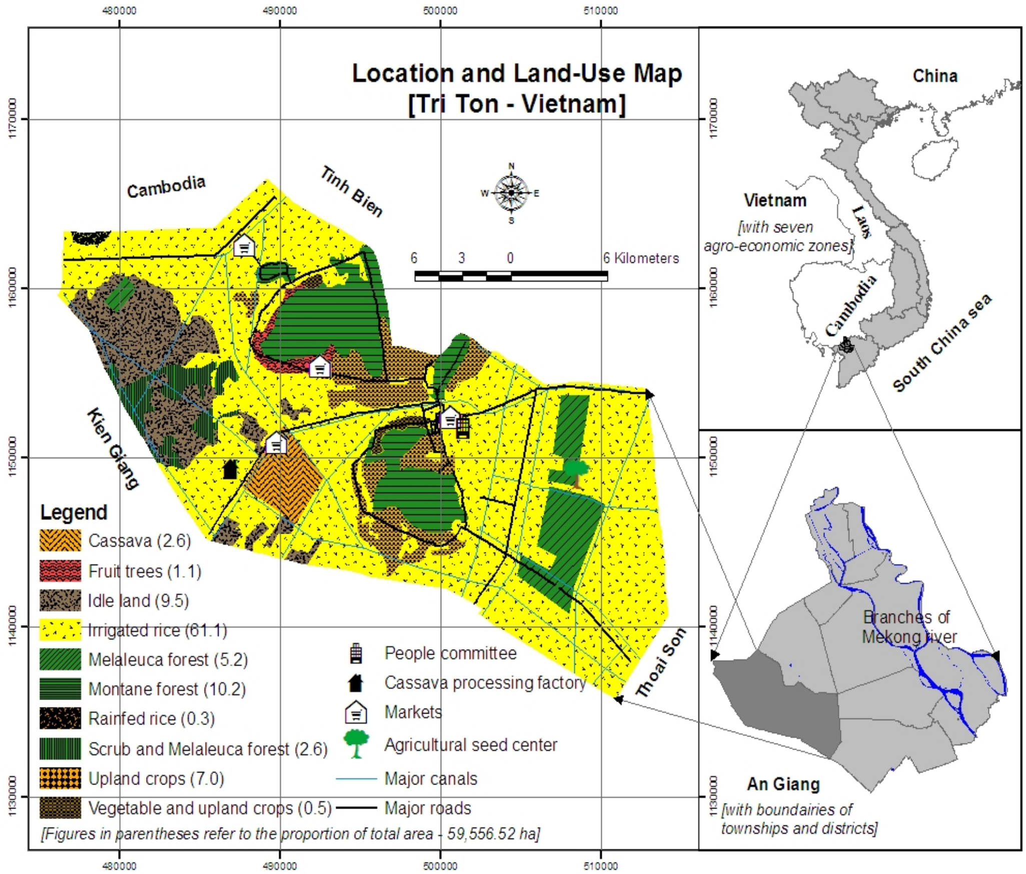

Figure 1. **Location and land use of the study area. (Land use interpreted from Landsat ETM Plus 2003)**

Methodology

Figure 2 presents the research procedure of the study. Basically, the methodology is based on the FAO's framework for land evaluation (FAO, 1976) for land suitability classification.

Data sources

The basic materials used were

- soil map of 2005 (1:65,000 scale) gathered from An Giang University
- climatic data (1998-2000) collected from the meteorological department in An Giang

- topographic map (1:5,000 scale) from the department of natural resources and environment in An Giang
- location of infrastructures recorded used Global Positioning System (GPS)
- land use map visually interpreted from Landsat ETM+ (Enhanced Thematic Mapper Plus) acquired in July 2003 from the U.S. Geological Survey (USGS)
- socioeconomic data gathered by administering a structured questionnaire to 64 sampled households. All the households in lowland and upland were listed and, 32 households were randomly selected from each category for questionnaire survey, and
- other secondary data from published and unpublished agricultural statistics and reports.

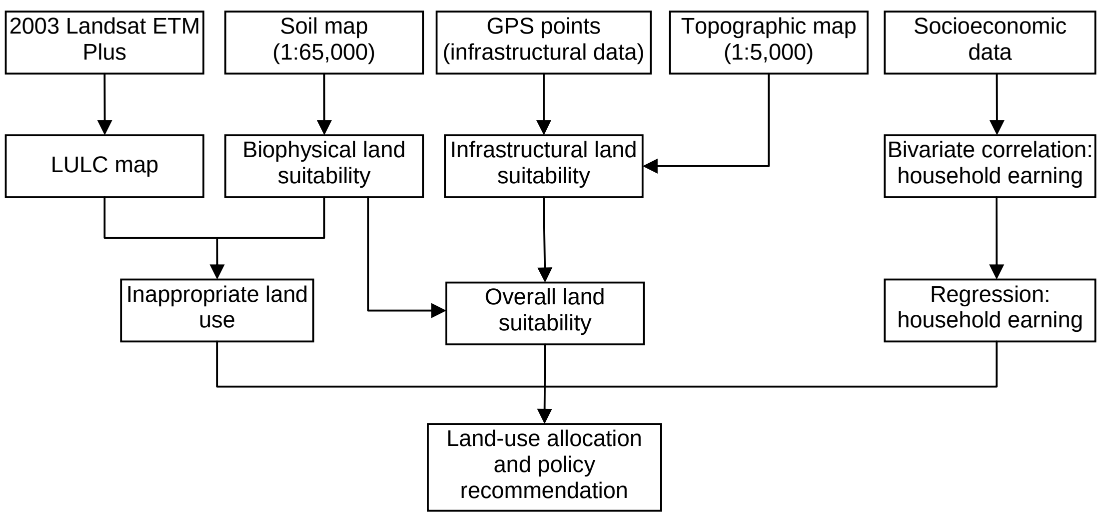

Figure 2. **Flowchart of research procedure**

Land suitability classification

For employing FAO framework of land evaluation, the physical parameters directly related to crop production were considered for analysis. They were temperature, rainfall, soil texture, soil reaction (pH KCl), nutrient availability e.g. N, P, K, CEC, and slope. Soil samples were collected from the field and analyzed for,

- soil texture: Robinson method
- soil reaction: extracted by 1N KCl 1:25, to be measured by acidometer
- nitrogen: extracted by 2M KCl 1:10, to be measured by spectrophotometer
- available phosphorus: Bray II method
- potassium: destructed by $BaCl_2$ 0,1 M and analyzed using atomic absorption spectrometry (AAS)
- cation exchange capacity: extracted by 30 ml 0.1 M $BaCl_2$ 2.5 gram soil, to be standardized with EDTA 0,01M and
- organic matter: Walkley-Black method.

The attributes were then encoded in the soil map layer according to its representative soil mapping units. Rainfall and temperature map were prepared from climate data. Basic infrastructural types considered for analysis involved accessibility to main roads, canals, markets, agricultural seed centers and agricultural product processing factories, for which GPS locations were recorded. Accessibility was measured using buffering technique for each type infrastructure.

The limitation condition method described by Sys *et al.* (1991a,b) based on expert knowledge as described by various researchers, like Maes (1987), LDD (1992), Rodriguez (1995), and Wandahwa and Van Ranst (1996) was used for rating the land suitability classes, i.e. lower individual rating was considered limiting the overall suitability. Weightage for each diagnostic soil parameter was calculated according to the significant influence on the crop growth by using the pair-wise method developed by Saaty (1980). Soil limitations such as hill-forestlands, roads, rivers, etc. were coded as 0 to explicitly exclude constraint areas from suitability maps (Nath *et al*, 2000).

Arc/Info was used to perform suitability computations and geo-process different thematic maps. The suitability was assessed irrigated rice, cassava and upland crops. The final suitability map comprising highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and unsuitable (N) were produced based on the biophysical and accessibility characteristics using the formula introduced by Bonham-Cater (1994). S1 category refers to the 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 category refers to 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. Similarly, S3 has increased limitations compared to S2 and N category has so severe limitations that they are simply not suitable for the specified use evaluated against. For the crops being evaluated, crop-wise land-use requirements were determined which sets out the threshold for the criteria considered in analysis for each suitability category. This is necessary for comparing with the land characteristics in determining the suitability level for the crops being evaluated.

Land-use alternatives were developed by overlaying land-use map with land suitability maps considering only S1 and S2 classes as these have insignificant or moderate limitations without affecting a sustainable land use. Furthermore, land mapping units where marginally suitable for the said crops would be allocated by other field crops. All the analyses were carried out using ArcView 3.3 GIS software.

Socioeconomic analysis

The nature of socioeconomic situation of the farm HHs influences the relative stability of agricultural production systems through production, economic benefits and environmental protection (Shrestha, 2000). In this study, we explored some of the major aspects of production system, economic return of the three major land-use systems and important socioeconomic factors of production using Statistical Package Social Science (SPSSx). First, a correlation matrix was constructed to evaluate the association between variables. Subsequently a backward multiple regression was deployed to perform determinants of household earnings. The entry into the regression equations was set at $\alpha < 0.05$.

Results and Discussion

Biophysical land suitability classification

For the crops assessed, no highly suitable class was found in the area. In Table 1, Majority of the area was found moderately suitable, ranging between 55.7 (cassava) to 86.5 percent (upland crops). About 2.4 (upland crops) to 34.2 percent (cassava) of the area fell in the marginally suitable category, and another one-tenth in not suitable category in case of all the crops. The not-suitable category includes included mountainous areas at very high degree of physical soil limitation which could not easily be corrected and not economic as well to put under production.

When comparing land quality with land requirements, the major constraints found to be corresponding with each land suitability classes for all crops were in general low soil reaction and insufficient available phosphorus and potassium.

***Table 1.* Biophysical land suitability for major crops**

Crops/ cropping patterns	Area (%)			
	S1	S2	S3	N
Irrigated rice	-	70.6	19.3	10.1
Cassava	-	55.7	34.2	10.1
Upland crops	-	86.5	2.4	11.1

Comparison of the present land uses with the analyzed suitability classes was also conducted to examine the mismatch. It is to note that only S1 and S2 suitability classes were considered for comparison as these classes have less constraints and theoretically justifiable return. The analysis revealed that almost 20 percent of area currently under irrigated rice is not suitable for rice cultivation in terms of obtaining justifiable return. Similarly, almost 70 percent area under existing upland cultivation is not suitable as well.

Infrastructural land suitability classification

Besides biophysical suitability, access to infrastructure for procuring agricultural inputs and disposing harvest place an important role. For example, market is one of the key requirements and distance to market is vital in enhancing income and good security of rural farmers (Pandey and Minh, 1998). This study considered in the analysis the accessibility to not only market but also other important infrastructure, such as transportation network (road, canals), agricultural seed center and cassava mill. The accessibility maps were created based on the information obtained through field observation and semi-structural interviews with key informants. Most residents lived along main canals and roads, and their farms were likewise located in the sphere of 1.5 km.

Accessibility to main canals and roads within 1.5 km and market within 2 km was examined to be critically affecting the transportation costs of agricultural production from either HH farms to their houses or markets nearby (Son, 2005). Proximity to agricultural seed center was found significantly associated with increased average yield of crops within 3 km in terms of providing good varieties for farmers. Exceptionally for those HH cultivating cassava proximity to cassava milk mill was particularly important within 3 km to minimize transportation costs (Son, 2005). These information were used to buffer the respective infrastructure types and final suitability classes. Unsuitable class was not applied for this kind of assessment as there were no severe constraints significantly affecting the suitability of a given land-use type.

The resultant infrastructural classification indicated that the proportion percentage of the area in the most suitable category ranged between 5.9 to 29.6 percent in which irrigated rice was found to be wider infrastructural suitability range than other crops (Table 2). In moderately suitable category, majority of the area ranging from 55.3 to 64.9 percent was observed for all cases. About 10.3 to 32.8 percent fell in marginally suitable category because of limitations in infrastructural accessibility. In land-use planning point of view, decision makers could be based upon this assessment either to modify proximity or ratings and weightings in respect to satisfied agricultural production and consumption.

Table 2. **Infrastructural land suitability for crops**

Crops/ cropping systems	Suitability class (%)		
	S1	S2	S3
Irrigated rice	29.6	60.1	10.3
Cassava	5.9	64.9	29.2
Rice-based upland crops	11.9	55.3	32.8

Socioeconomic evaluation

- <u>Economic efficiency</u>

For all three land-use types, production system of rice-based upland crops under scheme of spring-winter rice crop followed by autumn-summer upland crops gave a highest benefit-cost ratio (1.4) (Table 3), followed by irrigated rice, viz two crops per year (1.0).

***Table 3.* Economic indicators of different crops**

Indicators	Irrigated rice	Cassava	Rice-based upland crops
Size of holding (ha)	1.8	1.8	1.6
Total cost (VND)	7,743.6	4,887.1	9,956.9
Gross return (VND)	13,870.2	4,509.5	13,177.8
Per ha net return (VND)	7,364.9	-377.6	3,220.9
B:C ratio	1.0	-0.1	1.4

Note: 1 USD = 15,766 VND at the time of survey

Cassava, an economic crop of export importance, had recently been unprofitable (-0.1) since its yield drastically decreased because of inappropriate land-use and management. The reason for higher B:C in case of rice-based upland-crop system was that the farmers intercropped leguminous crops into their fields which helped increase the soil fertility and thus higher production of the rice crop (Son, 2005).

- <u>Selection of crop varieties and farming problems</u>

According to 40.6 percent of respondents, crop variety was an important factor influencing land-use decision making followed by market as a factor for determining the uses of land according to 29.7 percent respondents. Although soil types were an important factor for land-use allocation, only 23.4 percent took this criterion into account of decision consideration due to farmer's insufficient knowledge on the land capability as well as soil conservation measures. A very low percentage of farmers (6.3 percent) decided to put their land for certain use based on palatability or taste of crops (Son, 2005).

Regarding the problems in production, as much as 39.1 percent of respondents stated diversification of production systems, such as rice-based upland crops with animal husbandry, could not be practiced due to lack of capital. Diversification could give higher benefit however would require relatively high investment too. The second major problem was lack of water for irrigation during dry season in upland areas as identified by 31.3 percent respondents. Besides, occurrence of insects and pests (21.9 percent) was less noticed because of the fact that farmers had applied high-yielding varieties which were able to resist major local pests and diseases. Although only 7.8 percent of respondents conceived land degradation to be a noted problem in terms of declined soil fertility, it might be more serious in future in the lack of timely and appropriate conservation measures (Son, 2005).

- <u>Credit source, agricultural extension and marketing channels</u>

Provision of credit is important to farmers to enable them to improve as well as diversify their farms. Out of surveyed HH, 62.5 percent had standing loans. Large and medium farmers were more easily to borrow money and access loans or credits for production than small farmers because they could show better collateral security. As much as 63.2, 78.6 and 41.2 percent of large, medium and small farmers, respectively borrowed money from the banks for agricultural production implying inadequate financial resources for agricultural cultivation irrespective of farmer's category. Farmers got loans from different credit sources for different purposes. The medium and large farmers almost borrowed money for growing rice and upland crops whereas small farmers borrowed money for different purposes, e.g. rice cultivation (42.9 percent), upland-crop production (28.6 percent), livestock husbandry (14.3

percent) and others (14.3 percent) including fish raising and small-scale trade (Son, 2005).

Mass media and extension center take an important part in forecasting market information to help farmers making right land-use decisions. Majority (80 percent) of surveyed HH took part in short-training courses on various aspects of agriculture at least once a year to catch up with new farming techniques. Ironically most of them were men while women likely took care of HH farms. Information from TV broadcast was also one of the most important ways to encourage farmers to adopt new farming techniques. However, it was only suitable for the rich, but for the poor because of economic difficulties (Son, 2005).

Majority of farmers unofficially accessed to marketing channels through the neighbors (56.3 percent), middlemen (20.3 percent) who acted as marketing information providers and agricultural product buyers. This significantly influenced farmer's land-use decision making as well as helped them dealing with an enormous amount of agricultural products in the area. Other marketing sources were from TV (15.6 percent) and agricultural executives (7.8 percent) (Son, 2005).

- <u>Determinants of household earnings</u>

The Pearson correlation matrix showed that altogether twelve variables were strongly related with the household earnings. These were land holding size, average HH size, educational attainment, agricultural extension, number of males, number of females, rice production cost, upland-crop production cost, income from rice production, income from off-farm activities, income from upland crops, and income from husbandry. The regression analysis indicated that five of them have significant relationship with the household earnings (Table 4). The fitted model consisted of five determinants reflecting the economy of households. The P-value < 0.05 (F-statistics

543.15, df 63) indicated that the relation was significant at 95 percent coefficient limit and the model explaining 98 percent of variance (R^2 = 0.98). The standard error (S.E.), which showed the standard deviation (S.D.) of the residuals, was 1,960.27. The Durbin-Watson (DW) statistics of 2.06, which is greater than 2, so there was no significant autocorrelation in the residuals or no significant correlation due to sequence of variable input in the analysis. All the variables included in the model had positive relation with household earnings except educational attainment. This is crucial issue in case of a rural setup that lower educational attainment is not only associated with low earning but also negatively affecting natural resources management in general.

Table 4. **Multiple regression analysis of household earnings**

Parameter	*Coefficient*	*S.E*	*t-statistic*	*P-value*
Intercept	-511.91	1,071.94	-0.48	0.63
Income from rice production (VND)	1.01	0.02	52.03	0.00
Cost of upland-crop production (VND)	0.49	0.30	1.62	0.11
Income from upland crops (VND)	0.84	0.16	5.37	0.00
Income from husbandry (VND)	1.00	0.19	5.27	0.00
Income from off-farm activities (VND)	1.15	0.17	6.91	0.00
Educational attainment (index)	-2,943.48	2,201.67	-1.34	0.19
R^2 = 0.98 R^2 (adjusted for d.f.)= 0.98				
Standard error of estimate (S.E.) = 1,960.27				
Durbin-Watson (DW) statistic = 2.06				

Note: Weighted education index (1: undergraduate; 0.75: high school; 0.5: secondary; 0.25: primary; and 0 = illiterate)

Adequate understanding of the socioeconomic situation and the determining factors of production are important to come up with the land-use strategies to accommodate the real needs of the land users in developing appropriate and realistic land-use strategies. In this study, the above analysis was duly considered when formulating interventions to the existing cropping context with respect to improving farmer's income and preserving land resources.

Land-use allocation

With respect to allocating the land areas for the best use based on its land quality, the analysis showed that a large proportion of the area (44.3 percent) was found to have optimal biophysical and infrastructural suitability for irrigated rice (Figure 3), which could be put under extensive cultivation with its required land management for the sake of food security. About 2.2 and 2.6 percent of the area were likewise found to be suitable for cultivation of upland crops and cassava, respectively. As much as 0.02 to 9.2 percent of the area had a potential for expanding the said crops, of which 5.6 and 9.2 percent could be in succession projected for monocropping irrigated rice and upland crops. A large proportion of 14.5 percent found unfavorable for the said crops should be concerned for other land uses, and infrastructural improvement was another important aspect to address the problem.

From the land management view-point, for all cases the requirement was same, namely appropriate cultivars and soil conservation measures were encouraged to address noted soil constraints. Specific to this was that lime could be applied to respond to increased soil pH. Mulching, particularly for upland-crop monocultivation and rice-based upland crops, would help to enhance soil organic matter content so that the physical condition of the soil would be maintained in long-term. Besides, appropriate and timely application of phosphorus and potassium could result into higher yields.

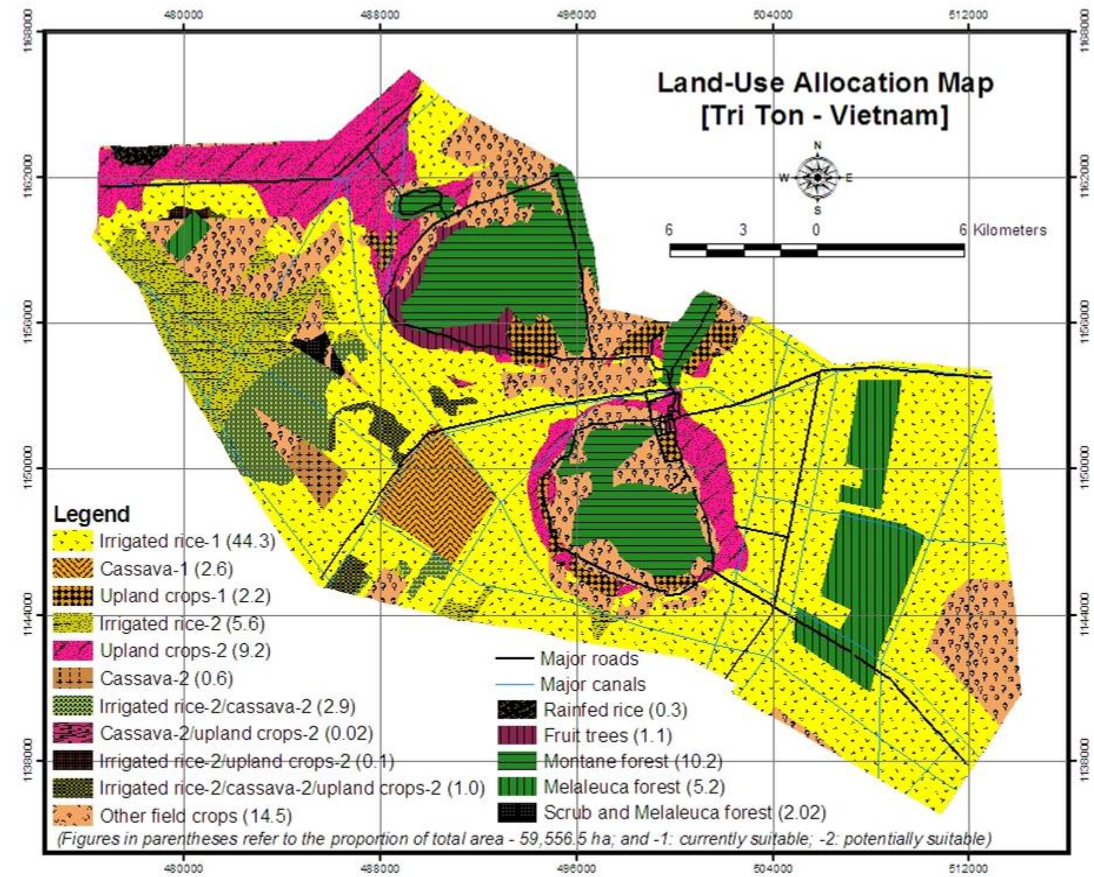

Figure 3. **Spatial distribution of land-use alternatives**

Conclusion

Sub-optimal land use is one of the major reasons for land degradation and a grave challenge for sustainable agricultural production. As elsewhere, inappropriate use of land against its inherent quality is prevalent in Tri Ton district of Southern Vietnam too. Land suitability analysis showed that none of the areas is highly suitable for the selected three major land-use types, i.e. irrigated rice, cassava, and upland crops, indicating relatively poor land quality in the study area. This also indicates that such lands can be degraded and easily loose the productive potential if no timely appropriate measures are undertaken. Low pH and low fertility are among the major soil constraints indicating either the overexploitation of soils inherent capacity to produce or cultivation in the marginal lands. A comparison of the current land use with the land suitability analysis indicated that almost one-fifth of current land use under irrigated rice is not suitable and hence not sustainable in the long run. The situation is even worse in case of upland crops with 70 percent area currently under upland crops is not suitable for upland crops cultivation. On the other hand, the area has good infrastructure to support the agricultural production as shown by the infrastructure suitability where relatively higher percentage of land areas fall in highly suitable category.

Monocropping, lack of adequate moisture or irrigation water, insect/pests prevalence and land degradation are the major problems in the production system in the area. The socioeconomic factors which influence the land users' decision-making related to land uses are crop variety, market facilities, and soil types. The fact that low benefit-cost ratio for the major land-use types also reaffirms the less productive agricultural system in the area due to low productive capacity of soils as shown by land suitability analysis. In deed, the household income is much related with the income from various production systems, such as crop and livestock, and education attainment basically reflecting the awareness level. Hence, it would be very important to address the problem in each production system to collectively uplift the land users' economic situation. In this regard, to address the problem of misuse of land and to attain a sustainable agricultural system, the proposed land-use allocation recommends the appropriate crops to best suit the land quality and the socioeconomic requirements of the land users. This is however should be supported by other necessity of the production systems, including the support to land users in relation to credit access and extension services.

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Acknowledgements

The paper is based on the first author's M.Sc. work financed by NORAD as a M.Sc. scholarship grant through the Asian Institute of Technology (AIT). Thanks to NORAD and AIT. The authors would like to express their appreciation to Dr. Ganesh P. Shivakoti and Dr. Edward L Webb, and two anonymous reviewers for their valuable comments on the manuscript.