GIS–based Land Evaluation for Combining Economic Crops as a Model for Agricultural Land Use Planning

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ABSTRACT

The land suitability map in general is established based on individual crop which provides inadequate information for land use planning. This evaluation is then formulated with objective of delineating units of land as to their suitability for combining economic crops with regarding the legal conservation areas. The study area, Chi watershed, covers extensively in Northeast Thailand with an area of about 49,500 sq km. The major economic crops in the area are rice, sugar-cane, cassava and rubber tree. The suitability assessment for each crop was conducted using the method as described in FAO guidelines. For each crop, land suitability unit was established using overlay process of the defined theme layers or land qualities. As a result the suitability map with their associated class attributes for rice, sugar-cane, cassava and rubber tree were carried out. In addition, the conservation areas in the watershed were also digitally encoded in GIS database. Simultaneously, overlay process was then performed of the suitability layers and conservation areas with selection criteria of identifying conservation area, highly and moderately suitable classes. The resultant map obtained is a result of combination of defined suitability class of combining crops and the conservation areas. The planning alternative that best matches land uses to the highly and moderately suitable land areas was suggested with respect to the conservation area.

1.BACKGROUND

Agricultural land use planning requires spatial information of the suitability of land for a number of economic crops within the areas. To date, the FAO guideline on the land evaluation system (FAO, 1983) is widely accepted for the evaluation. The system is based primarily on an integration of land qualities as related to individual crop requirements. The similar system developed by Sys et al. (1991) reports the crop requirements based on the experiments/ experiences for the land in the tropics. To formulate the land use planning, the evaluation has to provide the alternatives with less marketing risk. To lessen the risk the combination of economic crops within the area should be evaluated. Rice, cassava, sugar-cane and rubber tree are important export crops and products from Thailand. The crop area covers extensively or over 70% of the total cultivated land in Northeast Thailand. In Thailand, land classification has been conducted since the past three decades. The classification system included land capability for field crops and land suitability for rice (Land Development Department (LDD), 1996) To date, the land suitability maps are defined as the inherent capacity of a soil to grow crops. The overall map production is still used the inherent capacity of soils for the suitability land unit. Recently, those maps were digitally encoded in GIS database. In addition a number of pilot projects were undertaken to test the land evaluation using GIS. There still needs to establish the modeling of land suitability, considering the integration of the land qualities concerned. With the advent of technology, the establishment and integration of land qualities for the evaluation are effectively conducted using satellite data and GIS functionalities (Yamamoto et al., 2003, Thavone et al., 1999, Quang Duc, 1999, Mongkolsawat et al., 1999 and Mongkolsawat et al. 1997). The reports mostly provided the similar concept, using different modeling for the land quality integration. The land qualities defined may vary from region to region depending upon the information available and techniques used. In the study area, the land utilization types include rice, cassava and sugar-cane, as well as a promising rubber tree recently the expansion of the planted areas is evident. The misuse of land is commonly practiced, the unsuitable land, forest reserves and sloping lands have been encroached on for agriculture. This study will provide GIS-based information about the suitability of land for individual crop, a combination of selected economic crops. Based on which the agricultural land use planning can be formulated with higher reliable and informative and eventually to lessen the marketing risk. The objective of this study is then to undertake the GIS-based information including land suitability for integrating economic crops at watershed level, to support agricultural land use planning.

2. STUDY AREA

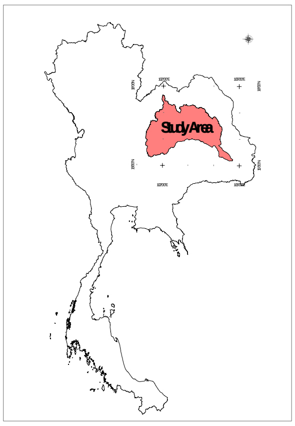

Figure 1. Study area

The study area covers the extensive areas of the central part of northeastern Thailand of Chi watershed being used for test area to represent agricultural land use planning in the region. The Chi watershed is drained eastward to Mun river and eventually to the Mekong river in the border of Thai-Lao,PDR. Physiographically, the Chi is formed by the prominent topography in the upstream and flat to gently undulating landscape in the central and downstream of the river. The current land use is restricted to dipterocarp and evergreen forests on the upstream/ mountain, field crops on the well drained soil of the gently undulating areas, and paddy on the flat and low lying areas. The isolated patches of remnant forest are commonly found throughout the Chi. Geologically the Chi is underlain by a thick sequence of Mesozoic sediment, the Korat Group ranging in age from upper Triassic to Tertiary. The extensive alluvial plain is underlain by Maha Sarakham Formation (a Formation of the Korat Group) which was deeply weathered in the Tertiary period and contains considerable quantity of evaporites interbedded with sandstones siltstones and sandy shades. The occurrence of this Formation coincides with the distribution of salt affected soils. The soils on the undulating topography are mainly derived from alluvium of sandstones origin. The mean annual rainfall ranges from 1000-1500 mm. and is increased from the west to the east of the region.

3. METHODOLOGY

3.1 Land suitability for crops

Selected crops/plants (rice, cassava, sugar-cane and rubber trees) was based mainly on the method as described by FAO (1983). For each crop, land units resulting from the overlay operation of the defined land qualities were digitally established. The crop requirement in terms of land qualities to be used in the evaluation process were reviewed (Sys et al., 1993, LDD, 1996, FAO, 1983, Mongkolsawat et al., 1999, Mongkolsawat, 1997, Paiboonsak et al., 2004a, 2004b). In the Chi, some land qualities as defined by FAO with negligible difference within the region were excluded for the evaluation. Moreover the experiment reports and regional experiences were reviewed to define the land qualities. In the Chi, the qualities used in the evaluation are selected with reference to the land uses considered and the nature of the land units. The land qualities to be used in this evaluation include water availability (W), Soil (S), Salt Hazard (Sa) and Terrain (T). Each of which is considered as a thematic layers in the GIS database. Determinations of the diagnostic factors and the factor rating are summarized in table1, 2, 3 and 4 for low land rice, sugar-cane, cassava and rubber tree respectively. The suitability evaluation for the crops in the Chi watershed is based on the equation:

Suitability = W x S x Sa x T with the following procedures.

a) Water availability (W): Rainfall data of 27 years (1975-1990) recorded by the Meteorological Department were used for the establishment of W layer. Mean annual rainfall for the entire of the Northeast was determined at each station with the Kriging interpolation the spatial W was digitally performed. The spatial W was then divided in to 4 classes as defined in table 1, 2, 3 and 4 for the crops to be evaluated.

b) Soil (S): The S land quality was determined using the combination of Nutrient Availability Index (NAI) and Physical properties (PP) of soil, (S = NAI x PP). The NAI, is based on the method developed by Radcliffe et al. (1982) and is given by NAI= N x P x K x pH. Soil map provides information of N, P, K and pH, those of which were used in the overlay process to create the spatial layer of NAI. The values of rating factor of the NAI component were given in the table 1, 2, 3 and 4. The physical properties of soil is defined as a multiplication of soil drainge (dr), texture (t) and depth (d) (PP = dr x t x d). Each of the properties can be obtained from the soil map.

c) Salt hazard (Sa): The soil salinity is an important edaphic constraints for the crops and is originated from the Maha Sarakham geoglogie Formation which underlies the areas. The availability of soil salinity potential map was used to assign the factor rating for the evaluation.

d) Terrain (T): The terrain is a matrix of slope gradient and landform. The map of the slope and landform combination was digitally established and value assigned was given as in the sub-table 1a, 2a, 3a, and 4a for rice, sugar-cane, cassava and rubber tree respectively. Each of the defined land qualities with their associated attribute was digitally encoded in GIS database to create four thematic layers. The diagnostic factors of each layer were assigned values of factor rating (S1=highly suitable, S2=moderately suitable, S3=marginally suitable and N=unsuitable).

Table 1. Land quality and factor rating for rice.

Land use requirement			Factor rating			
Land quality	**Diagnostic factor**	**unit**	**S1 (1.0)**	**S2 (0.8)**	**S3 (0.4)**	**N (0)**
Water availability (W)	**Annual rainfall**	mm.	**>1,500**	**1,100-1,500**	**800-1,100**	**<800**
Soil(S)	**S=NAI x PP**		**>0.6**	**0.3-0.6**	**0.1-0.3**	**<0.1**
	Nutrient Availability Index (NAI)		>0.5	0.1-0.5	<0.1	-
	NAI=N x P x K x pH					
	N	%	>0.5	0.08-0.5	0.04-0.08	<0.04
	P	ppm	>50	25-50	10-25	<10
	K	ppm	>60	30-60	<30	-
	pH	-	5.6-7.3	7.4-7.8, 4.5-5.5	7.9-8.4, 4.0-4.5	>8.4, <4
	Physical Properties (PP)		>0.8	0.4-0.8	0.1-0.4	<0.1
	PP=dr x t x d					
	Soil drainage (dr)	Class (USDA)	poor/very poor	Moderate	well	very well
	Soil texture(t)	-	C, SiC, CL, SiCL, AC	C, SCL, L, SiL	SL, LS	S, G, SC
	Soil depth(d)	cm.	>50	25-50	15-25	<15
Salt hazards (Sa)	**Soil salinity**	-	**non-saline**	**Low**	**Medium**	**High**
Terrain (T)	**Landform & slope**	Class & %	***Combination of landform and slope (Table 1a)***			

Remark: L=Loam, SiCL=Silty clay loam, SiL=Silty loam, SCL= Sandy clay loam, CL=Clay loam, SL=Sandy loam, C=Clay, LS=Loamy sand, SC=Sandy clay, SiC=Silty clay, S=Sand, G=Gravel soil, SC=slop complex, AC=Alluvial complex

***Suitability evaluation**:* S1=Highly suitable (1.0), S2=Moderately suitable (0.8), S3=Marginally suitable (0.4), N=Unsuitable (0)

Table 1a. Landform and slope factor for rice

Slope (%) \ Landform	Flood Plain	Low Terrace	Middle Terrace	High Terrace	Foot Slope & Erosion Surface	Mountain & outcrop
0-2	S1	S1	S3	N	S2	N
2-5	S2	S2	N	N	N	N
>5	N	N	N	N	N	N

Remark: S1=Highly suitable (1.0), S2=Moderately suitable (0.8), S3=Marginally suitable (0.4), N=Unsuitable (0)

Table 2. Land quality and factor rating for sugar-cane.

Land use requirement			Factor rating			
Land quality	**Diagnostic factor**	**unit**	**S1 (1.0)**	**S2 (0.8)**	**S3 (0.4)**	**N (0)**
Water availability (W)	**Annual rainfall**	mm.	**1,600-2,500**	**1,200-1,600**	**900-1,200**	**<900**
Soil(S)	**S=NAI x PP**		**>0.6**	**0.3-0.6**	**0.1-0.3**	**<0.1**
	Nutrient Availability Index (NAI)		0.5	0.1-0.5	<0.1	-
	NAI=N x P xK xpH					-
	N	%	>0.2	0.1-0.2	<0.1	-
	P	ppm	>25	6-25	<6	-
	K	ppm	>60	30-60	<30	-
	pH	-	6.1-7.3	7.4-7.8,5.1-6.0	7.9-8.4,4.0-4.5	>8.4, <4
	Physical Properties (PP)		>0.8	0.4-0.8	0.1-0.4	<0.1
	PP=dr x t x d					
	Soil drainage (dr)	Class (USDA)	very well/well	moderately well	somewhat well	Very poor/ poor/somewhat poor
	Soil texture(t)	-	C, L, SCL, SiL, Si, CL, L	SiCL, SL	SiC, LS	C, G,SC,AC,S
	Soil depth(d)	cm.	>100	50-100	25-50	<25
Salt hazards (Sa)	**Soil salinity**	-	**non-saline**	**Low**	**Medium**	**High**
Terrain (T)	**Landform & slope**	Class & %	***Combination of landform and slope (Table 2a)***			

Remark: L=Loam, SiCL=Silty clay loam, SiL=Silty loam, SCL= Sandy clay loam, CL=Clay loam, SL=Sandy loam, C=Clay, LS=Loamy sand, SC=Sandy clay, SiC=Silty clay, S=Sand, G=Gravel soil, SC=slop complex, AC=Alluvial complex

***Suitability evaluation**:* S1=Highly suitable (1.0), S2=Moderately suitable (0.8), S3=Marginally suitable (0.4), N=Unsuitable (0)

Table 2a. Landform and slope factor for sugar-cane.

Slope (%) \ Landform	Flood Plain	Low Terrace	Middle Terrace	High Terrace	Foot Slope & Erosion Surface	Mountain & outcrop
0-2	N	N	S1	S2	S1	N
2-5	N	S1	S2	S3	S2	N
5-12	N	S2	S3	S3	S3	N
12-20	N	S3	S3	N	N	N
>20	N	N	N	N	N	N

Remark: S1=Highly suitable (1.0), S2=Moderately suitable (0.8), S3=Marginally suitable (0.4), N=Unsuitable (0)

Table 3. Land quality and factor rating for cassava.

Land use requirement			Factor rating			
Land quality	**Diagnostic factor**	**unit**	**S1 (1.0)**	**S2 (0.8)**	**S3 (0.4)**	**N (0)**
Water availability (W)	**Annual rainfall**	mm.	**1,100-1,500**	**9,00-1,100 1,500-2,500**	**500-900 2,500-4,000**	**<500 >4,000**
Soil(S)	**S=NAI x PP**		**>0.6**	**0.3-0.6**	**0.1-0.3**	**<0.1**
	Nutrient Availability Index (NAI)		>0.5	0.1-0.5	<0.1	-
	NAI=N x P x K x pH					-
	N	%	>0.2	0.1-0.2	<0.1	-
	P	ppm	>25	6-25	<6	-
	K	ppm	>60	30-60	<30	-
	pH	-	6.1-7.3	7.4-7.8, 5.1-6.0	7.9-8.4, 4.0-4.5	>8.4, <4
	Physical Properties (PP)		>0.8	0.4-0.8	0.1-0.4	<0.1
	PP=dr x t x d					
	Soil drainage (dr)	Class (USDA)	very well/well	moderately well/somewhat well	somewhat poor	very poor/poor
	Soil texture(t)	-	C, L, SCL, SiL, Si,CL,L,SL,SiCL	LS	SiC	C, G,SC,AC,S
	Soil depth(d)	cm.	>100	50-100	25-50	<25
Salt hazards (Sa)	**Soil salinity**	-	**non-saline**	**Low**	**Medium**	**High**
Terrain (T)	**Landform & slope**	Class & %	***Combination of landform and slope (Table 3a)***			

Remark: L=Loam, SiCL=Silty clay loam, SiL=Silty loam, SCL= Sandy clay loam, CL=Clay loam, SL=Sandy loam, C=Clay, LS=Loamy sand, SC=Sandy clay, SiC=Silty clay, S=Sand, G=Gravel soil, SC=slop complex, AC=Alluvial complex
***Suitability evaluation**:* S1=Highly suitable (1.0), S2=Moderately suitable (0.8), S3=Marginally suitable (0.4), N=Unsuitable (0)

Table 3a. Landform and slope factor for cassava.

Slope (%) \ Landform	Flood Plain	Low Terrace	Middle Terrace	High Terrace	Foot Slope & Erosion Surface	Mountain & outcrop
0-2	N	N	S1	S2	S1	N
2-5	N	S1	S2	S3	S2	N
5-12	N	S2	S3	S3	S3	N
12-20	N	S3	S3	N	N	N
>20	N	N	N	N	N	N

Remark: S1=Highly suitable (1.0), S2=Moderately suitable (0.8), S3=Marginally suitable (0.4), N=Unsuitable (0)

Table 4. Land quality and factor rating for rubber tree.

Land use requirement			Factor rating			
Land quality	**Diagnostic factor**	**unit**	**S1 (1.0)**	**S2 (0.8)**	**S3 (0.4)**	**N (0)**
Water availability (W)	**Annual rainfall**	mm.	**1,500-2,500**	**1,200-1,500**	**1,100-1,200**	**<1,100**
Soil(S)	**S=NAI x PP**		**>0.6**	**0.3-0.6**	**0.1-0.3**	**<0.1**
	Nutrient Availability Index (NAI)		>0.5	0.1-0.5	<0.1	-
	NAI=N x P x K x pH					-
	N	%	>0.2	0.1-0.2	<0.1	-
	P	ppm	>15	10-15	3-10	<3.0
	K	ppm	>30	<30	-	-
	pH	-	>5.0-7.3	>7.3-8.0, >4.0-5.0	>3.5-4.0	>0.8, <3.5
	Physical Properties (PP)		>0.8	0.4-0.8	0.1-0.4	<0.1
	PP=dr x t x d					
	Soil drainage (dr)	Class (USDA)	well	moderate	poor	very poor
	Soil texture(t)	-	L, SCL, SiL, Si, CL, SiCL, SiC	SL	LS	C, G, SC, AC, S
	Soil depth(d)	cm.	>150	100-150	50-100	<50
Salt hazards (Sa)	**Soil salinity**	-	**non-saline**	**Low**	**Medium**	**High**
Terrain (T)	**Landform & slope**	Class & %	***Combination of landform and slope (Table 4a)***			

Remark: L=Loam, SiCL=Silty clay loam, SiL=Silty loam, SCL= Sandy clay loam, CL=Clay loam, SL=Sandy loam, C=Clay, LS=Loamy sand, SC=Sandy clay, SiC=Silty clay, S=Sand, G=Gravel soil, SC=slop complex, AC=Alluvial complex

***Suitability evaluation**:* S1=Highly suitable (1.0), S2=Moderately suitable (0.8), S3=Marginally suitable (0.4), N=Unsuitable (0)

Table 4a. Landform and slope factor for rubber tree.

Slope (%) \ Landform	Flood Plain	Low Terrace	Middle Terrace	High Terrace	Foot Slope & Erosion Surface	Mountain & outcrop
0-2	N	N	S1	S1	S1	N
2-5	N	S3	S2	S2	S2	N
5-12	N	S2	S2	S2	S2	N
12-20	N	S3	S3	S3	S3	N
20-35	N	S3	S3	S3	S3	N
>35	N	N	N	N	N	N

Remark: S1=Highly suitable (1.0), S2=Moderately suitable (0.8), S3=Marginally suitable (0.4), N=Unsuitable (0)

The evaluation model for each crop was given using the values of the factor rating as follows: Suitability = W x S x Sa x T These could be performed by spatial overlay with the suitability model of the defined four layers.

The result yielded 4 classes according to the resultant proposed in table 5.

The reliability of the suitability map for each crop was assessed, based on the suitability maps conducted by other agencies including the ground truth survey. A number of approximations and the corrections of the land unit were made. The iteration of the process was performed to eventually obtain a satisfactory result.

Table 5 Suitability evaluation for rice, sugar-cane, cassava and rubber tree.

Suitability Class	Rice	Surgar-cane	Cassava	Rubber tree
S1	0.64-1.00	0.64-1.00	0.80-1.00	0.80-1.00
S2	0.40-0.64	0.40-0.64	0.64-0.80	0.32-0.80
S3	0.01-0.40	0.01-0.40	0.01-0.64	0.01-0.32
N	<0.01	<0.01	<0.01	<0.01

3.2 Land suitability for crop combinations

In the evaluation for crop combinations, the suitability for each of the crops concerned is obtained. The overlay process was further performed on these suitability layers with model criteria of only highly and moderately suitable classes selected for identifying the suitability for the crop combination.

3.3 Agricultural land use planning

Consideration of land in terms of suitability, management and conservation is needed for the land use planning. In this procedure, the suitability for the combination of crops, conservation areas and community areas were integrated, providing the land unit for the planning. The integration was digitally performed by the overlay process with selection criteria defined for the planning with the suitability, conservation areas and community uses.

The schematic chart of the methodology process is illustrated in figure 2.

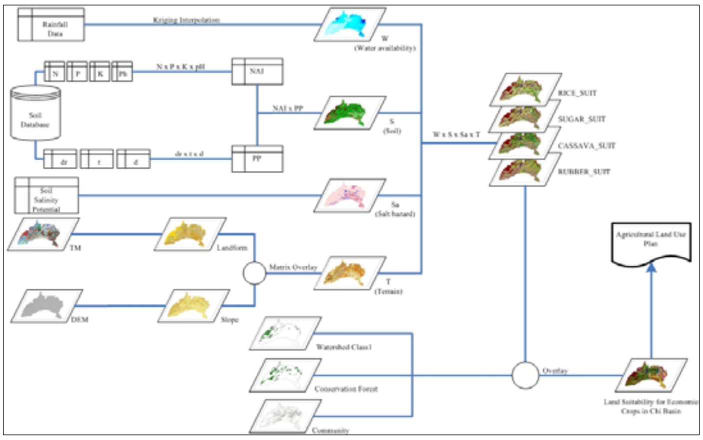

Figure 2. Schematic of the methodology process

4. RESULTS AND DISCUSSIONS

4.1 The Suitability maps

The suitability map resulting from the spatial overlay of the land qualities for rice, sugar-cane, cassava and rubber tree are shown in figure2 The suitability area in addition to the spatial information of the crops is shown in table 6. The study provides the overall insight into each land quality for crops and the suitability resulting from the integrations of the land qualities spatially and quantitatively. It is evident from the study that land suitability for cassava covers over 30% of the area for highly and moderately suitable land.

Table 6 The suitability area for rice, sugar-cane, cassava and rubber tree, Chi watershed, Northeast of Thailand.

Class	%			
	Rice	Sugar-cane	Cassava	Rubber tree
Highly suitable	7.10	5.93	23.81	3.01
Moderately suitable	8.27	7.10	8.44	18.16
Marginally suitable	23.41	14.68	6.74	3.84
Unsuitable	37.77	48.83	37.55	51.54
Unclassified	3.04	3.04	3.04	3.04
Conservation	14.91	14.91	14.91	14.91
Community	3.04	3.04	3.04	3.04
Water body	2.46	2.46	2.46	2.46
Total area of the Chi = 49,477 sq.km.				

The high suitability land for rice, sugar-cane, cassava and rubber tree cover areas of about 7.10, 5.93, 23.81 and 3.01% respectively (table 6). The conservation areas cover extensively in the dissected erosion surface and mountainous area where the land slope is evident. For the conservation requirements, the legal forest reserves are not covered by this assessment. The information obtained were further analyzed in the second stage to prepare the land unit for the crop combination.

Cassava and sugar-cane are the combination crops that normally occupy the upper terraces of well drained soils. With these information, the alternatives for agricultural land use are dynamic and varied according to the cost benefit of the combination. Normally the low input of cropping factors and high return with the sustainability of land are recommended. To make any decision, it is necessary to develop alternatives for the areas that require methods of selection.

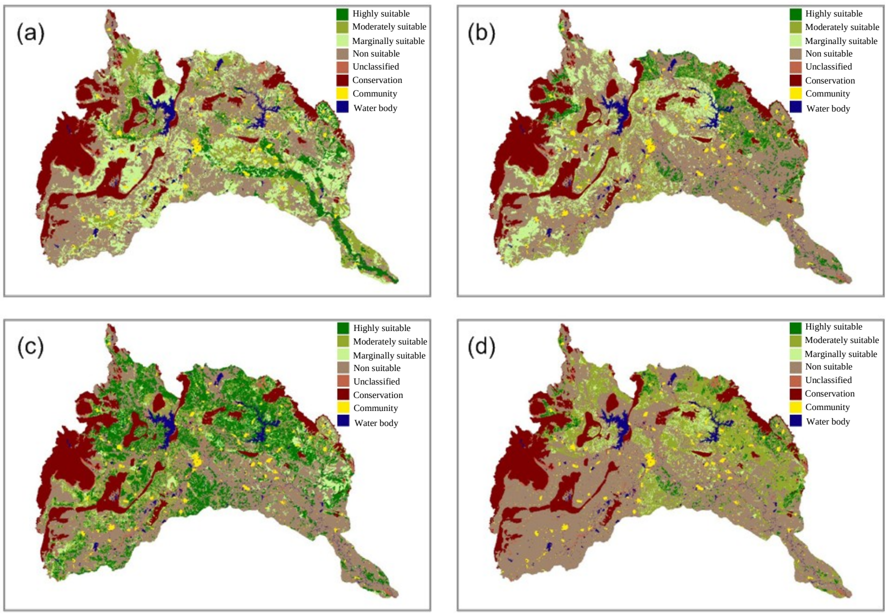

Figure 3. Suitability map for rice(a), sugar-cane(b), cassava(c) and rubber tree(d)

4.2 Agricultural land use plan

The agricultural land use plan, based on the combination of crops, is shown in Figure 4. The areas occupied by each unit are illustrated in table 7.

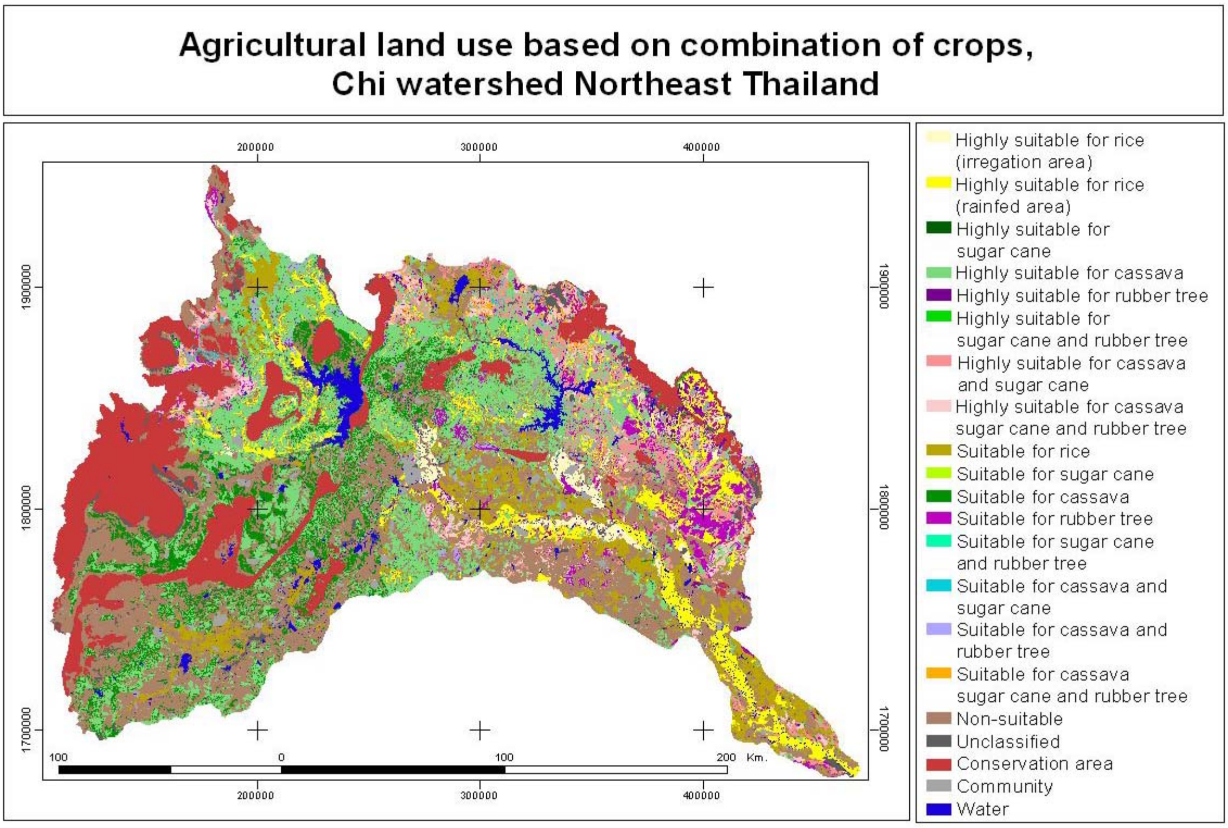

Figure 4. Agricultural land use based on combination of crops, The Chi watershed Northeast Thailand.

The study provides information about the areas suitable to the crops, not only individual crop but also the crop combination. This is to offer the alternatives for agricultural land use in order to lessen the marketing risk. The land suitable for rice could be found extensively in the flood plain of the watershed. The legal reserve areas are restricted to the mountain areas with steep slope normally covering with dipterocarp and evergreen forests. The land use plan as identified in this study can be applied at watershed area. At this scale we need a broad planning strategy, policies, priorities and operational planning to put the work implemented. The integration of development and conservation is then needed. In this process we still need the economical and social analysis, public and executive discussion and the plan formulation to fulfill the planning. However, the spatial information obtained offers the decision maker with reasonable suitability maps.

It should be observed that the variation in the result is due apparently to the values of each land quality assigned, particularly the soil and water availability. This will require further empirical research to determine these values.

5. CONCLUSIONS

In conclusion, GIS-based land evaluation can provide thematic layers which were possibly formulated the dynamic scenarios for the establishment of integrated information. The integration process with geographic references is widely accepted for creating the spatial decision support system. In terms of land management the watershed is the area best suited for natural resource management to allocate land uses to land for sustainable development. With the GIS-based land evaluation, it is possible to revise land use plan if necessary for the future.

Table 7 Agricultural land use, The Chi watershed, Northeast Thailand.

Suitability	Area	
	Sq. Km.	%
Highly suitable for rice (irregation area)	666.85	1.35
Highly suitable for rice (rainfed area)	2,732.70	5.52
Highly suitable for sugar cane	6.41	0.01
Highly suitable for cassava	8,899.81	17.99
Highly suitable for rubber-tree	174.31	0.35
Highly suitable for sugar cane and rubber tree	46.25	0.09
Highly suitable for cassava and sugar cane	1,614.91	3.26
Highly suitable for cassava, sugar cane and rubber tree	1,266.92	2.56
Total of highly suitable area	*15,408.15*	*31.14*
Suitable for rice	3,141.54	6.35
Suitable for sugar cane	0.87	0.00
Suitable for cassava	3,244.68	6.56
Suitable for rubber tree	1,559.10	3.15
Suitable for sugar cane and rubber tree	2.59	0.01
Suitable for cassava and sugar cane	75.49	0.15
Suitable for cassava and rubber tree	346.63	0.70
Suitable for cassava, sugar cane and rubber tree	302.70	0.61
Total of suitable area	*8,673.59*	*17.53*
Total of highly suitable and suitable area	**24,081.74**	**48.67**
Non-suitable	13,791.42	27.87
Total of non-agriculture	**11,603.85**	**23.45**
Unclassified	1,506.47	3.04
Conservation area	7,375.39	14.91
Community	1,502.91	3.04
Water	1,219.08	2.46
Total	**49,477.00**	**100.00**

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