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Original Article

Integration of land qualities for assessing land suitability for rice in the Chi basin

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Abstract

Land suitability is generally established based on a combination of land qualities required by rice. In this study, the evaluation is accomplished with objective of examining a quantitative aggregation of land qualities with the multicriteria decision analysis (MCDA) model using GIS. The study area is the Chi basin, Northeast Thailand with an area of about 4,947,700 ha. The procedure of fusing the land qualities entailed the excluded area, the MCDA model applied for fusing the land qualities in the rest while the multiplicative model used with limiting conditions. The land qualities used in the MCDA encompass water availability, nutrient availability index, nutrient retention, water retention, salt hazard. Each was treated as a thematic layer in the GIS database. The rooting condition is limiting condition used for spatial overlay with the MCDA layer by the multiplicative model. The results obtained are checked against the harvesting plots and Land Development Department (LDD) map, yielding high accuracy. It is evident from the study that land suitability for rice covers about 26% of the area for highly and moderately suitable land. The GIS technology offers the tool to effectively model the land suitability with its capability in variable fusion.

Keywords: fusion of land qualities, rice, the Chi basin, GIS

1. Introduction

Thailand's paddy production, mostly rainfed main season rice accounts for about 30 million tons, about 55 % of which is for export (Vanichanont, 2004). The government efforts to limit the expansion in rice planting areas and the discontinuation of the paddy pledging program in 2015 were result from a decline in the export price (Royal Thai Government, 2015). Aerial orthophotography analysis depicted the total bund- paddy fields in Thailand of about 11.7 million ha or 47.68 % of the agricultural areas (Office of Agricultural Economics: OAE, 2012b). Over 66 % of bund-paddy fields are found in Northeast Thailand where rice yield is relatively low. An accurate land suitability map is requisite for allocating the suitable areas in support of rice planting continuation.

Problem encountered in the establishment of land suitability unit is a formulation of optimally combining land qualities and their ratings to match with the unit. In the process of assessing the land suitability, combining the individual land quality rating into an overall suitability varies greatly according to circumstances. In Thailand, the method of limiting conditions, based on soil unit appended by other land a quality is used (Land Development Department [LDD], 1991). The availability of land suitability for rice made available to public as Agri-map is to limit the rice planting areas in marginal lands (Agri-map online, 2016). To satisfy the rice requirements, an interaction of land qualities may include its limiting conditions and additive effects. The method of limiting conditions should always be followed where there is an assessment of not suitable (N), the procedure is relevant to the well-known law of minimum in agriculture which implies that

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the crop yield will determined by the lowest supply of the plant nutrient. As for the additive effect, the multicriteria decision analysis (MCDA) is widely used in many studies for land suitability. The MCDA is used with twelve geographical data sets as input in the method, achieving good result after cross checking the model with the existing maps (Samanta, Pal, & Pal, 2011). This study conducted in Papua New Guinea to improve agricultural land management. with an advent of GIS and Fuzzy membership model, successful use of the technology for assigning a pixel to any one suitability class and matching the soil properties with more than one suitability class to different extents was achieved (Ahamed, Rao, & Murthy, 2000). Another study applied a MCDA carried out in GIS environment to delineate suitable production areas for five major crops in West Bengal, India (Santra & Mitra, 2016). It synergies the limitation method of land capability classification (Kliengebiel & Montgomomery, 1961), productivity potential evaluation process (Requier, Bramao, & Cornet, 1970) and crop suitability framework of Food and Agricultural Organization of United Nations (FAO, 1976).

Attempts to our study are to apply MCDA for additive effect and multiplicative model for those having limiting conditions. This study examins an integration of land qualities excluding the management and conservation requirements, which are essential for the most of land evaluation. Hence, the objective of this study is to examine a quantitative aggregation of land qualities with the MCDA model using GIS.

2. Study Area

The study area encompasses an extensive portion of the central part of northeastern Thailand. It includes the Chi basin, which is being used as an evaluation of suitability area for rice in the region (Figure1). Covers an area of about 4,947, 700 ha and is drained to the east by the Mun River and eventually by the Mekong River at the Thai-Lao, PDR border. Physio-graphically, the Chi basin is formed by the strong topography in the upstream portion and flat to gently undulating landscapes in the central and downstream portions of the river. The land cover consists of dipterocarp and evergreen forests in the upland mountain zone, field crops on well drained soils of the gently undulating areas, and paddy rice on the flat and low lying areas. Isolated patches of remnant forest are commonly found throughout the Chi basin. Geologically the area is underlain by a thick sequence of Mesozoic sediments, the Korat Group ranging in age from upper Triassic to Tertiary. The extensive alluvial plain is underlain by the Maha Sarakham Formation (a formation of the Korat Group), which was deeply weathered in the Tertiary period and contains considerable quantities of evaporates interblended with sandstones siltstones and sandy shales. The occurrence of this formation coincides with the distribution of salt affected soils. The soils on the undulating landscapes are mainly derived from alluvium of sandstone origin. The mean annual rainfall ranges from 1,000-1,500 mm. and increases from the west to the east portions of the region.

3. Materials and Method

A model of deriving overall land suitability for rice is evaluated by matching between a set of land qualities and crop requirement (Food and Agricultural Organization of United Nations [FAO], 1983). For rice crop, its requirements in terms of the set land qualities to be used in the evaluation process were previously reviewed (FAO, 1983; Mongkolsawat, Thirangoon, & Kuptawutinan, 1997; Sys, Ranst, Debaveye, & Beernaert, 1993). In the Chi Basin, some of the FAO defined land qualities that yielded negligible difference within the country were excluded from the evaluation. Further, various experimental field reports and regional experimental were also reviewed to help define the land qualities.

As for the process of fusing the land qualities, the upland, well drained soils are excluded and then the MCDA model is applied for fusing the land qualities in the rest. The MCDA is a weighted sum applied for entities having additive effect (Dodgson, Pearman, & Phillips, 2009) while the multiplicative model used with limiting conditions (FAO, 1983). We set the suitability classes, based on the fusion with reference to the rice yield collecting nationwide for a decade (2004-2013) (OAE, 2004, 2005, 2006, 2007, 2008, 2009, 20 10, 2011, 2012a, 2013). An integrated model of land qualities (Figure 2) with following definitions was conducted.

3.1 Excluded areas

Rice requires high water condition and imperfectly to moderately well drained soils on which the upland areas are excluded layer and assigned as not suitable class) Sys, Ranst, & Debaveye, 1991 .(In the FAO guidelines the oxygen availability is land quality by which soil drainage is diagnostic factor .Soil drainage as defined by Soil Science Division Staff (2017) most of which are given for digital analysis. The

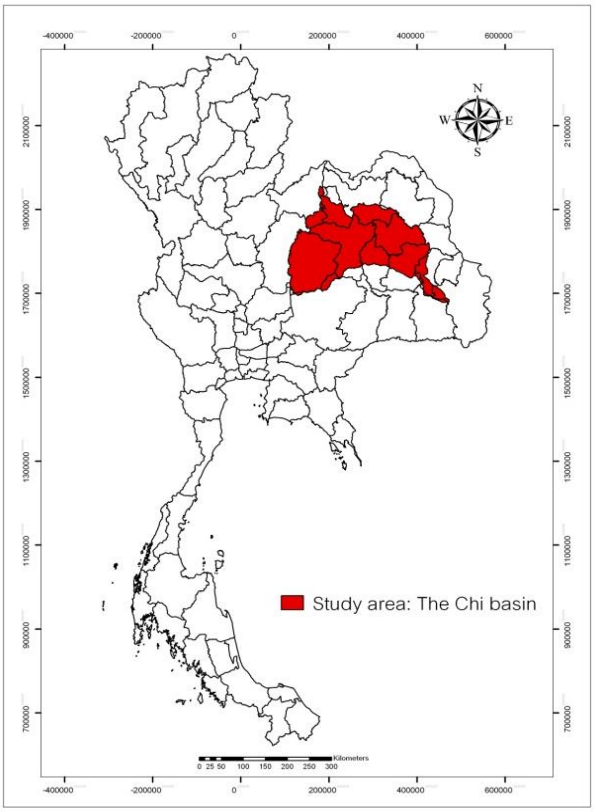

Figure 1. Study area: Chi Basin.

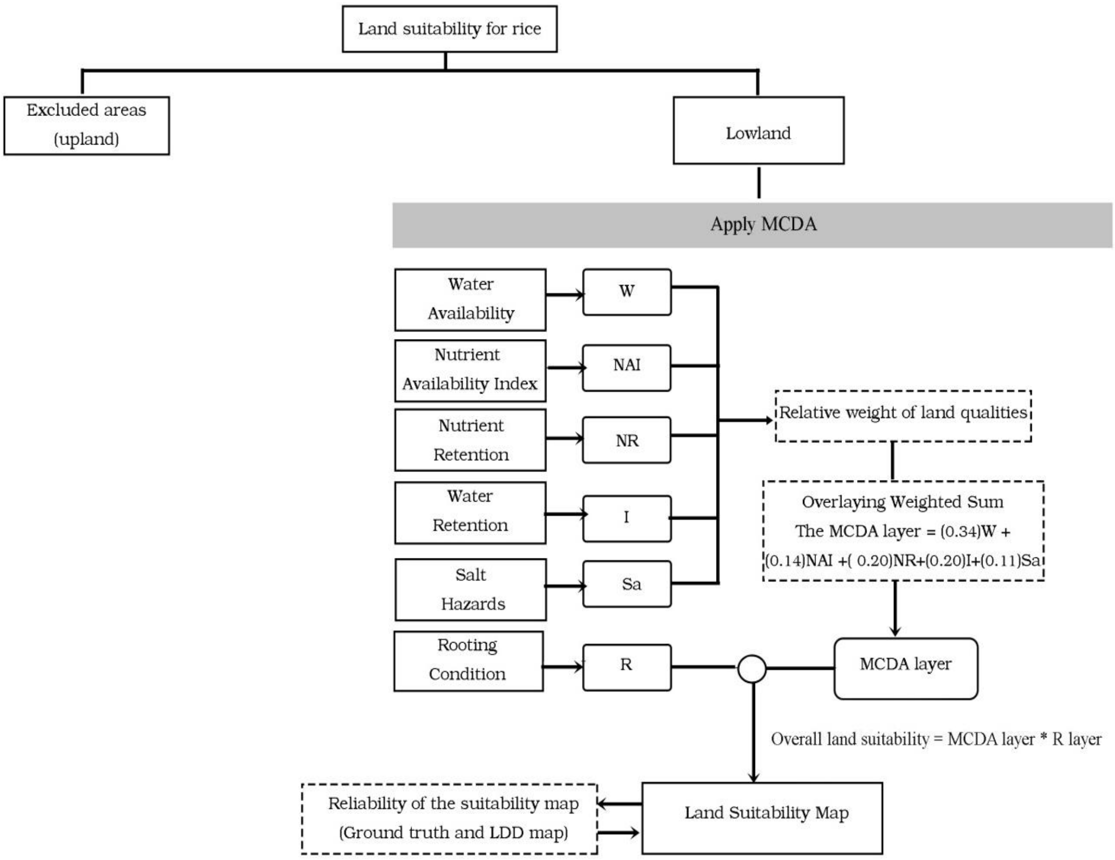

Figure 2. Schematic chart and MCDA model.

drainage class available from digital soil map and its associate attributes was used for the creation of the excluded areas (LDD, 2011).

3.2 MCDA

The land qualities used in this step of evaluation included water availability (W), nutrient availability index (NAI), nutrient retention (NR), water retention (I), salt hazard (S). Each was treated as a thematic layer in the GIS database. Determination of the factor rating values for individual land quality ranging from 1.0, 0.8, 0.4 and 0.1 for highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N). The MCDA evaluation for the rice in the Chi basin is based on the weighted sum of land qualities with the following definitions:

$$\text{MCDA}= \sum_{i=1}^{n} W_i X_i \quad (1)$$

where W_i is weighted score, X_i is land quality rating (Dodgson *et al*., 2009) .

Details of the information used are as follows:

a) Water availability: Rainfall data of 33 years (1975-2008) recorded by the Meteorological Department were used for the establishment of the 'W' layer. Spatially interpolated, mean annual rainfall for the entire Northeast region of Thailand was conducted with Kriging of the station data to yield a 'W' spatial map. The spatial 'W' layer was then divided to 4 suitability classes as defined by Mongkolsawat, Putklang, and Noppitag (2009) for the crop to be eva-luated (Table 1). The factor ratings 1.0, 0.8, 0.4 and 0.1 are assigned for S1, S2, S3 and N respectively, according to mean annual rainfall.

b) Nutrient availability index: The NAI, is based on the method developed by Radcliffe and Rochette (1982) and is given by NAI= N x P x K x pH. The digital soil map layers and associated attributes provided information of N, P, K and pH, (in Table 1) those of which were used in the overlay process to create the spatial layer of NAI. The values of the rating factor of the NAI component were given by Mongkolsawat *et al*. (2009).

The lower limit of the NAI is set at $(0.8)^4$ or 0.4096, $(0.4)^4$ or 0.026 and $(0.1)^4$ or 0.003 for the factor rating 1.0, 0.8 and 0.4 respectively.

c) Nutrient retention: The NR used is defined as follows: NR = CEC* BS where CEC is cation exchange capability and BS is base saturation. The establishment of this layer was performed by spatial overlay of CEC and BS the values of factor rating of the NR was assigned and given by Charauppat and Mongkolsawat (2003) in Table 1.

d) Water retention: Water retention was compiled from soil texture on which the factor rating values for crop was based. The values assigned to the crops are referred to a number of studies (Mongkolsawat *et al*., 2009; LDD, 19 91) by which the 'I' layer was established in Table 1.

Table 1. Factor rating of land quality for rice.

Land quality	Diagnostic factor	Unit	Weight scores	Factor rating			
				S1(1.0)	S2(0.8)	S3(0.4)	N(0.1)
W	Mean annual rainfall	mm.	0.34	>1,500	1,100-1,500	800-1,100	<800
NAI	NAI =N*P*K*pH	-	0.14	>0.4096	0.4096-0.026	0.026-0.003	<0.003
	N						
	P	%		>0.5	0.08-0.5	0.08-0.04	<0.04
	K	ppm		>50	25-50	25-10	<10
	pH	ppm		>60	30-60	<30	-
		-		5.6-7.3	7.4-7.8	7.9-8.4	>8.4
					4.5-5.5	4.0-4.5	<4.0
NR	NR=CEC*BS	-	0.20	>0.64	0.0.16-0.64	0.01-0.0.16	<0.01
	CEC	Cmol/kg		>15	5-15	<5	
	BS	%		>35	<35		
I	Soil texture	-	0.20	CL,SiC, SiCL,C	L,SiL	LS,SCL ,SL	S,G,SC
Sa	Soil salinity	Class	0.11	Non-saline	Slightly saline	Moderately saline	Strongly saline
R	Soil depth	Cm.	-	>50	25-50	15-25	<15

Remarks: L = Loam, SiCL= Silty clay loam, SiL=Silt loam, SCL = Sandy clay loam, CL= Clay loam, C=Clay, LS= Loamy sand, SC=Sandy clay, SiC = Silty clay, S=Sand

e) Salt hazard : Soil salinity is an important edaphic constraint for the crop and originates from the Maha Sarakham geologic formation which underlies the areas. An available soil salinity potential map (Mongkolsawat & Paiboonsak, 2006) was used to assign the factor rating for the evaluation in Table 1.

Each of the defined land qualities with their associated attributes was digitally encoded in GIS database to create the five thematic layers .The diagnostic factors of each layer were assigned with factor rating values (S1=1.0, S2 = 0.8, S3 =0.4 and N =0.1). The formula for computing the MCDA in this study is as follows :

The MCDA layer = (0.34)W+(0.14)NAI+(0.20)NR+ (0.20)I+(0.11)Sa (2)

The weight score designated to the land qualities in Equation 2 results from a calculation as described by (Samanta *et al*., 2011). The creation of a matrix to assign the weights with relative score, 1, 2 and 3 was performed where the higher score is more important .The weight score to the land qualities used is shown in Table 1 .Averaging the score in the column gives the weight assigned to land qualities as in the Equation 2 .The weighted sum tool, which is available in ArcGIS version 10.1, is used to overlay five layers, multiplying each layer by its given weight, and then summing them together . The MCDA layer obtained is used for further analysis.

3.3 Land quality limitation

In USDA land capability classification the soil are grouped according to their potentialities and limitations for sustained production of the common cultivated crops (Kliengebiel & Montgomomery, 1961.) Rooting condition (R) is major land quality that plays important role in the land suitability evaluation due to its limitation for crops. Soil depth is diagnostic factor for the crop that has a significant limitation (Sys *et al*., 1993) Soil map development by LDD (2011) provides the soil depth by which the factor rating values for the rice were assigned (Mongkolsawat *et al*., 2009). This layer is digitally encoded in GIS database with attributes of factor ratings (Table 1).

3.4 Overall suitability

The overall land suitability for rice is calculated with the multiplicative model:

Overall land suitability = MCDA layer *R layer (3)

where the obtained result was assigned 0.79 for S1, 0.32-0.79 for S2, 0.04-0.31 for S3 and less than 0.04 for N.

3.5 Validation

The reliability or accuracy of the suitability map for rice was assessed, based on the sample of harvesting plots of 1*1 m^2 .We used 60 exemplars distributed throughout the Chi basin to obtain the rice yields covering all suitability classes (Figure 3). Moreover, the result obtained was assessed, based on the suitability map compiled by LDD (2011). The decision for assigning the class was done by the rice yields collecting nationwide survey by OAE (2004-2013). The result map to be obtained uses to establish a cross tabulation to compare with the field-based class, LDD map and the suitability map for validation by which the Kappa statistic (K) was applied (McCloy, 2006).

The definition of K is:

$$K = \frac{p_o - p_e}{1 - p_e} \quad (4)$$

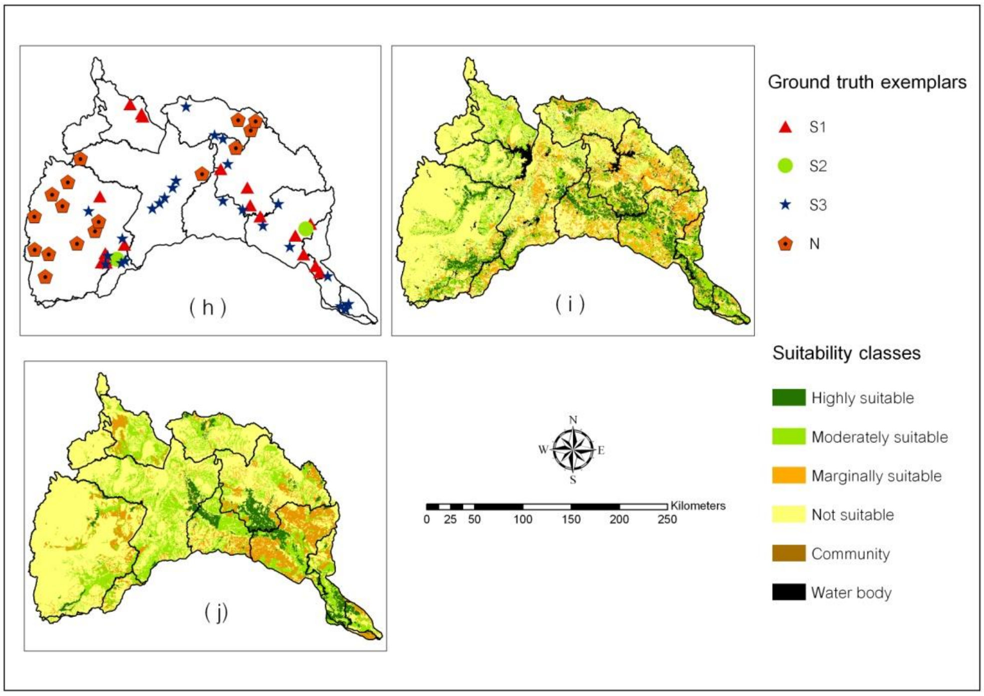

Figure 3. Ground truth exemplars (h), land suitability for rice (i) and the LDD map (j).

Where p_o is the overall agreement between the classification and p_e is the sum of the probabilities of each classification independently classifying pixel into each class.

The formulation and testing the model was performed and testing, followed by the iteration of the model to the geo-referenced ground information to create the best result .

4. Results and Discussion

4.1 Suitability rating maps

Suitability rating maps of land qualities were achieved using spatial analysis tools of GIS (Figure 4). In these maps, their suitability was divided into four classes; the suitable level was defined as 1.0, 0.8, 0.4 and 0.1 for S1, S2, S3 and N respectively .The map database provides overall insight of individual land quality and used for management requirement within the unit .Some land quality layers were created by more than quality by degrees of limitation, for example: NAI = N*P*K*pH. Meanwhile, the suitability rating map has certain relationship with the other and jointed into overall suitability.

4.2 Suitability map

The land suitability map for rice resulting from the spatial overlay of the land qualities for rice is shown in Figure 3. The suitability is in addition to the spatial information of the rice is shown in Table 2. The study provides the overall insight into each land quality for rice and the suitability resulting from the fusion of land qualities spatially and quantitatively. It is evident from the study that land suitability for rice covers over 26% of the area for highly and moderately suitable land. The unsuitable lands include the excluded areas (upland) and portions of the lowland. The highly suitable land is mostly found on flood plain of the Chi basin. As for the combination of land qualities used their limitations represented by multiplicative model while those having supplementary effect applied additive model. Fusing the component model provided the overall suitability for rice. It can be noted that within a set of land qualities there still have limitation layers. So that the multiplicative model was applied to create the meaningful result. A number of approximations and corrections of the land unit were subsequently made. This iteration was performed and tested to select a satisfactory result with reference to the yields of the harvesting plots. However, matching the suitability class with the yields is difficult task, not all trials are well fitted to the model because of different degrees of the crop management.

The finding in response to the rice yields as collected from the OAE applies for setting the S1, S2, S3 and N . A comparison of the rice yield between the harvesting plots and OAE data the S1, S2, S3 and N can be set as follows :

S1 =greater than $\overline{X}$+1/2 SD
S2 =between $\overline{X}$+1/2 SD to X-1/2 SD
S3 =between $\overline{X}$ - 1/2SD to X -1SD
N =less than S3

where $\overline{X}$ is the mean of nationwide rice yields, and SD is the standard deviation. The result obtained including means and their SD of nationwide rice yields and various regions is shown in Figure 5 .Average rice yield in Thailand is 2,991.23 kg/ha, the Central region produces highest yield, accounting for 3,954.26 kg/ha while the lowest yields are found in the Northeast.

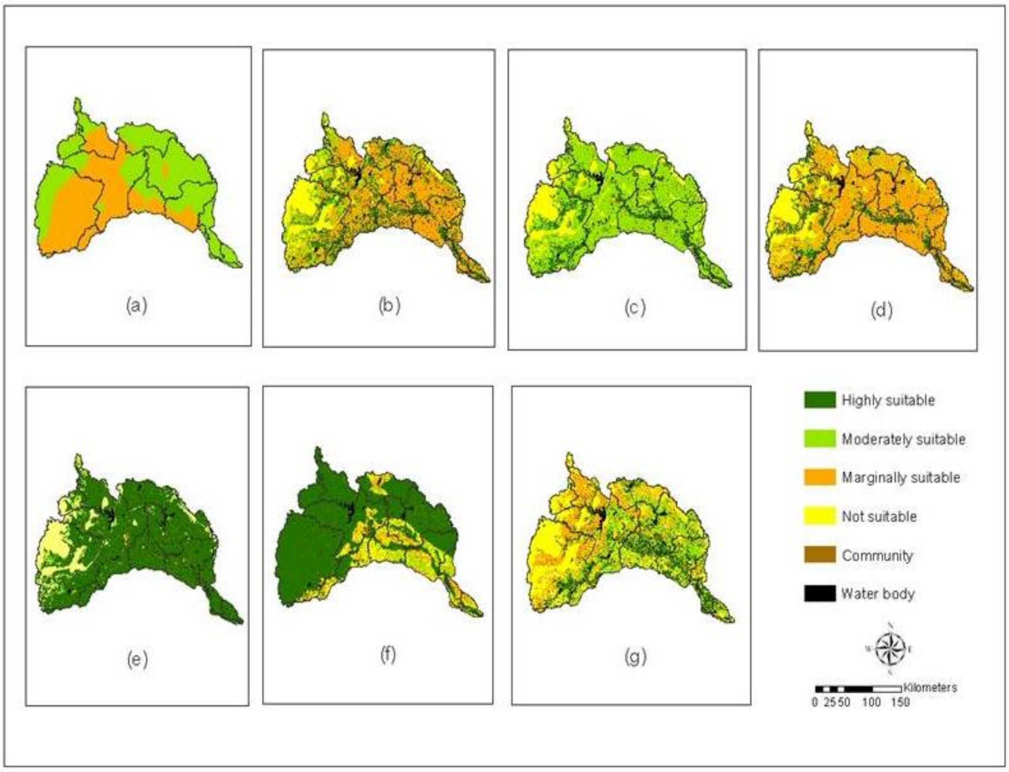

Figure 4. Suitability rating maps of land quality (a), water availability (b), nutrient availability index (c), nutrient retention (d), water retention (e), rooting condition (f), salt hazard and (g), oxygen availability.

Table 2. Suitability area for rice.

Land suitability for rice	Area(ha)	Percent (%)
S1	460,663	9.311
S2	844,037	17.059
S3	727,673	14.707
N	2,658,536	53.733
Total area of the Chi = 4,947,700 ha		

4.3 Reliability of suitability map

As the matter of the validation of the result, we compared the suitability map with the rice yields from the harvesting plots (ground truth), the confusion between ground truths of 60 locations and the suitability map is shown in Table 3. It indicates overall accuracy of 79.66 % with Kappa coefficient 0.71. The producer's accuracy and user's accuracy found in Table 3 show satisfactory result. As a result of the statistic, the agreement between the result maps and ground truth is reliable for this study.

Another comparison between the land suitability map and the map compiled by LDD was made, the agreement between established map and LDD map (Figure 4) with overall accuracy, Kappa coefficient, user's accuracy and producer's accuracy is shown in Table 4. Of 60 location samples overall accuracy is 81.66 % with Kappa coefficient 0.75, it indicates highly reliable result. And comparison between the harvesting plots (ground truth) and the LDD map it indicates overall accuracy of 68.33 % with Kappa coefficient 0.57 shown in Table 5. The mismatches are likely due to intensive land management and high level inputs made by individual farmers.

The results obtained are relevant to both of the harvesting plots and LDD map so that the synergistic approach, integrating land qualities by MCDA model is feasible. We can apply the method not only for the Chi Basin but also for the country as a whole. However, it would suggest caution in the application of this model. Numerous factors likely contribute to the apparent inaccuracies of the output map. The validation was less than perfect because the dynamic of some land qualities.

5. Conclusions

In conclusion, the excluded area combined with MCDA model is provision to contribute an approach to a combination of land qualities with reliable results. The results provide a mixed model for proposing the limiting conditions and supplement effects on which the model was based. In addition, a set of land qualities may be formed on the multiplicative model to achieve the layer for MCDA. The experiments and experience in agriculture help support in the efforts for the procedure used.

The GIS technology offers the tool to effectively model the land suitability with its capability of variable integration. The socio-economic aspect is beyond the scope of this study so that the evaluation is not perfect. Further, empirical study on choices of factor rating should be carried out to match with land characteristics. In terms of land management,

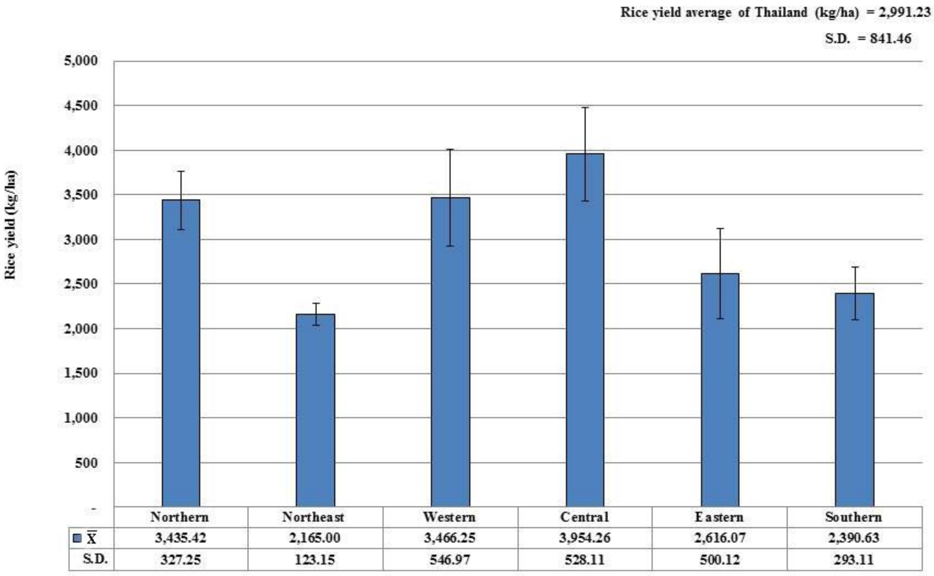

Figure 5. Mean of rice yield by region (OAE, 2004 -2013).

Table 3. Confusion matrix between the result maps and ground truth.

The result map	Ground truth					User's accuracy (%)
	S1	S2	S3	N	Total	
S1	13	2	3	0	18	92.85
S2	1	1	0	0	2	14.28
S3	0	3	19	2	24	85.71
N	0	0	0	16	16	88.23
Total	14	8	22	18	60	
Producer's accuracy (%)	72.22	50.00	78.26	93.75		

Overall Accuracy 79.66%; Kappa Coefficient of 0.71

Table 4. Confusion matrix between the result maps and The LDD map.

The result map	The LDD map					User's Accuracy (%)
	S1	S2	S3	N	Total	
S1	13	2	0	0	15	92.85
S2	1	11	1	2	15	73.33
S3	0	2	10	3	15	90.90
N	0	0	0	15	15	75.00
Total	14	15	11	20	60	
Producer's accuracy (%)	86.66	73.33	66.66	100.00		

Overall Accuracy 81.66%; Kappa Coefficient of 0.75

Table 5. Confusion matrix between the ground truth and The LDD map.

Ground truth	The LDD map					User's Accuracy (%)
	S1	S2	S3	N	Total	
S1	7	9	2	0	18	100.00
S2	0	2	0	0	2	13.33
S3	0	4	16	4	24	80.88
N	0	0	0	16	16	80.00
Total	7	15	18	20	60	
Producer's accuracy (%)	38.88	100.00	66.66	100.00		

Overall Accuracy 68.33%; Kappa Coefficient of 0.57

the watershed is the area best suited for natural resource management and allocation of land uses for sustainable land development. The maps and their associated statistic provided the area best suited to rice zoning. With GIS-based land evaluation, it is also possible to revise land use plans as needed in the future.

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