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Integration of land evaluation and the analytical hierarchical process method for energy crops in Kanchanaburi, Thailand

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ABSTRACT: The main objective of this study is to evaluate the land suitability for cultivation of some economically important energy crops, which are sugarcane and cassava, in Kanchanaburi province, Thailand. To achieve this goal, multi-criteria decision making (MCDM) integrated with the 1976 FAO framework for crop plantation was used to assess suitable areas for growing these crops. Several biological and economical factors involved in the analysis were selected based on the FAO framework and experts' opinions. Their data were kept, displayed, and used as individual and combined GIS layers. Each factor received a weight and a score which represented its relative importance in the suitability evaluation by using the analytical-hierarchical process method which is one of the widely used MCDM techniques. A land suitability map for each crop selected was produced based on the linear combination of weight and rating score of each factor involved and classified into 4 suitability classes according to the FAO standard. The proportion of the area highly suitable or moderately suitable for cultivation of sugarcane was 52%, and for cultivation of cassava, 45%. Only a small percentage of the area was not suitable. Typically, the most suitable areas for both crops were located in the eastern and lower part of the province having highly fertile soil and abundant water resources available therein. It was also found that most parts of the suitable area of both crops were located in the existing agricultural land (but being used for other crops/plants).

KEYWORDS: multi-criteria decision making, GIS, sugarcane, cassava

INTRODUCTION

It is clear that the energy crisis has spread all over the world as the price of petroleum has dramatically increased in recent years. One possible solution to ease this problem is to find renewable energy source such as ethanol as an alternative to petroleum. Ethanol is a liquid obtained from biomass of agricultural raw materials. Typically, two of the most popular crops for producing ethanol are sugarcane and cassava because they are cheaper than other candidate crops. As a result, the Thai government has recently issued a new policy in order to increase production of these two crops to meet growing demand in the energy market. The main objective of this study is therefore to find suitable areas for cultivating these crops efficiently.

The land evaluation method is the systematic assessment of land potential to find out the most suitable area for cultivating some specific crop. Theoretically, the potential of land suitability for agricultural use is determined by an evaluation process of the climate, soil, water resources, topographical, and environmental components under the criteria given and the understanding of local biophysical restraints[1]. At present, this process could be done efficiently and conveniently by using multi-criteria decision making (MCDM) integrated with a geographic-information system (GIS), which is an essential tool in storage, management, and analysis of spatial and non-spatial data. In the process, data of all selected factors (for each crop) are kept, displayed, and managed as individual or combined GIS layers which make them convenient to be analysed together spatially. Each factor (or criterion) is given a specific weight, which represents its relative importance in the suitability evaluation, by using some MCDM techniques like multi-criteria evaluation (MCE) or analytical hierarchical process (AHP). Each criteria weight could be multiplied with its associated criteria suitability rating (or score) for each land mapping unit and the results (from all factors) could be summed to produce a suitability score for each land unit of the final suitability map later using the GIS overlay technique.

There have been a number of studies that have employed the above methods. Ceballos-Silva and López-Blanco[1] applied the MCE approach to delineate suitable areas for maize and potato crops in Toluca, Central Mexico. Relevant criteria for crops and suitability levels were defined according to FAO standards, and criteria maps were introduced in the MCE algorithm to obtain a suitability map for each crop. Prakash[2] studied land suitability analysis for rice in the Dehradum district, India. The parameters for evaluation included soil, climate, irrigation area, and some socio-economic data (markets and infrastructure). In that study, the AHP technique was integrated with fuzzy logic to determine suitable area for the crop. Thapa and Murayama[3] used the AHP technique to evaluate land suitability for peri-urban agriculture in Hanoi city. The results showed that this technique could be very effective in helping policy makers to carry out a rapid assessment of the land. In addition, Boonyanuphap et al[4] assessed suitable areas for banana plantation in Phitsanulok province, Thailand using several combined factors. After that, the suitable area obtained was overlaid with a current land use map to find new possible sites for banana plantations in that province.

DATA AND METHODS

Study area

The study area is Kanchanaburi province which covers an area of 19 483 km^2 and is divided into thirteen districts. The topography of Kanchanaburi is a combination of mountain ranges, valleys, and river plains (Fig. 1). The northern and western parts are mostly covered with mountain, there is undulating land in the northeast, and the far east and the south are river plains. Important water resources found in the province are four dams and three main rivers. The local climate is tropical savannah, like most areas in Central and Northern Thailand.

There are 51 classified soil types in Kanchanaburi which fall into 14 great soil groups. These soil groups are formed from various soil parent materials, i.e. granite, limestone, and sandstone shale which can be weathered in place or transported by flood. Only 35% of the provincial area is not protected forests or conservation zones and can therefore be used for doing agriculture. Within this area, the most predominant soil groups found are paleustalfs and paleustults which occupy about 31.5% and 30.7% of the area, respectively, spreading in the east, west, and south.

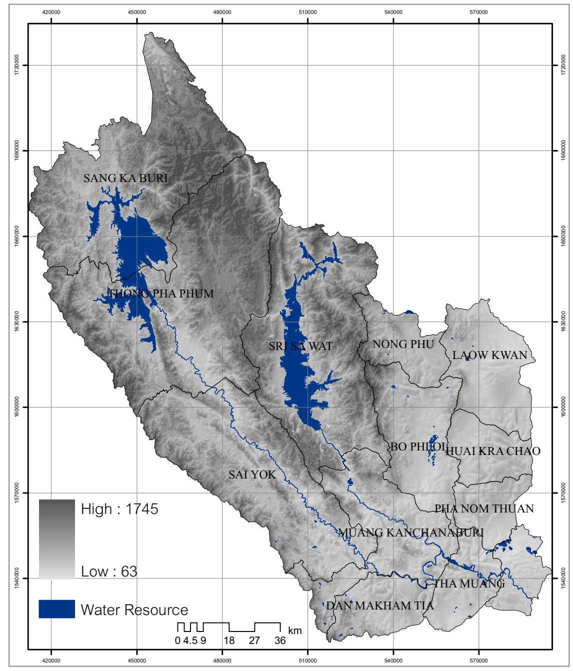

Fig. 1 Topography map of Kanchanaburi province, Thailand.

Data sources

The data used in this study were collected from a variety of sources. Firstly, the primary data from the field survey were collected through observation and questionnaires answered by experts in the field for identifying factors that are important for sugarcane and cassava planting in Kanchanaburi province. Also, a Lansat-5 TM satellite image from 2006 was used for land use/cover (LUC) classification along with GPS data, digital maps, and statistical data.

For land suitability evaluation, 9 factors (in the form of 9 GIS-based layers) were used for sugarcane and 10 for cassava. These factors were chosen according to 1976 FAO framework[6] and professional opinions given by 20 experts in this field through questionnaires distributed. The physical factors were topography (slope), climate (annual rainfall, temperature), soil potential and water supply (distance from water body, stream or rivers, irrigation zone). The socio-economic factors were the distance from main road and the distance from sugar factories, or the distance from cassava chip point, the cassava modifying factory.

The degree of suitability of each factor for each land unit studied was classified as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), or not suitable (N), as seen in Table 1. The clas-

Table 1 Classification criteria in land suitability analysis for sugarcane and cassava.

Classification criterion	Factor suitability rating for sugarcane				Factor suitability rating for cassava			
	S1	S2	S3	N	S1	S2	S3	N
Slope[5] (%)	0–12%	12–20%	20–35%	>35%	0–12%	12–20%	20–35%	> 35%
Rainfall (mm.)	1200–1500	1500–2500, 900–1200	2500–4000, 500–900	<500 >4000	1600–2500	1200–1600 2500–3000	900–1200 3000–4000	<900 >4000
Temperature[5] (°C)	25–29	30–32 14–24	33–35 10–13	>35, <10	24–27	28–31, 19–23	32–35, 18–15	>35, <15
Soil suitability	high	moderate	marginal	not	high	moderate	marginal	not
Stream (m)	<500	500–1000	1000–1500	>1500	<500	500–1000	1000–1500	>1500
Waterbody (m)	<500	500–1000	1000–1500	>1500	<500	500–1000	1000–1500	>1500
Irrigation zone (km)	inside	outside 0–1	outside 1–5	outside >5	inside	outside 0–1	outside 1–5	outside >5
Distance from road (km)	< 1	1–5	5–10	>10	< 1	1–5	5–10	>10
Distance from sugar factory (km)	<50	50-75	75–100	>100	<50	50–75	75–100	>100

sifying criteria followed the FAO crop requirement guidelines. Restricted areas including conservation areas, fertile forest, and watershed class A areas were masked during the evaluation process as it is unlikely that these areas would be employed for agricultural use.

Generate criteria maps

The related factors, both bio-physical and socio-economical, were created and kept as GIS layers. Slope was generated from a digital elevation model. Rainfall and temperature were interpolated from their long-term average values using inverse distance weighted and spline methods, respectively. The raw data used were those collected during 31 years from 92 stations located around the province. Soil suitability for sugarcane and cassava was assessed by FAO land quality evaluation[5] which consists of 4 main factors: oxygen availability (soil drainage), nutrient availability (N, P, K, pH), nutrient retention capacity (cation exchange capacity and base saturation), and water retention (soil texture). With regard to water supply, river, water body, and irrigation distance were taken into consideration for proximity analysis. Concerning socio-economic factors, main road, factory (sugar, cassava modifying), and cassava chip point distance were considered and then analysed by the proximity method.

Determination of weight and score for each factor

Weight and score for each factor chosen in the study were determined based on the AHP[8,9]. This method evaluates the relative significance of all factors involved by assigning a weight for each of them in a hierarchical order. For the last level of the hierarchy, a suitability score (or rating) for each class of factors is given. The method is usually implemented using the pairwise comparison technique that simplifies preference ratings among decision criteria. In this study, experts' opinions were used to calculate the relative importance of the involved factors (or criteria)[10].

The first step to achieve this goal was developing questionnaires where experts were asked to determine the relative importance of each factor compared to one another. Results of the comparison (for each pair of factors) were described in term of integer values from 1 to 9 where higher number means the chosen factor is considered more important than the other. The overall results were kept (and managed) in the form of a pairwise comparison matrix where the relative weight (and score) for each critical factors could be derived[9].

In land suitability applications, land biophysical data are normally weighted and rated. In MCE using a weighted linear combination, the assigned weights need to be summed up to 1 for each category/sub-category defined. However, each factor in the last layer was classified into 4 suitability classes (S1, S2, S3, N) and their suitability scores were presented in the standardized format ranging from 0 (least suitable) to 1 (most suitable)[9]. The overall result of the weights and scores for each factor involved in each hierarchical layer is shown in Table 2 for sugarcane and Table 3 for cassava. Details of the derivation process of weights and scores using the AHP are discussed in Refs. 2, 7, 11–13. In addition, a critical review of the uses and limitations of AHP is given in Ref. 14.

To ensure the credibility of the relative significance used, the consistency ratio (CR) was also calculated. This value indicates the probability that the ratings were randomly assigned. Saaty[15] suggested

Table 2 Criteria weight and rating for sugarcane land suitability analysis.

Layer 1		Layer 2		Layer 3		Total	Layer 4	
Criteria	Weight 1	Criteria	Weight 2	Criteria	Weight3	Weight	Criteria	Rating
Biophysical	0.792	Topography	0.31	Slope	1	0.245	S1	1
							S2	0.375
							S3	0.160
							N	0.073
				Rainfall	0.849	0.202	S1	1
							S2	0.524
							S3	0.256
							N	0.102
		Climate	0.30	Temperature	0.151	0.036	S1	1
							S2	0.526
							S3	0.275
							N	0.118
		Soil potential	0.26	Soil potential	1	0.206	S1	1
							S2	0.464
							S3	0.201
							N	0.088
		Water supply	0.13	Distance from river/ stream	0.362	0.037	S1	1
							S2	0.432
							S3	0.203
							N	0.084
				Distance from water body	0.306	0.032	S1	1
							S2	0.445
							S3	0.261
							N	0.080
				Irrigation zone	0.332	0.034	S1	1
							S2	0.335
							S3	0.161
							N	0.073
Socio-economic	0.208	Market	1	Distance from main road	0.670	0.139	S1	1
							S2	0.503
							S3	0.237
							N	0.090
				Distance from sugar factory	0.330	0.069	S1	1
							S2	0.503
							S3	0.234
							N	0.090

that if the CR is smaller than 0.10 then the degree of consistency is fairly acceptable. But if it is larger than 0.10 then there are inconsistencies in the consideration, and the AHP may not yield meaningful results. Brief details of the CR calculation are given in Refs. 11, 13.

The AHP weights were calculated using Microsoft Excel. The values of the CR were also calculated and found to be 0.06 for sugarcane and 0.01 for cassava, which are acceptable for using the AHP.

Land suitability assessment

Land suitability maps were made using the GIS overlay technique available in ARCGIS 9.2 where spatial data of each factor were kept and displayed as GIS spatial layers (9 layers for sugarcane and 10 layers for cassava). The total suitability score R_{s} for each land unit (i.e. each raster cell in the map) was calculated from the linear combination of suitability score obtained for each factor (or criterion) involved:

$$R_{\mathrm{s}} = \sum_{i=1}^{n} W_i S_i,$$

Table 3 Criteria weight and rating for cassava land suitability analysis.

Layer 1		Layer 2		Layer3		Total	Layer4	
Criteria	Weight 1	Criteria	Weight2	Criteria	Weight3	Weight	Criteria	Rating
Bio-physical	0.708	Topography	0.392	Slope	1	0.278	S1	1
							S2	0.420
							S3	0.207
							N	0.089
				Rainfall	0.845	0.144	S1	1
							S2	0.465
							S3	0.224
							N	0.422
		Climate	0.241	Temperature	0.155	0.026	S1	1
							S2	0.497
							S3	0.245
							N	0.099
		Soil Potential	0.281	Soil potential	1	0.199	S1	1
							S2	0.597
							S3	0.154
							N	0.058
				Distance from stream / river	0.483	0.029	S1	1
							S2	0.491
							S3	0.249
							N	0.107
		Water supply	0.086	Distance from water body	0.341	0.021	S1	1
							S2	0.463
							S3	0.232
							N	0.114
				Irrigation zone	0.176	0.011	S1	1
							S2	0.420
							S3	0.231
							N	0.102
				Distance from main road	0.519	0.152	S1	1
							S2	0.481
							S3	0.244
							N	0.097
Socio-economic	0.292	Market	1	Distance from cassava chip point	0.323	0.094	S1	1
							S2	0.425
							S3	0.222
							N	0.089
				Distance from modify cassava factories	0.158	0.046	S1	1
							S2	0.442
							S3	0.225
							N	0.089

where n is the number of factors, W_i is the multiplication of all associated weights in the hierarchy of ith factor (as seen in Tables 2 and 3) and S_i is the rating given for the defined class of the ith factor found on the assessed land unit[1,17].

The total suitability scores from each land unit had a score ranging between 0 to 1 and were assembled to create land suitability map for each selected crop. Data in the maps were divided to represent 4 suitability classes according to the FAO framework[6,18], namely, highly suitable (0.8–1.0), moderately suitable (0.4–0.8), marginally suitable (0.2–0.4), and not suitable (0.0–0.2).

Suitability map application

The obtained suitability map was applied to real cultivation practice to find areas where sugarcane and cassava could be cultivated more in the future by cross-tabulating with land use/cover (LUC) map for 2006. The LUC map for 2006 was derived from a Landsat-5

Table 4 Proportion of area covered for each suitability class for sugarcane and cassava (total area, 4135 km^2).

Crop	S1	S2	S3	N
Sugarcane (%)	6.9	45.6	45.0	2.5
Cassava (%)	21.5	23.5	49.4	5.6

TM image taken on 3rd February 2006 and using 453-RGB combination. The supervised classification was employed using maximum likelihood. There were 12 LUC classes presented in the map.

RESULTS AND DISCUSSION

Classified land suitability maps

From the suitability maps obtained, as seen in Fig. 2 for sugarcane and Fig. 3 for cassava, it was found that the most suitable areas for these crops were located in the eastern and lower part of the province due to a fairly fertile soil and abundant water resources available therein. The highly suitable area for cassava plantation could be found more easily than for sugarcane because, as a drought resistant crop, it can grow in dry areas and sandy soil, whereas sugarcane needs more water and better quality soil to grow effectively. Normally, areas suitable for sugarcane can be found in the plain area close to main water resources, such as big rivers or reservoirs, while cassava could be planted in the more up-hill areas further away from the main rivers.

Results of the area coverage in the classified suitability map for both crops are shown in Table 4. It was found that about 52.5% of the area was classified as highly/moderately suitable for sugarcane plantation and 45.1% for cassava. Only a few percent was classified as not suitable area (2.46% for sugarcane and 5.57% for cassava). However, the amount of highly suitable area for cassava (21.5%) is significantly higher than that of sugarcane (6.9%). Results of the finding indicated that Muang and Sai Yok districts were potentially suitable areas for these crops, while Bophloi and Danmakham Tia districts were the potential areas for cassava plantation.

Classified LUC map using Landsat-TM image

From the accuracy assessment process, it was found that the overall accuracy of the classification result was 79.58% and the kappa index was 78%. Table 5 shows the area coverage of each LUC class found in Fig. 4. It could be seen that, from the total area of 19 382 km^2 of the province being classified, about 66% was classified as forest area while 28% was used for various agricultural uses, such as planting rice, sugarcane, cassava, and other crops/trees. Less than 1% was classified as urban/built-up area.

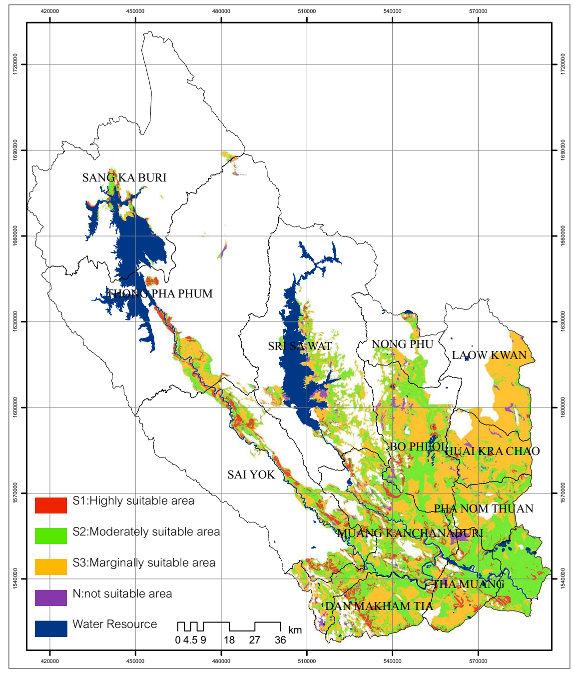

Fig. 2 Classified land suitability map for sugarcane in Kanchanaburi province.

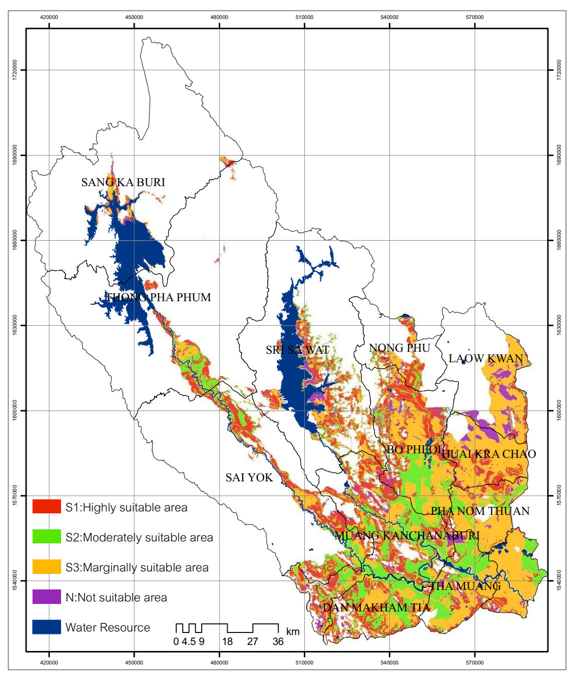

Fig. 3 Classified land suitability map for cassava in Kanchanaburi province.

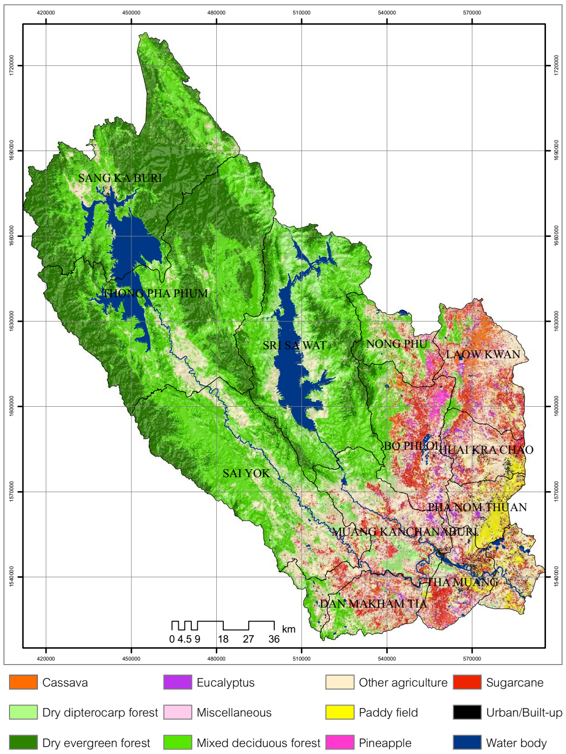

Fig. 4 LUC classes from 2006 Landsat-5 TM image.

Table 5 Area coverage of LUC classes in 2006.

LUC type	2006	
	km^2	%
Sugarcane	1253.94	6.47
Cassava	573.70	2.96
Paddy field	399.24	2.06
Eucalyptus	362.08	1.87
Pineapple	70.70	0.36
Other Agricultural	2758.31	14.23
Dry evergreen forest	5513.28	28.45
Mixed deciduous forest	5332.49	27.51
Dry dipterocarp forest	2018.62	10.42
Water body	812.01	4.19
Urban and built-up area	182.90	0.94
Miscellaneous	104.47	0.54
Total area	19381.74	100

Comparison between suitability map and LUC map

After land suitability maps for both crop were created (Fig. 2 and Fig. 3) and the restricted areas were marked, they were compared with LUC map in 2006 (Fig. 4) to find potential areas where these crops could be planted further apart from the existing growing area presently found in the LUC map. Results of the comparison for both crops (Tables 6 and 7), indicated that the highly and moderately suitable areas fell upon two LUC features which are forest areas (dry evergreen forest and mixed deciduous forest in particular) apart from the restricted area marked from the study, and the area which is currently employed for agricultural use already, especially for growing some crops/trees.

Considering plantation area of sugarcane and cassava in particular, it could be seen that the present growing areas for both crops are still small compared to the potential suitable area found in the analysis (highly/moderately suitable areas in particular). Therefore, it is still highly possible to expand growing area for these crops by converting the existing agricultural areas which are being used for other crops/trees (like paddy fields) to cultivate these two energy crops instead.

In summary, the government might consider providing some degraded forest areas (outside the conservation zone) for local farmers as land resources for growing these crops. If these suggestions were done efficiently, a significant increase in the amount of sugarcane and cassava production could possibly

Table 6 Percentage existing LUC for each sugarcane suitability class.

Suitability Class	S1	S2	S3	N
Cassava	5.17	5.23	10.16	6.87
Eucalyptus	3.29	3.62	6.66	4.74
Miscellaneous	1.07	1.08	0.46	0.60
Mixed deciduous forest	0.15	0.42	0.10	0.00
Pineapple	0.10	0.39	0.96	0.88
Paddy field	6.63	12.69	5.53	3.04
Sugarcane	25.53	30.16	27.26	19.45
Other agricultural land	48.30	40.34	45.39	51.15
Urban	1.87	3.25	1.52	2.23
Water body	7.89	2.82	1.95	11.03

Table 7 Percentage existing LUC for each cassava suitability class.

Suitability Class	S1	S2	S3	N
Cassava	8.49	8.66	10.75	12.26
Eucalyptus	4.54	4.62	5.19	6.54
Miscellaneous	0.81	0.97	1.21	0.57
Pineapple	0.08	0.02	0.03	0.08
Paddy field	4.67	6.31	12.33	4.19
Sugarcane	23.12	36.27	25.43	20.46
Other agricultural land	53.30	37.86	40.26	45.86
Urban	1.36	2.34	2.85	1.80
Water body	3.62	2.95	1.95	8.24

be achieved.

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