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Assessment of land use suitability for natural rubber using GIS in the U-tapao River basin, Thailand

Shahid Ali [a], Kuaanan Techato [b,*], Juntakan Taweenkun [c], Saroj Gyawali [d]

[a] Faculty of Environmental Management, Prince of Songkla University, Hat Yai, Songkhla 90112, Thailand
[b] Environmental Assessment and Technology for Hazardous Waste Management, Faculty of Environmental Management, Prince of Songkla University, Hat Yai, Songkhla 90112, Thailand
[c] Department of Mechanical Engineering, Faculty of Engineering, Prince of Songkla University, Kor-Hong, Hat Yai, Songkhla 90112, Thailand
[d] Research and Development Centre, GPO Box 9804, Kathmandu, Nepal

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Abstract

The assessment of available land resources for crops is an essential step in achieving sustainability in agricultural development. Thailand has been the world's leading rubber producing country since the 1990s. This research was conducted to assess the land use suitability for rubber trees in the U-tapao River basin. A geographical information system and multi-criteria decision making were used in parallel to establish the suitability of land for use as rubber plantations in accordance with the Food & Agriculture Organization framework. Various bio-physical and socio-economic factors were considered together with expert opinion. The weighting of each factor was conducted using an analytic hierarchy process. This study concluded that 14.46 percent of the basin area was highly suitable for rubber, 84.48 percent was moderately suitable, and the remainder was less suitable or unsuitable for the cultivation of rubber. This research will facilitate designing agriculture policies for sustainable agriculture development of the region.

Introduction

In Asia, especially in the Southeast Asian region, countries like Thailand, Malaysia and Indonesia have dominated global rubber cultivation over the last five decades (Somboonsuke, 2001). Thailand has been the world's leading rubber producing country since 1995, with an annual increase of 4–7 percent per year (Somboonsuke, 2001). Rubber is, therefore, one of the most important cash crops in Thailand and also has socio-economic importance owing to its productive value, the income from exports, and the job opportunities in this sector (Jawjit, Kroeze, & Jawjit, 2010). Rubber plantations dominate forest areas throughout Thailand where, the total planted area of rubber has increased by 1.71 percent per annum with an almost three-fold increase during the last four decades (Viswanathan, 2007). Compared to other parts of Thailand, the southern region has a higher concentration of rubber plantations, with 1,708,800 ha, or 84.62 percent of the total rubber planting area in Thailand situated in the region (Krukanont & Prasertsan, 2004). Within the southern region, Songkhla province has the highest density of rubber plantations covering 66.58 percent of the total planted area of the region. Since, the climate of the southern region is tropical (Khedari, Sangprajak, & Hirunlabh, 2002), it is highly suitable for rubber. Therefore, the area devoted to rubber plantations has been increasing rapidly accompanied by improving living standards among the local people (Simien & Penot, 2011; Somboonsuke, 2001).

* Corresponding author.
E-mail address: kuaanan.t@psu.ac.th (K. Techato).
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Even though rubber is one of the major economic crops of Thailand, only limited research relating to land suitability has been conducted (Prommee & Somboonsook, 2001). Mongkolsawat and Putklang (2010) discussed land use suitability for rubber using parameters such as the availability of water, oxygen, and nutrients in northeast Thailand and concluded 5.28 percent land was highly suitable and 16.70 percent land was moderately suitable with the remainder being less suitable or unsuitable for the cultivation of rubber. Mongkolsawat and Paiboonsak (2009) evaluated the land use suitability for rubber in the Chi watershed, central northeastern Thailand using multi-criteria decision making (MCDM) and GIS, based on a nutrient index, soil drainage, texture, depth, and salinity. They study concluded that 3.01 percent of land was highly suitable and 22 percent land was moderately suitable with the remainder being less suitable or unsuitable for the cultivation of rubber.

Conducting suitability analyses is very important for the sustainable agricultural development of any crop and the FAO guidelines on land suitability are the generally accepted standard for suitability analyses (Food & Agriculture Organization [FAO], 1983). Presently, MCDM accompanied by GIS is widely used in solving such problems, as it is more effective than other methods (Srisawat & Payakpate, 2016). MCDM is an efficient way to resolve complex problems related to decision making by classifying and analyzing them using decision criteria (Jankowski & Andrienko, 2001) and GIS is the most powerful tool available to analyze land use suitability (Tienwong, Dasananda, & Navanugraha, 2009).

In the U-tapao River basin in southern Thailand, to the best of the authors' knowledge, no studies have so far been conducted of land suitability for rubber cultivation even though it is the dominant crop grown in the basin. However, analysis of the land use data between 2000 and 2009 indicated that residential land use had increased to 96.16 percent after 2006, resulting in serious ecological problems in the basin (Gyawali, Techato, Yuangyai, & Monprapussorn, 2012). Therefore, an analysis of the suitability of the land for use as rubber plantations is essential. This study aimed to use MCDM in a GIS environment to identify which areas are most suitable for growing rubber as a means of aiding the sustainable development of this region.

Data and Methodology

Study Area

The area was in the U-tapao River basin, which is a sub-basin of the larger Songkhla Lake basin, within Songkhla province, Thailand. The basin is approximately 60 km long from north to south and 40 km wide from west to east comprising a total area of 2,305 km^2 and extending form 100° 10′ through 100° 37′ E and 6° 28′ through 7° 10’ N (Figure 1). The province where this river basin exists is famous for its fertile land, where rubber is the dominant crop in the plains, whereas the mountainous regions bordering the basin are dominated by forest land. Topographically, most of the land in the basin is flat. The annual average rainfall in the basin is 2,216 mm varying between 1,600 and 2,400 mm. The climate of the region where the basin is situated is governed by two monsoon seasons, the northeast and southwest monsoons. The annual average temperature does not exceed 28 °C, with the highest temperatures occurring in March—April and the lowest temperatures between November and January (Gyawali et al., 2012).

Data and Sources

The data collected for this research were relevant to the suitability criteria for rubber cultivation and were obtained from various sources. Field surveys were conducted from 2012 onward to collect primary data through observation, using informal interviews with local farmers, and group discussion with local communities in the study area as a part of the social research methodology. This information was used to determine a factor rating for a given land use type that could be used in the matching process of this research. The data related to the local topography were derived from a 1:50,000 digital elevation map which was provided by the Southern Remote Sensing Centre, Thailand. The data relating to climate were collected from the Southern Metrological Department, Thailand. The soil data were obtained using a 1:50,000 soil map provided by the Regional Land Department, Songkhla, Thailand. The data related to the socio-economic aspects were derived from the land use planning map of the Songkhla Lake basin, Thailand which was provided by the Southern Remote Sensing Centre, Thailand.

Criteria Setting

In land use suitability analysis, the selection of appropriate criteria (or factors) and sub-criteria is a very important step. In this study, the criteria were selected according to the FAO framework (FAO, 1983), available relevant literature, and opinions provided by 11 experts using the Delphi technique (Hsu & Sandford, 2007). The chosen experts were from the agricultural (rubber) sector or were academic researchers (with at least a master's degree) with strong knowledge of agricultural (rubber) plantations. The main goal, which was to establish the land use suitability for cultivating rubber, was evaluated based on two main criteria: bio-physical and socio economic (Ceballos-silva & López-blanco, 2003). The bio-physical category was subdivided into climate, topography, and soil whereas the socio-economic category was divided into livelihood and market (Table 1). These were then classified into four suitability classes: highly suitable (HS), moderately suitable (MS), low/marginal suitability (LS), or not suitable (NS) (Boonyanuphap, Wattanachaiyingcharoen, & Sakurai, 2004), as presented in Table 1.

Determination of Weight and Score for Each Criterion

In suitability analysis using the MCDM technique, assigning weightings to different criteria is an important task. Although there are various techniques for the development of weightings, in this study, the weightings were determined using the analytic hierarchy process (AHP). To avoid or reduce individual biases in factor weighting, pairwise comparison was also used during the AHP (Saaty,

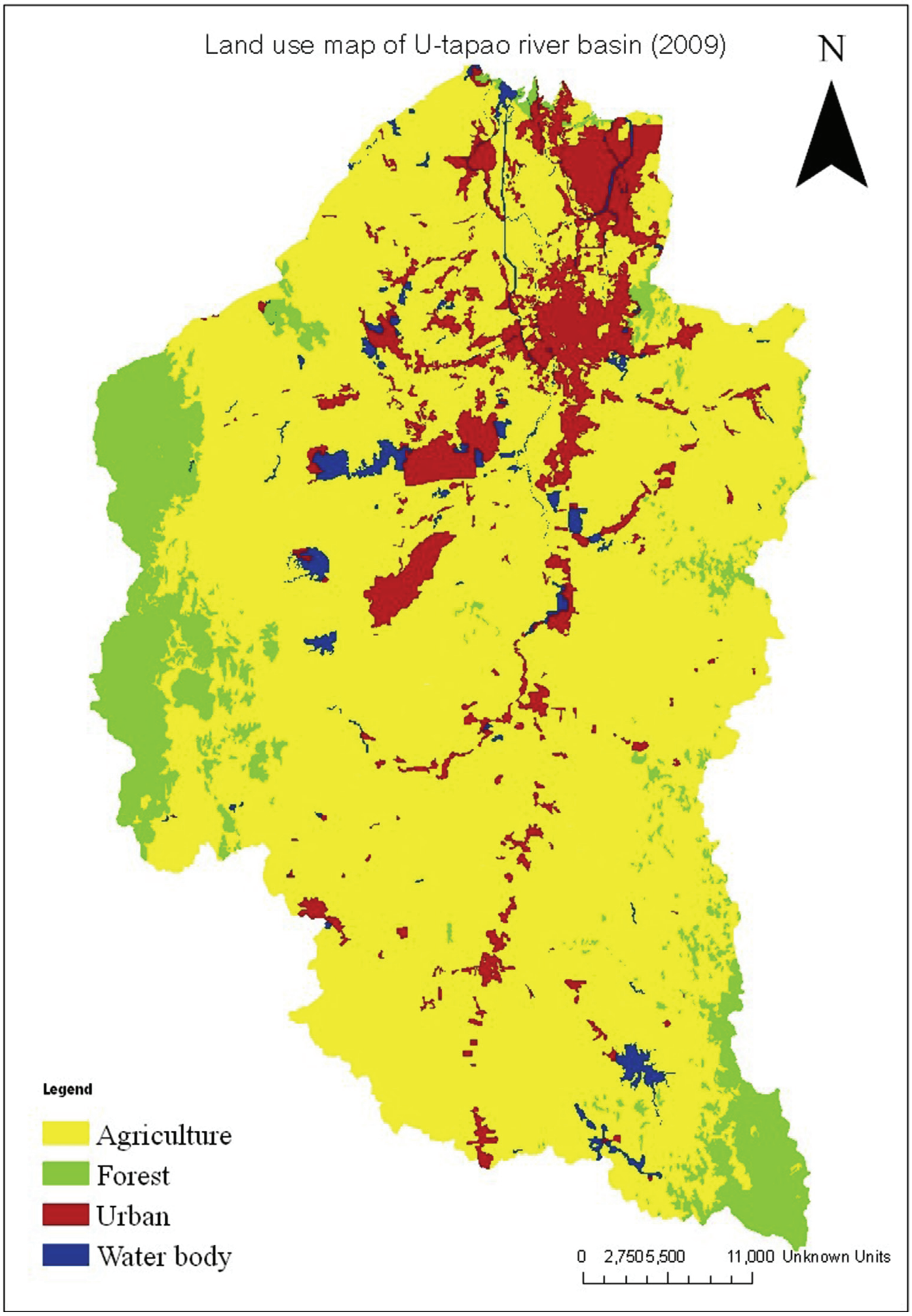

Figure 1 Land use map (2009) of U-tapao River basin, Thailand
Source: Gyawali et al. (2012)

1990). Pairwise comparison relies on judgments made between pairs of elements while attempting to prioritize a complete list of elements. A square matrix is formed (1), where comparisons are made between each pair of factors and the importance of each factor is assigned based on a scale of 1–9 (Saaty, 1990).

$$\boldsymbol{R} = \begin{vmatrix} 1 & x & y \\ 1/x & 1 & z \\ 1/y & 1/z & 1 \end{vmatrix} \tag{1}$$

where R is the pairwise comparison matrix formed to evaluate the, ‘x’, ’y’ and ’z’ criteria. Solving this matrix will

Table 1
Classification criteria in land suitability analysis for rubber cultivation

Classification criteria			Suitability Rating			
Main	Sub	Sub-sub	HS	MS	LS	NS
Bio-physical	Topography	Slope (%)	0–12	12–20	20–35	>35
		Elevation (m)	0–200	200–400	400–900	>900
	Climate	Rainfall (mm)	1500–2500	2500–4500 1200–1500	4500–5000 1100–1200	>5000 <100
		Temperature (^{0}C)	26–28	29–34 25–23	22–20	>34 <20
	Soil	Nutrients	Very high, high	Moderate	Low	–
		Texture	l, scl, sil, si, cl, sicl, sic	sl	sc	c, g, s
		Depth (cm)	>150	50–150	30–50	<30
		pH	5.1–7.3	7.4–8.0 4.0–5.0	3.5–3.9	>8.0 <3.5
		Drainage	Well drained, excessively drained	Moderately well drained	Somewhat poorly drained	Very poorly drained, poorly drained
Socio-economic	Livelihood	Population density (population/km^2)	<200	200–400	400–600	>600
		Available land use	Agriculture	Grass & shrub	Forest	Urban & waterbody
	Market	Distance to major road (km)	<1	1–5	5–10	>10
		Distance to factory (km)	<50	50–75	75–100	>100

Note: Soil texture: loam(l), silty(si), sandy clay loam (scl), silty clay loam (sicl), silty loam (sil), sandy clay loam (scl), clay loam (cl), sandy loam (sl), clay (c), sandy clay (sc), silty clay (sic), sand (s), gravel soil (g)

provide the weight of each factor which is then used to find the consistency ratio (CR) and to reconfirm the accuracy of the score. If the CR exceeds 0.10, then the pairwise values need to be readjusted and the process is reiterated until the CR is less than 0.10 (Saaty, 1990). In the current research, to find the significance level of each factor and for this purpose, questionnaires were distributed to experts and their opinions relating to each factor were compared with those relating to other factors to establish their importance.

Land Suitability Assessment

The ArcGIS 9.0 software application was used to construct a land suitability map for each factor. All the layers were then combined using the GIS overlaying technique (Mendas & Delali, 2012). The total suitability score (Rs) for each land unit was considered using the formula (2):

$$Rs = \sum_{i=1}^{n} WiSi \quad (2)$$

where n represents the number of factors involved, W_i represents the associated weightings in the hierarchy of the ith factor, and S_i represents the rating assigned to the ith factor based on the evaluated land unit. A score of between 1 and 4 was allotted to each land unit to construct the land suitability map. From the map data, the land areas were allocated to the four suitability classes based on the FAO framework as follows: HS, 3.0–4.0, MS, 2.0–2.99, LS, 1.0–1.99, NS, 0.0–0.99 (FAO, 1983).

Results and Discussion

At present, rubber is the dominant crop in the U-tapao River basin. Therefore, land use assessment for rubber

Table 2
Criteria and sub-criteria and their weightings for rubber land suitability analysis

Layer 1		Layer 2		Layer 3		Total Weight
Criteria	Weight 1	Criteria	Weight 2	Criteria	Weight 3	
Bio-physical	0.916	Topography Soil	0.270	Slope	0.750	0.1855
				Elevation	0.250	0.0618
			0.150	Drainage	0.148	0.0203
				pH	0.168	0.0230
				Depth	0.287	0.0394
				Nutrients	0.029	0.0039
				Texture	0.366	0.0502
		Climate	0.580	Rainfall	0.580	0.3081
				Temperature	0.420	0.2231
		Total	1.00			
Socio-economic	0.084	Livelihood	0.416	Population density	0.416	0.0145
				Available land use	0.584	0.0204
		Market	0.584	Distance to major road	0.580	0.0284
				Distance to factory	0.420	0.0206
Total	1.00	Total	1.00			1.0000

Note: Total weight = weight1 * weight2 * weight3

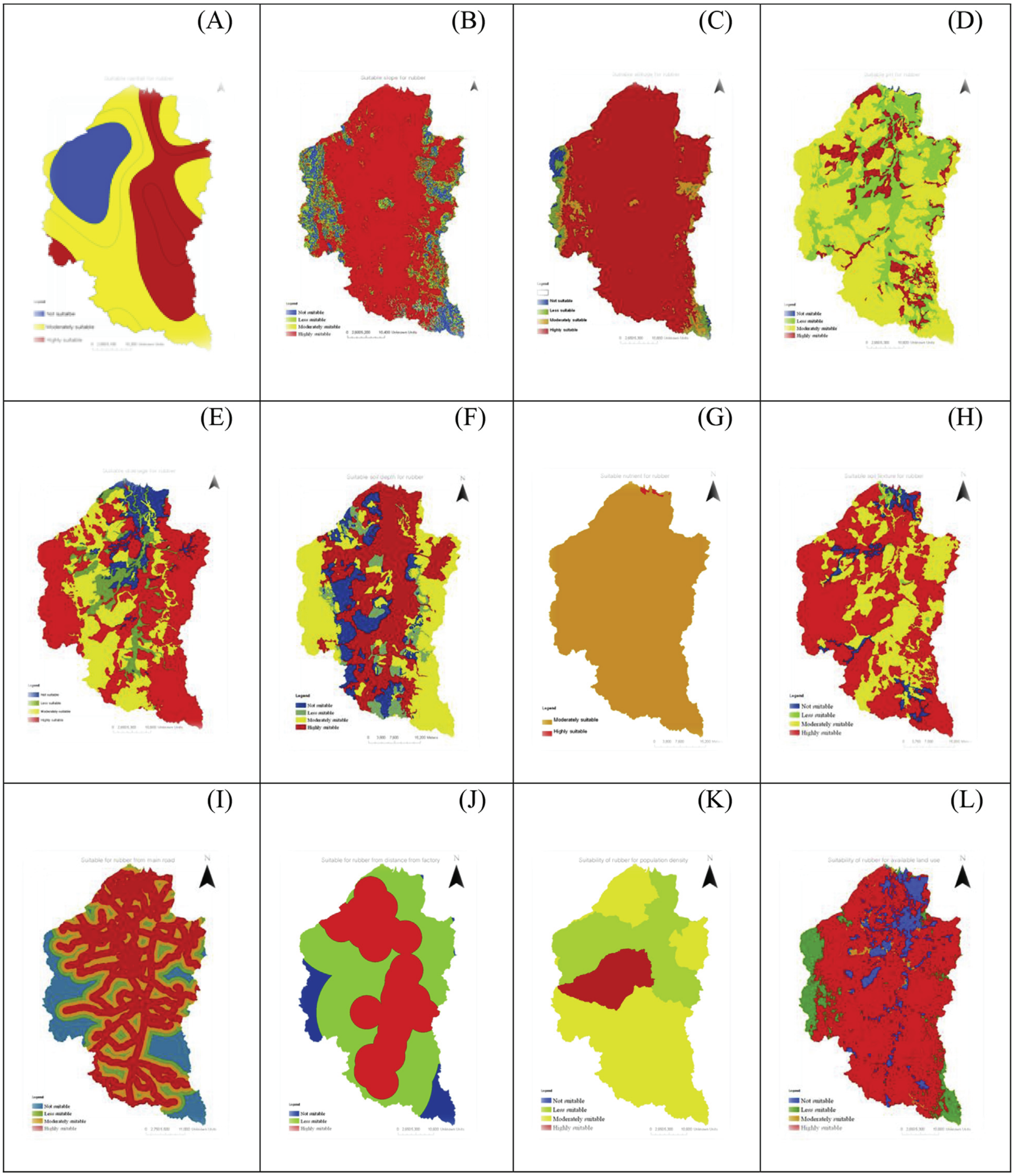

Figure 2 Land use suitability map of U-tapao river basin, based on different parameters: (A) Rainfall, (B) Slope, (C) Elevation, (D) pH, (E) Soil drainage, (F) Soil depth, (G) Soil nutrients, (H) Soil texture, (I) Distance to major road, (J) Distance to factory, (K) Population density, (L) Available land use map

cultivation is very important for the sustainable agricultural development of the basin. To the best of the authors' knowledge, this was the first study conducted on land use suitability for rubber cultivation in the basin and the results are summarized below.

The weights of the factors which had been determined using the AHP process are shown in Table 2. In this study, all the factors' relative weights were consistent; for example, in layer 2 for bio-physical (topography, soil, and climate) the CR was 0.055 and in layer 3 for soil (drainage, pH, depth, nutrients, and textures) the CR was 0.098 which were both less than 0.10. Moreover, in the case of MCDM, according to the weighted linear combination rule, the sum of the weights should be equal to 1 (Mendas & Delali, 2012) which was also verified.

Suitability Analysis

Bio-physical Aspects

Climate: Climate is a primary factor which directly affects the growth of rubber. Therefore, in this study both annual

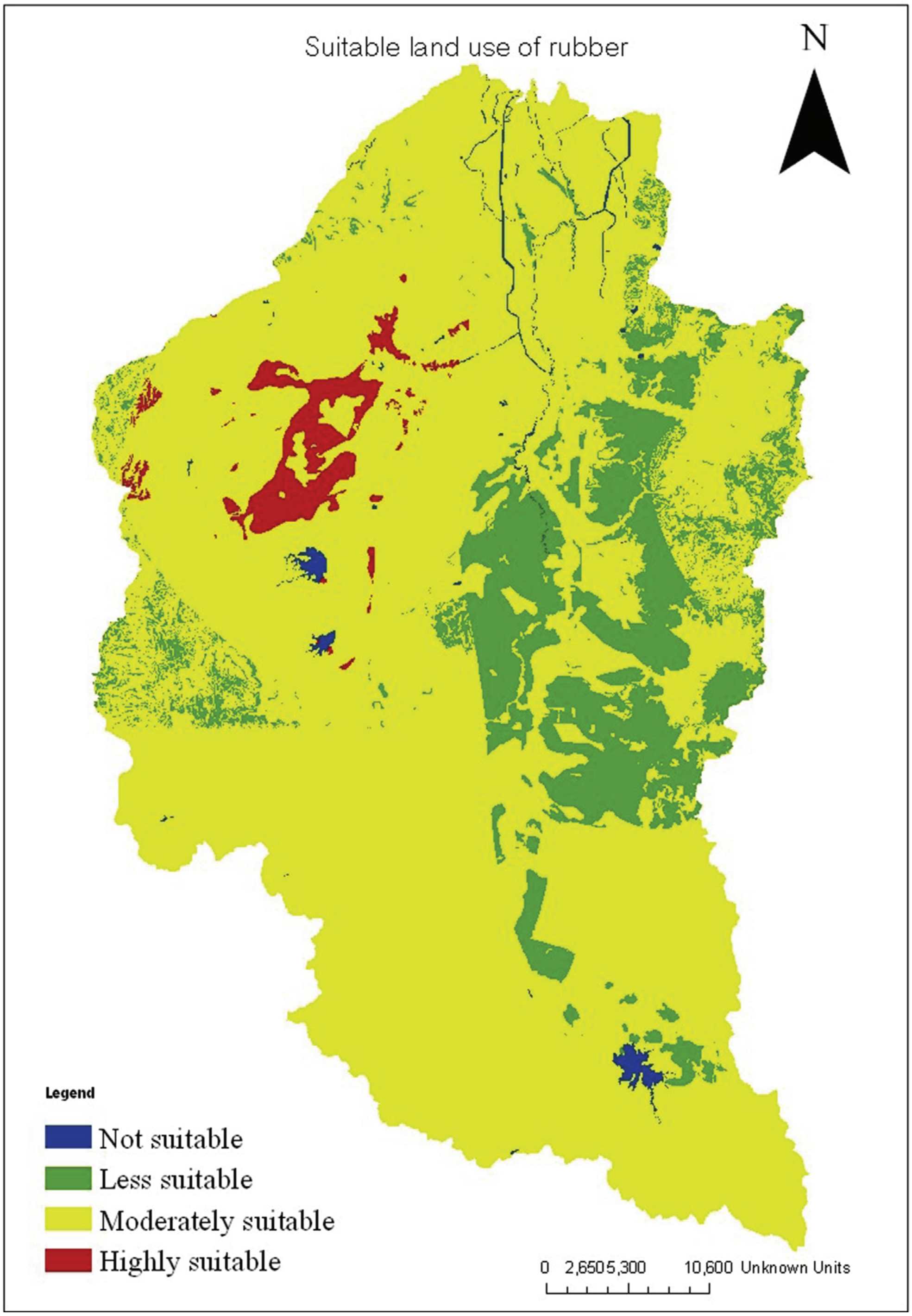

Figure 3 Map of land use suitability for rubber cultivation in the U-tapao River basin

rainfall and temperature were considered within the climate factor. From the data it was established that while the basin is highly suitable for rubber, based on the temperature which averages 28 °C, from the perspective of rainfall, 29.03 percent (669.15 km^2) of the basin area was highly suitable for rubber, 57.70 percent (1,329.98 km^2) was moderately suitable, and the remainder was in other less suitable classes (Figure 2A). It can be clearly seen that most of the land was either highly or moderately suitable based on rainfall aspect.

Topography: This is also one of the principal factors determining the suitability of land for rubber. Both slope and height need to be considered, as the cultivation of rubber on cliffs or high terrain is not recommended in order to preserve the integrity of the landscape. For the study area, 93.26 percent (2,149.64 km^2) of the basin area was highly suitable for rubber, with the remainder in other less suitable classes (Figure 2B). Similarly, most of the land was highly suitable based on elevation, with 86.12 percent (1,985.06 km^2) of the basin area highly suitable for rubber and the remainder was in other less suitable classes (Figure 2C).

Soil: This is yet another principal factor to be considered for rubber land use suitability. Based on soil texture, loamy or sandy loamy soil is suitable for rubber cultivation since it is easier to work and requires only moderate irrigation. From the perspective of the soil nutrients, rubber needs a modest level of nutrients, in contrast to coffee, tea, coconut, or palm oil. The acidity of the soil based on pH is another consideration as is the drainage of the soil. The results indicated that regarding the soil pH, 13.71 percent (315.78 km^2) of the basin area was highly suitable for rubber, 61.08 percent (1,407.89 km^2) was moderately suitable, and, the remainder was in other less suitable classes (Figure 2D).

The various suitability ranges for the soil drainage aspect were: 53.87 percent (1,241.47 km^2) of the basin area was highly suitable for rubber, 27.54 percent (634.79 km^2) was moderately suitable, and the remainder was in other less suitable classes (Figure 2E). The deeper and better drained a soil is, the more fertile it will be. The results for soil depth indicated that 42.37 percent (976.63 km^2) of the basin area was highly suitable for rubber and the remainder was in other suitability classes (Figure 2F), whereas for soil nutrients, 0.23 percent (5.31 km^2) of the basin area was highly suitable for rubber and the remaining 99.77 percent (2,299.69 km^2) was moderately suitable (Figure 2G), with no other categories. It can be seen that most of the land in the basin was either highly or moderately suitable for rubber cultivation based on soil texture as illustrated in Figure 2H.

Socio-Economic Aspects

Market: Among the socio-economic factors, nearness to market is highly desirable. In this study, nearness to market was sub-divided into two categories, nearness to main road and nearness to factory. The opinions of the experts consulted were highly inclined towards a shorter distance from the rubber plantation to the market being a vital factor and this was an important influence on the results of this study. The findings regarding suitability based on nearness to main road were, 24.01 percent (555.04 km^2) of the basin area was highly suitable for rubber, 25.03 percent (583.31 km^2) was moderately suitable, and the remainder was in other less suitable classes (Figure 2I). The distance from a factory was also thoroughly investigated and the land suitability ranges for this factor were 24.49 percent (564.53 km^2) of the basin area was highly suitable for rubber, with the remainder being of low suitability or unsuitable (Figure 2J). However, there was no moderately suitable area for this aspect.

Livelihood: Livelihood is also an important consideration for socio-economic purposes, and the land suitability ranges for rubber cultivation relating to livelihood were based on the population density where, 9.18 percent (211.72 km^2) of the basin area was highly suitable for rubber and 63.42 percent (1461.75 km^2) was moderately suitable (Figure 2K). To further strengthen the analysis of suitability for rubber cultivation, the available land use was also established, and the results indicated that 73.24 percent (1,695 km^2) of the basin area was highly suitable for rubber and the remainder were in other suitability classes (Figure 2L).

Suitability Map for Rubber Cultivation

By combining the suitability maps, an overall suitability map was obtained (Figure 3). As can be seen, the most suitable areas for rubber cultivation were in the northeastern part of the basin because of the suitable climate and the fertility of the soil. In the basin, the suitability assessment indicated 14.46 percent (333.34 km^2) of the basin area was highly suitable for rubber, 82.48 percent (1,901.35 km^2) was moderately suitable, 2.22 percent (51.07 km^2) was less suitable, and 0.83 percent (19.24 km^2) was unsuitable for the cultivation of rubber. The most suitable areas were all flat, near water, and had deep soil. The findings indicated that most of the area of the basin (96.94%) was highly or moderately suitable for rubber cultivation. The basin should therefore be preserved for rubber plantations.

The land suitability map of rubber was compared with the land use map for 2009 (Figure 1). This comparison showed that in the zone which was highly suitable for rubber cultivation, the dominant land use was rubber cultivation, covering 86.91 percent (287.89 km^2) of the available land, with rice paddy-fields covering 3.26 percent (9.91 km^2), and other agriculture activities covering 3.01 percent (7.84 km^2).

Conclusion and Recommendation

Land use suitability for rubber cultivation in Thailand has rarely been researched. Because of the growing population, urbanization is spreading rapidly in the U-tapao River basin, but the amount of agricultural land has been decreasing, without consideration for site suitability. The preservation of farming activities is necessary in suitable locations to ensure the proper utilization of land resources. Therefore, this study generated a land use suitability map for rubber cultivation using MCDM and GIS and considering three bio-physical factors (topography, soil, and climate) and two socio-economic factors (livelihood and market) which affect the classification of land use suitability. This study concluded that overall, bio-physical factors are more important than socio-economic aspects. From the perspective of bio-physical factors, climate is of greatest importance. From the socio-economic perspective, the market aspect is the most important factor.

From the overall map derived, it was found that the most suitable areas for rubber cultivation exist in the north of the basin because of its fertile soil and abundant water resources, and that only a small percentage of land is not suitable for rubber. To investigate the potential areas for rubber cultivation, the overall suitability map was compared with the land use/cover map for 2009 and based on that comparison, it is recommended that rubber cultivation should be expanded to areas shown as being currently under grass or scrub. Furthermore, rubber plantations are helping to maintain the greenery of the basin besides generating revenue. Therefore this study suggests making local farmers aware of the benefits associated with rubber cultivation. Future studies are recommended to consider more bio-physical and socio-economic factors to achieve improved results, and for data validity there must be cross checking, as this study relied on the reputation of the public organizations for accessible secondary data.

Conflict of interest

None.

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