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GIS-MCDM Approach to Determine Forest Plantation Areas in U-tapao River Basin in Songkhla, Thailand

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Abstract: Land suitability assessment is indispensable for the successful forest land use development. This will provide a rational basis to accomplish the land use decisions. Forest land degradation owing to distinct reasons (rapid urbanization, transformation to the agricultural land) has become a matter of great concern. Therefore, this research aim was to determine the forest plantation area in U-tapao river basin (URB), Southern Thailand. Multicriteria decision making (MCDM) technique was used in Geographic Information System (GIS) environment to find as well as to validate a suitable land for forest planation in the study area considering two main factors i.e. bio-physical and socio-economic. This study found that out of total area of the URB (2305 km^2), approximately 59.66 percent (1375.2 km^2) is highly suitable for forest plantation. This study may assist the future researchers and forest policymakers to take measures against the forest land degradation.

Keywords: Afforestation, land-use policy making, GIS, multicriteria decision making, Thailand

1. Introduction

Forestry is one of the most important natural resources to which ultimate human benefits are associated. However, the growing deforestation to get instant benefits or to build new cities has emerged as a huge threat to the livelihood of those who depend primarily on it for their survival apart from the increasing climate related concerns [1], [2]. The total forest coverage in Thailand was 30.92 percent by 2006 of the total land area compared to 1961, when it used to be 53.30 percent [3], this shows the pace of land coverage reduction for forests. Similarly, U-tapao river basin (URB) has faced land deficit for forest plantation over the years, as the available land has continuously been used up for other purposes, such as housing and agricultural land, thus threatening the sustainability of forest development. URB not only creates forest products as commodities and services contributing to the province economy, but also plays a vital role in environmental protection, livelihood improvement and poverty reduction. Thus, land evaluation is indispensable in order

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to systematically plan for the land usage which may reflect local, regional, and national priorities. Land use planning may involve multiple factors such as biophysical, socio-economic as well as cultural aspects [4], these factors will also be appropriate for the area of study . However, incorporating all these factors may require developing spatial data-based analysis. Recently, Geographical Information Systems (GIS) tool has revolutionized the storage and manipulation of spatial databases with great convenience [5]. Using this tool, multicriteria decision making (MCDM) technique could also be incorporated, which is known for managing complex decision-making purposes [6],[7]. MCDM has been widely used for site selection purposes on various subjects such as rubber, municipal solid waste and wind and solar farms sites identifications [8]-[10] - there is one of the mature decision tools and can be replicated in this study since the objective of this study is to identify suitable sites for forest plantation. The simultaneous use of both (GIS-MCDM) can prove to be efficient in agricultural studies, which involves a range of factors [11]. Previously, it has been employed in land suitability assessments for rubber tree, maize, rice etc. [7], [12]-[14]. To the best of our knowledge, GIS-MCDM technique has never been utilized for the determination of forest area plantation in URB so far despite the increasing land degradation for forest. Therefore, this research aims to promote afforestation by using the above sophisticated approach by considering bio-physical and socio-economic boundaries.

2. Materials and Method

2.1 Study Area

This study was conducted in U-tapao river basin, which is a sub basin of Songkhla lake basin located in southern Thailand on coordinates of 100º 10' through 100º 37' E and 6º 28' through 7º 10' N as shown in Fig. 1. In terms of area, the basin expands 60 km in north to south direction and 40 km from west to east direction [15], [16]. The climate of the basin is being controlled by two seasonal monsoons i.e. northeast and southwest monsoons, therefore the temperature of the basin varies between 24ºC and 32º C [15]. In the basin, more than 75 percent of the area is covered by agricultural land use and about 12.87 percent by forest. The forest land is mostly distributed in the hilly areas; the plains mostly host agriculture and grassland. Favorable climate conditions necessitate the further exploration of the basin for forests plantation.

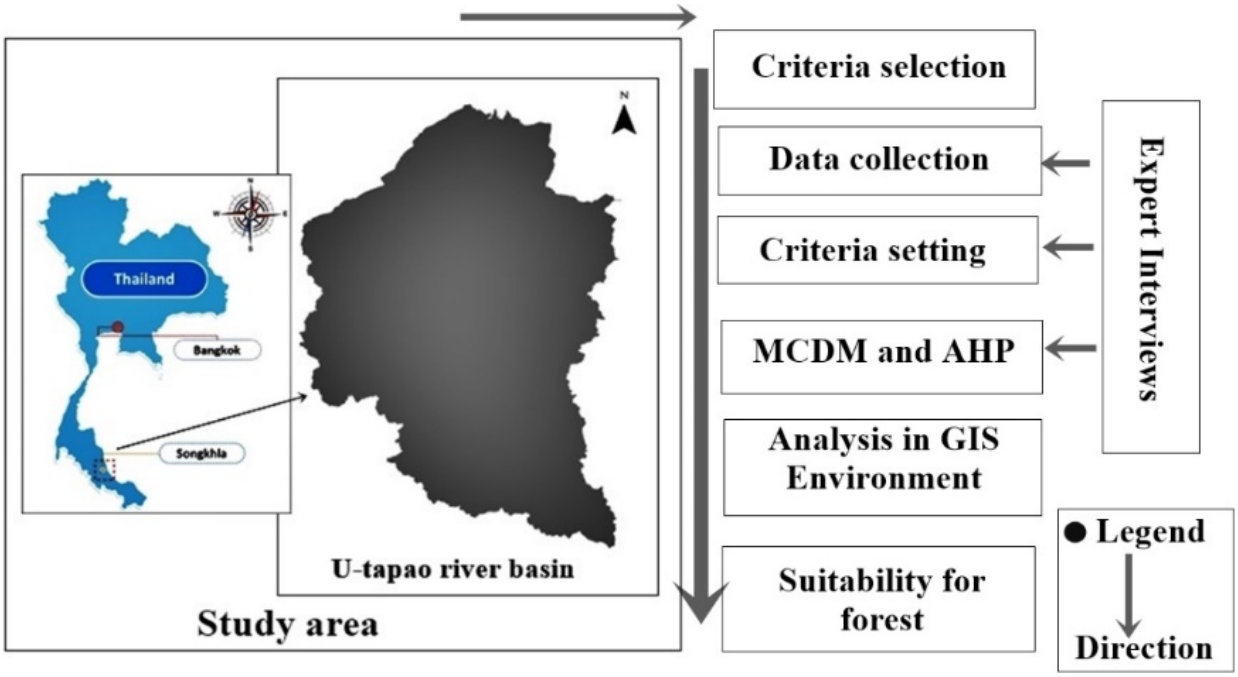

Fig. 1 - Methodology overview [Source: author's own]

2.2 Data Collection and Criteria Settings

The necessary secondary data were obtained from GEO-Informatics Research Center Songkhla, Thailand [17]. The criterion that influence the forests plantation were derived based on the previous studies and then incorporated with the expert's opinions and the field surveys, which is deemed as the primary data to this research. Field surveys helped to give a broader understanding of the study area and the threats to the forest land due to unawareness of the ultimate benefits associated with forestation. The field survey was conducted during 2012-2013, during which informal meetings were arranged with the local farmers and the public who were associated with the forestation in U-tapao river basin either directly or indirectly. There were in total 11 experts who shared their opinions in the form of questionnaires and a Delphi interviewing approach was implied in this process [18], [19]. The experts were chosen based on their academic or

practical understating with the forest plantation. Most of them were government officers who were working for public sector forestry departments. The opinions and the literature-based knowledge outline the criteria for forest plantation, that is in compliance with the FAO guidelines (see Table 1) [20]. The main criterion surfaced from literature-based knowledge are bio-physical and socio-economic. Furthermore, these two main criterions are categorized into topography, climate, soil, distance factor and livelihood et cetera.

2.3 MCDM-AHP in GIS Environment

Multicriteria decision making is well known for decision making purposes used by various researchers, for example, L. Diaz and C. Romero [21] used it for forest planning to solve forest management problems, G. Mendoza [7] used MCDM approach to combine factors in a suitability analysis of land for potential land uses, so as we are using it here, as site suitability assessments of afforestation involve many parameters, making it complex to decide which parameters has the higher influence and how. Therefore, MCDM is used because it can handle both qualitative and quantitative criteria and resolve the conflicts between the criteria and decision makers [21]. Analytical hierarchy process (AHP) under MCDM was initially introduced by Saaty; this approach helped to arrange the problem into top to bottom model, where the goal remains at top and the alternatives are placed at bottom [22]. In case of this study, the goal is to find the suitable areas for forest planting in U-tapao basin. The AHP inputs from the experts can be combined by constructing a pairwise-comparison matrix, that leads to find the best alternative. In this research the 11 expert's opinions helped to construct a pairwise matrix shown as under (1).

$$\boldsymbol{M} = \begin{vmatrix} \mathbf{1} & \boldsymbol{j} & \boldsymbol{k} \\ \mathbf{1/j} & \mathbf{1} & \boldsymbol{l} \\ \mathbf{1/k} & \mathbf{1/l} & \mathbf{1} \end{vmatrix} \qquad (1)$$

M is the pairwise comparison matrix formed to evaluate the, 'j', 'k' and 'l' scores of criteria, that represents the relative importance of one criterion over another criteria, for example, if 'j' represents the score of importance of factor 'x' over factor 'y', then reciprocally '1/j' will represent the importance of factor 'y' over factor 'x'. This concept was reflected to calculate the relative weight of all the criteria in this study. As, the expert opinions involved may lead to inconsistency in the judgements, a mechanism is essential to maintain the consistencies between the judgments. Yet again, Saaty [22] has formulized a way to check the inconsistency as under,

$$CR = \frac{CI}{RI} \qquad (2)$$

CR is the consistency ratio which can be obtained by dividing the consistency index (CI) with Random index (RI) value as referred by [23]. The CR should not be more than 10%, otherwise the judgments may have a serious inconsistency that need reevaluation. This has been thoroughly maintained in this study. The computed weights which will appear in results was, then assigned to the respective factors in GIS environment, to produce a thematic map for each factor. At the final stage, all of the individual thematic maps were combined by utilizing the overlaying technique in the GIS environment to find the final suitable area for forest. The results are shown in next section [7], [24].

Table 1 - Criteria selection and divisions for forest plantation in this study

Main criteria	Sub-criteria	Sub-sub-criteria	Highly suitable	Moderately Suitable	Low Suitable	Not suitable
Bio-physical	Topography	Slope	0 to 12	12 to 20	20-35	>35
		Elevation	0-400	400-600	600-1000	>1000
	Climate	Temperature	24 to 28	28 to 30	30-32	<24 and >32
		Rainfall	>2000	1500-2000	1000-1500	<1000
	Soil	Texture	l,scl,sl	ls,sil,sc,cl,sicl	si, sic, sc	c, g, s
		Nutrients	very high, high	moderate, low	nil	nil
		pH	5 to 6	4- 5 & 6 - 7	3-4 & 7-8	<3 and >8
		Depth	>150 cm	50-150cm	30-50cm	<30cm
		Drainage	excessively drained & well drained	moderately drained	somewhat poorly drained	very poorly drained
Socio-economic	Distance factor	Main Road	>5km	4-5km	2-4km	<2km
		River	0-500m	500-1000m	1000-2000m	>2000m

	Livelihood	Population density	100/sq.km	100-300/sq.km	300-500/sq.km	>500/sq.km
		Land use	current forest land	grass and shrub	agriculture	urban and wet land

Note: Sources: [20], [24]

3. Results and Discussion

In the U-tapao river basin, protection of forest is very important. In recent period, deforestation rate in the U-tapao river basin has stopped, but lack of suitability analysis of forest has affected the effective planning concept for decision makers. Therefore, this study has provided the clear picture of suitability status of forest in the basin level. In this study, the weights of the factors that have been calculated using AHP can be seen in Table 2., which shows that the bio-physical factor is three times more important than the socio-economic factor for forest plantation. Among bio-physical factors, climate is the most important parameter, but in the case of socio-economics, livelihood holds more importance. Moreover, in this research the experts' judgments were perfectly consistent and the CR for factors in layer 2 under bio-physical (topography, climate and soil) was 0.055<0.10; CR for factors in layer 3 under soil (texture, nutrients, pH, depth and drainage) was 0.098<0.10 and the CR for remaining factors were 0.0.

Table 2 - AHP based weights of the criterion used in this study for forest plantation

Layer 1		Layer 2		Layer 3		
Criteria	**Weight**	**Sub-criteria**	**Weight**	**Sub-sub-criteria**	**Weight**	**Total Weight**
Bio-physical	0.75	Topography	0.394	Slope	0.75	0.221
				Elevation	0.25	0.073
		Climate	0.4545	Temperature	0.42	0.143
				Rainfall	0.58	0.197
		Soil	0.1515	Texture	0.29	0.033
				Nutrients	0.04	0.005
				pH	0.10	0.012
				Depth	0.27	0.030
				Drainage	0.28	0.031
Socio-economic	0.25	Distance factor	0.4166	Main Road	0.34	0.035
				River	0.66	0.08
		Livelihood	0.5834	Population density	0.41	0.060
				Land use	0.58	0.085
Total sum						1.000

3.1 Bio-physical

In bio-physical criteria, climate is the most significant factor because it affects the growth of vegetation and forest resulting in direct or indirect losses of biomass increments. In this study, annual temperature and rainfall were considered as climatic factor. The temperature between 24 ^{0}C to 28 ^{0}C is considered as highly suitable for forest, however, the average temperature of the whole basin is about 28 ^{0}C, which is perfect for forest growth, as shown in Fig. 2(a). Moreover, the annual rainfall more than 2000 mm is considered as highly suitable for forest. In the basin, the area about 234.98 km^2 (10.19%) land area is highly suitable for forest based on rainfall Fig. 2(b).

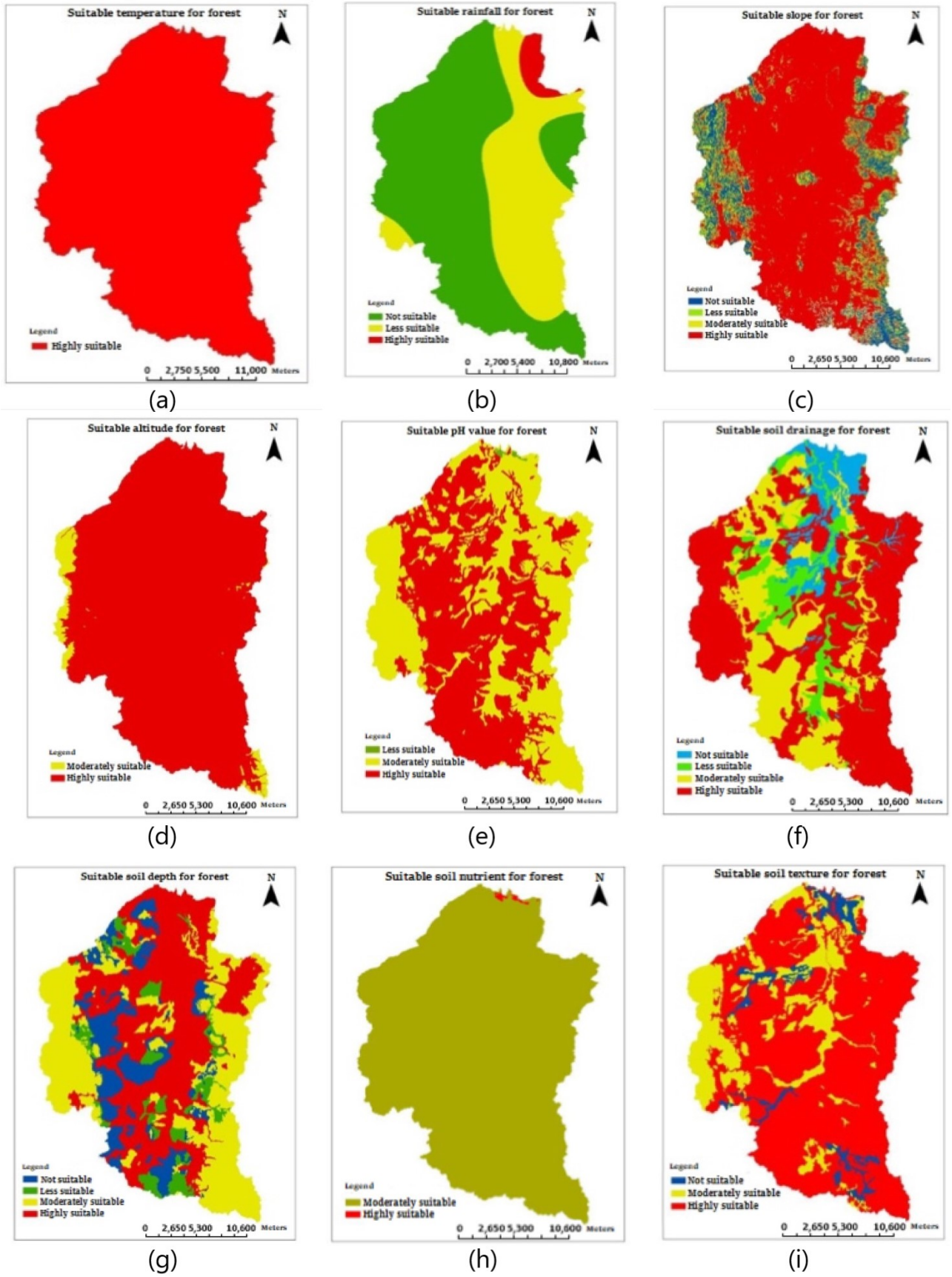

Fig. 2 - (a-l) Land use suitability map of URB, based on different parameters, with legend showing area: Not suitable (blue), Less suitable (green), Moderately suitable (yellow/dark yellow) and Highly suitable (Red)

Topography is the second most significant factor in bio-physical and in this study, slope and elevation were considered for topography aspect. As a result, we got to know that in the basin, 2149.64 km^2 (93.26%) area has slopes between 0-12, which is highly suitable for forest Fig. 2(c). On elevation aspect, 2084.64 km^2 (90.44%) is highly suitable for forest Fig. 2(d). And among soil types, soils that are deep, well drained, with desirable texture and structure are suitable for forestry. The pH is also one of the factors of the soil analysis, where in the study, 1196.93 km^2 (51.93%) land area has pH of 5-6 as in Fig. 2(e). The study also found that 1241.47 km^2 (53.86%) land area is highly suitable for forest based on drainage as in Fig. 2(f), 976.63 km^2 (42.37%) land area is highly suitable for forest in terms of soil depth as in Fig. 2(g). and in context of nutrients 2299.69 km^2 (99.77%) land area is moderately suitable for forest, yet enough favorable for forest Fig. 2(h). Based on soil texture, 1420.57 km^2 (61.63%) land area of the basin was found to be highly suitable for forest Fig. 2(i).

3.2 Socio-economic

The socio-economic criteria comprising of distance and livelihood factors has been assessed in this study. Based on the suitability criteria as defined earlier in methodology section, it was found that, 583.31 km^2 (25.31%) land area is highly suitable for distance from main road to the forest plantation area Fig. 3(a). Moreover, according to forest experts, nearer distance from the river is highly suitable for forest plantation than farther from the river. Therefore, in this study 567.03 km^2 (24.60%) land area is highly suitable for forest and 660.24 km^2 (28.64%) land area is moderately suitable on the basis of proximity to the river Fig. 3(b). In terms of population density under the livelihood factor, the study found 212 km^2 (9.19%) area is highly suitable for forest and the area about 1368.59 km^2 (59.37%) as moderately suitable Fig. 3(c). This study has also proposed that 296.53 km^2 (12.86%) is highly suitable for forest in the land use category. However, the remaining are in other suitability classes as shown in Fig. 4(a).

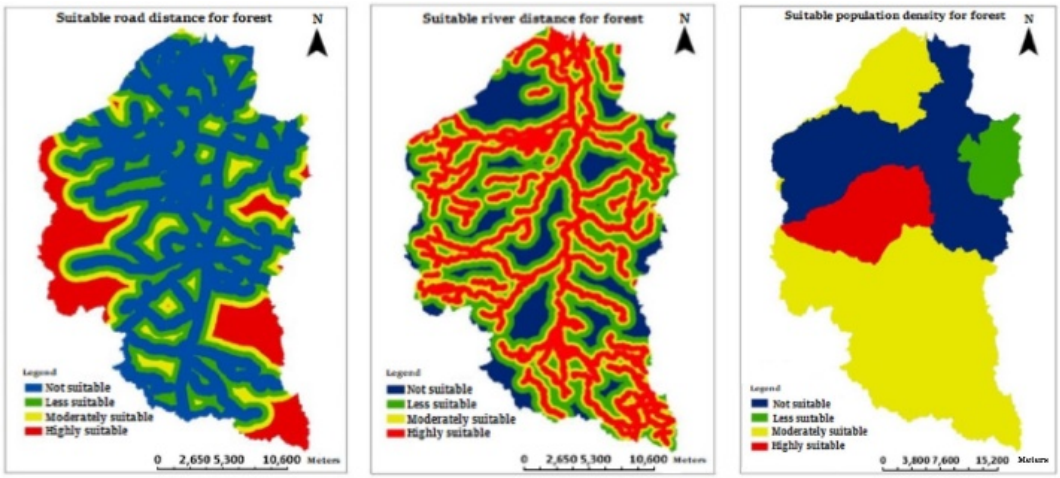

Fig. 3 - (a-c) Land use suitability map of URB, based on different parameters, with legend showing area: Not suitable (blue), Less suitable (green), Moderately suitable (yellow) and Highly suitable (Red)

3.3 Land Use Suitability for Forest

The final land use suitability map of forest can be seen in Fig. 4(b) that came as a result of integrating the thematic maps of all factors in ArcGIS. The highly suitable land for forest is about 1375.2 km^2 (59.66%), moderately suitable land for forest is about 910.56 km^2 (39.50%), and less suitable land for forest is very negligible (<0.01 km^2). The area of water body is 19.24 km^2 (0.83%).

3.3.1 Comparison of the Suitability Map of Rubber with Land Use Map of 2009

The land use suitability map is compared with actual land use map of URB of 2009. While comparing, in the highly suitable zone of forest, the most dominating land use is agriculture which covers area about 1188.47 km^2 land and 86.42% of zone land. Forest land itself covers about 54.92 km^2, which is 3.99% of zone area. Urban built up land covers about 77.22 km^2 and 5.61% of zone area whereas other remaining land uses just cover 54.59 km^2 and 3.98% of zone area.

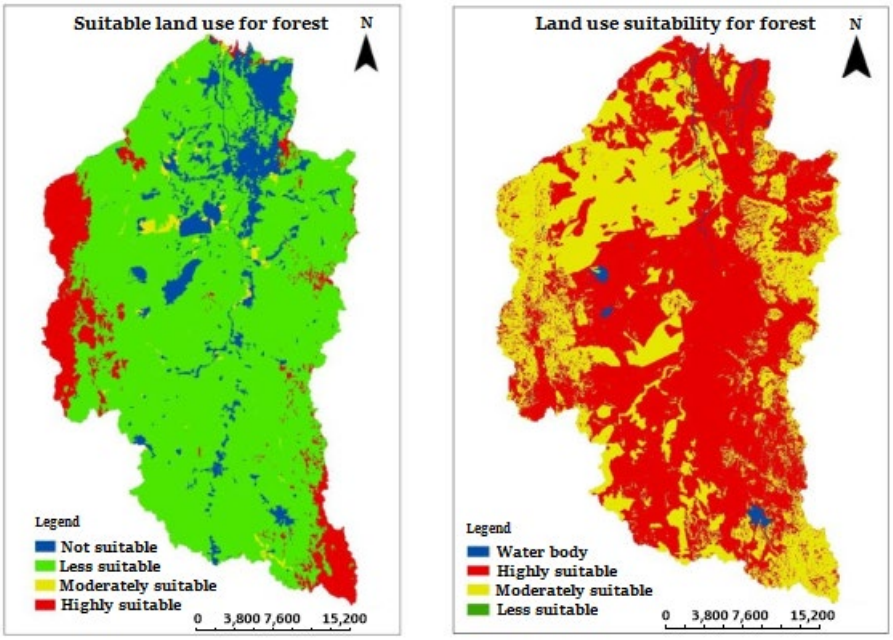

Fig. 4 - (a) Land use suitability of forest on available land use criteria; (b) Land use suitability map of forest in URB

4. Conclusion

This research was conducted to determine the suitable forest plantation areas in URB, considering two main factors i.e. bio-physical and socio-economic. MCDM in GIS environment was used and weights of the parameters were determined based on experts' opinions as part of social research methodology. The research in the results section concluded that U-tapao has most significant potential for forest plantation as 1375.2 km^2 was judged as highly suitable for forest plantation which is significantly a huge land mass, therefore, the URB should be preserved for forest plantation since it plays a vital role in environmental protection and livelihood improvement. The dominant crop in URB was rubber due to favorable conditions, yet it doesn't sideline the preservation of forest land for afforestation. Furthermore, the land use suitability map was also compared with actual land use map of URB of 2009 to validate the concerns and issues related to forest plantation in URB.

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