Suitable Site Selection for Teak Plantations using GIS Technique at Phyu Township, Taungoo District, Bago Yoma, Myanmar

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ABSTRACT

This study describes the selection of suitable sites for large-scale commercial teak plantations at Phyu township, Taungoo District, Bago Yoma region, Myanmar. Geographic Information System (GIS) was applied to analyze seven variables relevant to a land requirement for a teak plantation, including topography (slope and elevation), climate (mean annual temperature and annual precipitation), and soil characteristics (soil pH, soil depth and soil texture). All relevant secondary data were collected and downloaded and subsequently transformed into grid-based GIS with a resolution of 200-m. Besides the land requirement parameters, we used the FAO matching technique to determine site classes for teak plantations. Each parameter was weighted and ranked according to its importance and contributions to the growth of teak trees. The accumulated scores were reclassified into four classes (i.e., ‘0’ as unsuitable, ‘1’ as marginally suitable, ‘2’ as moderately suitable, and ‘3’ as highly suitable). By masking the highly and moderately suitable areas with the existing forest, urban areas as well as water bodies, current land use map, and the practically suitable areas cover approximately 932 km^2 (42%) of the study area, and they are potentially promoted for teak plantations.

1. INTRODUCTION

Teak (*Tectona grandis*) is one of the globally most important tropical timber species found in semi-evergreen forests, mixed deciduous forests, and deciduous dipterocarp forests (Blaser *et al*., 2011). Among these forests, the best quality of teak trees grows in mixed deciduous forests with cleaner and straighter boles (Myint, 2012). Natural teak forests cover parts of India, Myanmar, the Lao People’s Democratic Republic, and Thailand (Keiding *et al*., 1986). The extent of natural teak forests has declined in all countries, mainly due to unsustainable logging and encroachment for agriculture. For instance, natural teak forests in Myanmar declined from 45 % of the country land area in 1999 to 38 % in 2010 (FAO, 2010), while more than two-thirds of the forest in Thailand disappeared between 1960 and 1990 (Ongsomwang, 1995). The recent extent of natural teak forests was estimated to about 29 million ha, and almost half is found in Myanmar (13.5 million ha), followed by Thailand (8.7 million ha) and India (6.8 million ha) (Kollert and Cherubini, 2012). In contrast, teak plantations outside the natural distribution and indigenous five countries were early introduced in Java, Indonesia, in the 14th century and Sri Lanka in 1680 (Pandey and Brown, 2000). Nowadays, teak is planted in more than 70 tropical countries throughout Asia, Africa, Latin America, and Oceania (Jerez and Coutinho, 2017). FAO (2016) reported that more than 20 countries had identified teak as a national priority species for economic plantations. Large scale teak plantations are found in India (2.5 million ha) and Indonesia (1.5 million ha). Thailand has the third-largest planted teak area in the world (about 0.8 million ha), while Myanmar is ranked as the fourth (ITTO, 2009). According to FAO (2015), Myanmar has about 461,000 ha of teak tree plantations or 49% of all planted forests in the country.

Teak has a large and environmentally diverse distribution. It can grow best between latitudes from 23° N to 10° S in areas with adequate climate conditions and with diverse soil categories that have diverse chemical properties. Kaosa-ard (1981) mentioned that rainfall/soil moisture, temperature, light, geological formation, and soil conditions are important factors controlling the natural distribution of teak. It requires an altitude between sea level and 1,200 m and an annual rainfall of 500 mm to 5,000 mm (Bermejoa *et al*., 2004; Camino *et al*., 2002; Pandey and Brown, 2000). Highly productive sites generally have high rainfall. A dry period is still crucial for teak's development as teak grown without a dry period has weaker timber. Thus, teak requires a monsoon climate with a distinct dry period of at least three months (Camino *et al*., 2002). It can also exist under a range of temperatures (2 – 48 °C), but the optimal temperature range is from 23° C to 35° C (Kanchanaburangura, 1976). Teak grows best on fertile, well-drained, alluvial soils with a neutral or slightly acid pH. The range of soil pH in teak forests is within 5.0 to 8.0, although the optimal soil pH is between 6.5 and 7.5 (FAO, 1998). Limiting soil factors for teak growth include shallowness, hardpans, waterlogging, compaction, or heavy clays with low contents of calcium, magnesium, and phosphate (Weaver, 1993). Teak can grow on soil rich in limestone, granite, schist, gneiss (Kaosa-ard, 1981). The best sites for teak have a soil depth of 90 centimeters or more and are located on medium to flat slopes at the base of a mountain or in valleys where there are no strong winds (Pandey and Brown, 2000). Growth is stunted when the slope is above 20%, or elevation exceeds 1,000 meters (Camino *et al*., 2002).

Myanmar contributes to more than 40% of the global teak wood trade coming mainly from natural teak forests (Midgley *et al*., 2015), which occur in the Shan State in the East and the Rah-Khine State in the Western watershed of the Ayeyarwady and Chindwin rivers (Gyi and Tint, 1995). However, the wood-based industry in Myanmar started facing difficulties after 2014, when the government significantly reduced wood productions derived from logging concessions (from 100,000 m^3/y to 10,000 m^3/y). The long-term viability of this industry most likely depends on private-owned teak plantations, which are now 14-15 years old (MRT: Myanmar Wood Based Industry - per communication). This phenomenon is relevant to the on-going ITTO Teak Project in the Mekong that aims at strengthening the smallholders of teak plantations through the legal supply chain (ITTO/BMEL, 2019). Besides, Bago Yoma is the main region for teak plantations because of a particular teak plantation program carried out by the Forest Department since 1998 (FD, 2000).

It is, therefore, always essential to assess a suitable site before plantation establishment (Tanaka *et al*., 1998). Suitable site selection is the main factor for any type of valuable tree species and has significant effects on the sustainable production and sustainable management system. Well-managed plantations can provide not only commercial benefits but also many environmental benefits by reducing soil erosion, slowing water run-off because of a variety of habitats, and their richness in diversity too (Aoudji *et al*., 2014). Plantation establishment with a combination of site selection could increase productivity to 8 to 12 m^3 per hectare and yield 15 to 20 m^3 per hectare per year on a short rotation of 20 years with appropriate silvicultural practices (Enters, 2000). This fact suggests the importance of site selection for teak plantations.

This research was conducted at the Phyu township, one of the areas of the Bago Yoma region that is recognized as the home of teak because of the excellent quality of natural teak wood (Keh and Aung, 1995). In the current situation, the dominance of the teak forest in the study area is lesser than in other townships among the Bago Yoma region due to its poor environmental conditions (FD: Phyu Township Forest Department -per communication). Furthermore, most of the previously established teak plantations do not take into account any proper scientific research, in particular in site quality. Suitable site selection for teak plantations with the appropriate methods and techniques is essential and should be done before any plantation establishment. Based on these points, our research aim focuses on identifying a suitable area for teak plantations by applying Geographic Information System (GIS) and FAO land evaluation method.

2. METHODOLOGY

2.1 Study area

The Phyu township of Taungoo District, Bago Yoma Region is located between the latitudes of 18˚ 48′ N and 18 ˚ 13′ N and longitudes of 95˚ 50′E and 96 ˚ 34′E, in the southern central part of Myanmar as shown below in Figure 1. Bago Yoma occupies an area of about 39,400 km^2 and consists of four districts: Bago, Taungoo, Pyay, and Tharawady. Bago and Taungoo districts are located in the eastern part of the province, while the two other districts are in the western part. The Phyu township, covering approximately 2,100 km^2, boarders with Kyauk-Kyi and Htan-Ta-Pin townships on the east, Kyauk-Ta-Kar township on the south, Nat-Ta-Lin and Pauk-Kaung on the west and Oak-Twin on the north. Geographically, teak trees dominate more in the west region of Bago Yoma than in the eastern region.

According to Taungoo District Forest Management Plan (FD, 2016), there are three reserved forests with an area of 100,680 ha and two protected public forests with an area of 61,937 ha. The total area of teak plantations is about 8,500 ha. The remaining forest area is about 70 % of the total land area of Phyu township and primarily found in the reserved forests and protected public forests, whereas the unclassified forest area (degraded forests) is about 4 % and the agricultural land area is 26%. Mixed deciduous forest dominates in Phyu township, and common non-teak hardwood species are Htauk-Kyant (*Terminalia crenulata*), Kanyin (*Dipterocarpus grandiflorus*), Hnaw (*Adina cordifolia*), Padauk (*Pterocarpus macrocarpus*), Pyin-Ka-Toe (*Xylia dolabriformis),* Yon *(Anogeissus acuminata),* Pyin-Ma *(Lagerstroemia speciose)*, and Binga (*Mitragyna rotundifolia*), which all can grow well with teak (Orwa *et al.*, 2009). The characteristic bamboo species are Kyathaung-Wa (*Bambusa polymorpha*) and Wa-Bo (*Dendrocalamus brandisii*).

The topography of the study area consists of flat terrain in the east and hilly area in the west with a slope of less than 14° and with an elevation ranging from 10 to 569 m above the sea level (https://earthexplorer.usgs.gov/). The area mostly has an average annual mean temperature of 29 °C (ranging between 11 °C and 42 °C) and an average annual rainfall of 2,116 mm (ranging between 1,339 mm and 2,966 mm). Total rainy days are about 120 through the year (DMH, 2018). Phyu township mainly includes two types of soil, such as Eutric Gleysols (meadow alluvial) and Dystric Nitosols (lateritic). The mountainous western area includes meadow alluvium (silty clay loam), which is the best locality for teak growth, while the lowland area is dominated by lateritic soil, which is not suitable for teak plantations. The soil properties are mostly slightly acidic, with pH level ranging from 4.7 to 6.8 and soil depth ranging between 132 cm and 200 cm (https://files.isric.org/soil-grids/data/recent/**)**.

Phyu township is composed of 18 wards (equivalent to sub-districts) and 58 village tracts. The total population of the township is 256,985, of which 64,261 are residing in the city area of the Phyu Township. The total number of households in the township is 49,074. Among them, 36,705 are village households. Most of the people depend mainly on agriculture, such as rice and various kinds of beans for their daily food supply.

2.2 Data collection

According to previous studies (e.g., Kaosa-ard (1981); Tanaka *et al.* (1998)), spatial data, which are essential to determine the suitable area for teak plantations, include topography, climate, and soil characteristics. In addition, land cover data is also essential to promote areas for plantations (Güler *et al.*, 2007). Topographic factor includes slope and elevation; climatic factor covers rainfall and temperature, and soil properties are soil pH, soil depth, and soil texture. Most data are classified as secondary data collected from different sources. The following secondary data shown in Table 1 was used to analyze the research objective.

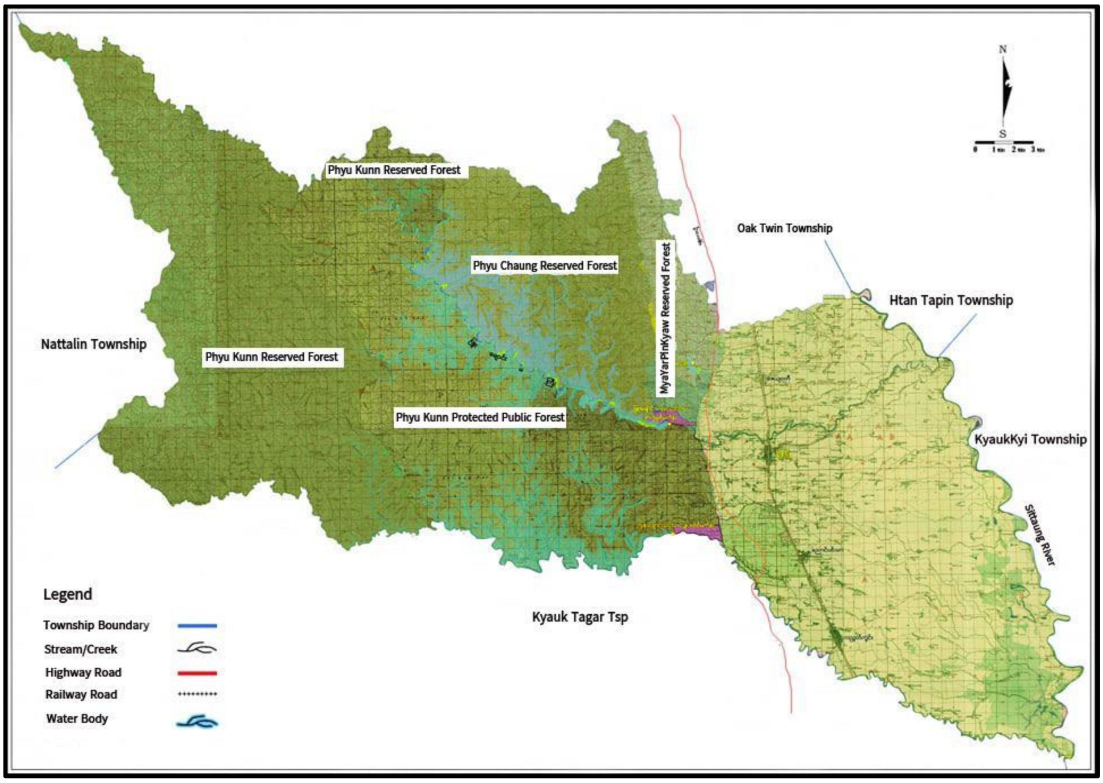


Figure1 Location of Phyu Township in Taungoo District, Bago Region

Table 1 Different types of variables for identifying site suitability

Main Factor	Variable	Source
Topography	Digital elevation model (DEM at 30-m resolution)	https://earthexplorer.usgs.gov/
Climate	Annual mean temperature, annual precipitation	https://www.worldclim.org/
Soil	Soil pH, soil depth, soil texture	https://files.isric.org/soilgrids/data/recent/
Land cover	Land use and land cover	https://rlcms-servir.adpc.net/en/landcover/

2.3 Limitation

It has some limitations to collect data from different sources because some available data covers only a limited area of the study area. For instance, there is only one weather station located at the city center of the Taungoo District (DMH: Department of Meteorology and Hydrology, Phyu Township). Also, there are only three soil sample sites in the study areas, according to the Forest Research Institute (FRI). Nevertheless, we also conducted a reconnaissance survey to visually observe teak plantations and collected additional soil characteristic data (e.g., soil texture, soil depth) in the study area.

2.4 Method

The study includes five main steps to complete the research objective. They are GIS data conversion and projection, reclassification of selected variables, assigning ranking and weighting scores of variables, spatial analyses, and site suitability mapping. The general flow of the study procedure is shown in Figure 2, and each step is explained below.

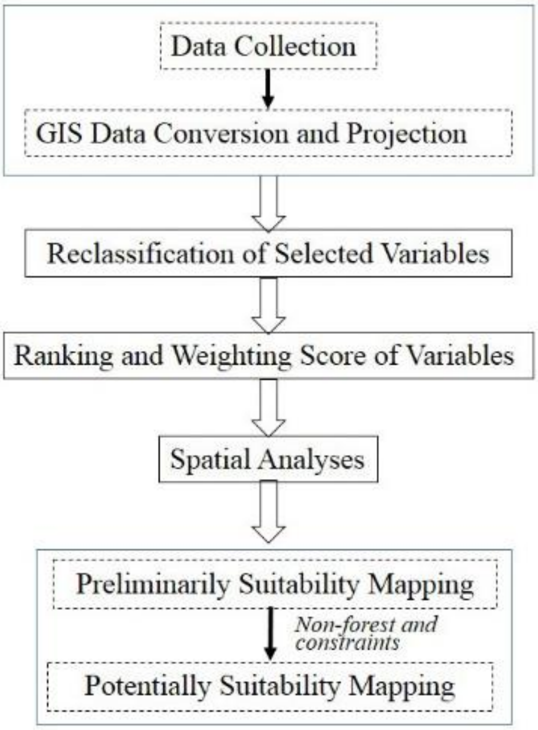


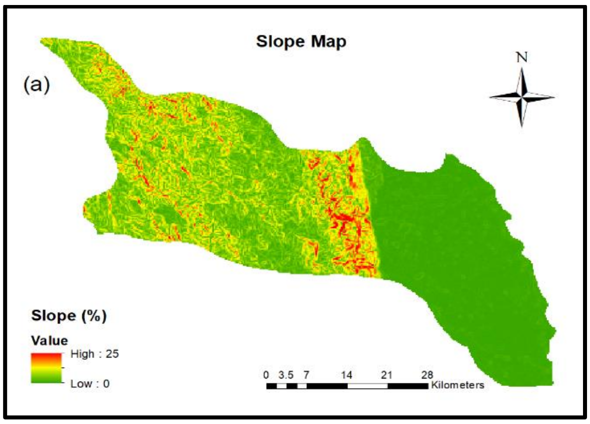
Figure 2 The general flow of the study procedure

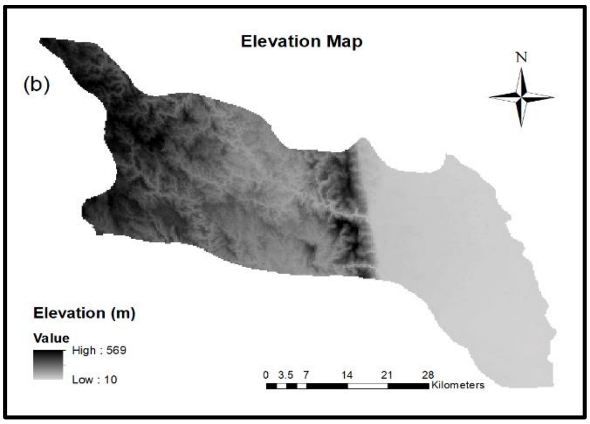
2.4.1 GIS data conversion and projection

The digital elevation model (DEM) of 30 m resolution covering the study area was downloaded from the United States Geological Survey or USGS (https://earthexplorer.usgs.gov/), and slope and elevation were derived from this DEM model. As a climatic dataset, annual mean temperature and annual precipitation of the study area were selected. These two climatic datasets were freely downloaded from the WorldClim- Global Climate Data, 2016- version 2 (https://www.worldclim.org/), which consists of free bioclimatic data. These climatic data cover the period of 1970-2000 with a spatial resolution of 30 seconds (~1 km^2). The soil dataset, soil type, the properties of soil pH, soil depth and soil texture of the study area were freely downloaded from World Soil Information (https://files.isric.org/soilgrids/data/recent/) released from 2017 with a spatial resolution of 250 m. Soil property is the most critical factor for the distribution of teak growth.

The forest type map prepared by Myanmar's Forest Department was very coarse and not up-to-date (FD: Forest Department, Myanmar). Therefore, a current land-use/land-cover map (2018) at 30 m resolution was downloaded from the SERVIR-Mekong project funded by the US Agency for International Development (USAID) (https://rlcms-servir.adpc.net/en/landcover/).

All spatial data were resampled to 200 m resolution, which is relevant to the minimum size of allocated forest land to smallholders for teak plantations in the Bago Yoma region (Oo, 2019). Besides, all raster data were projected to WGS 1984 datum and UTM zone 47 N using various tools of GIS software and spatial analyst before the subsequent analyses. The projected seven GIS variables are shown in Figure 3.





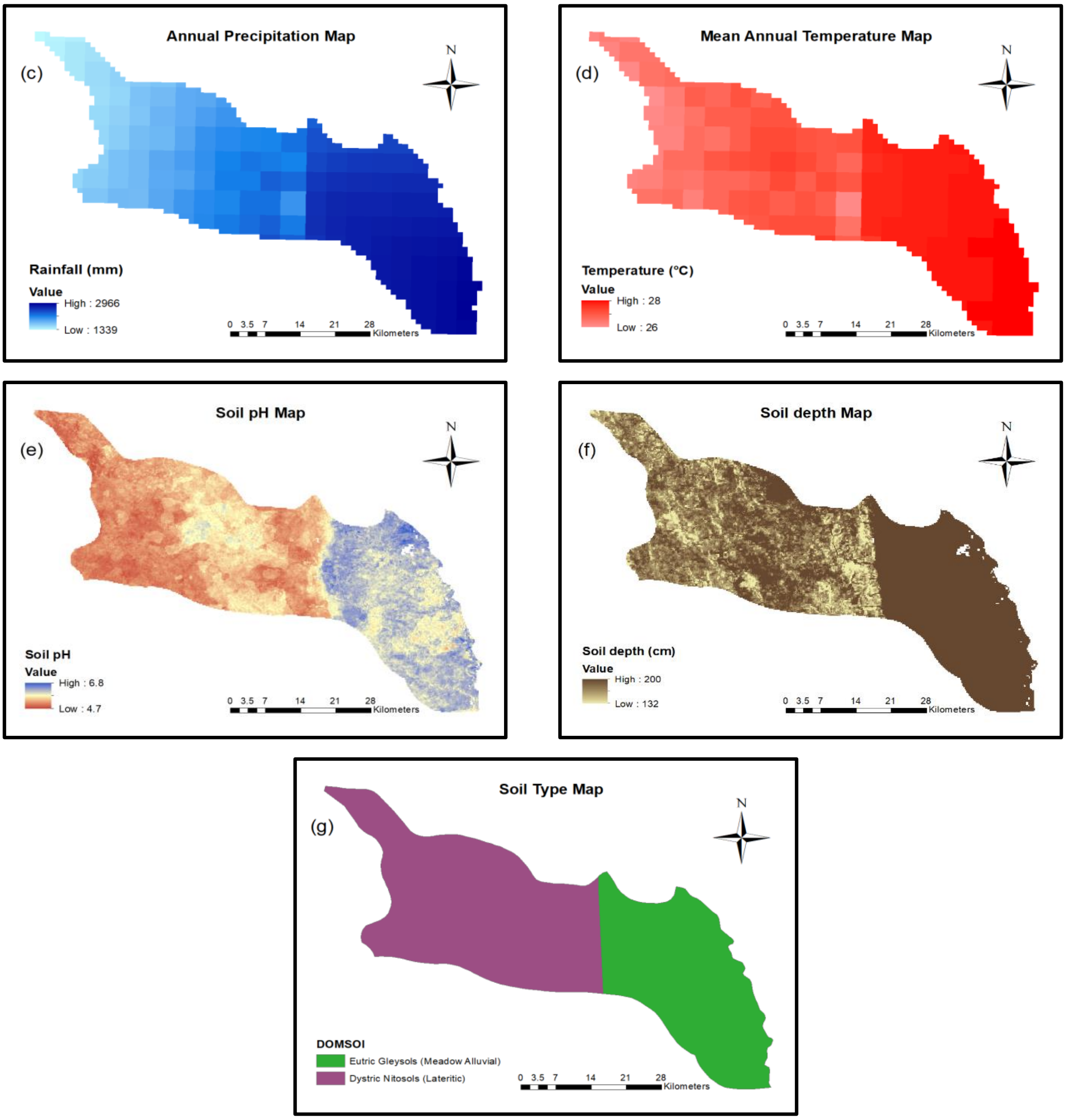


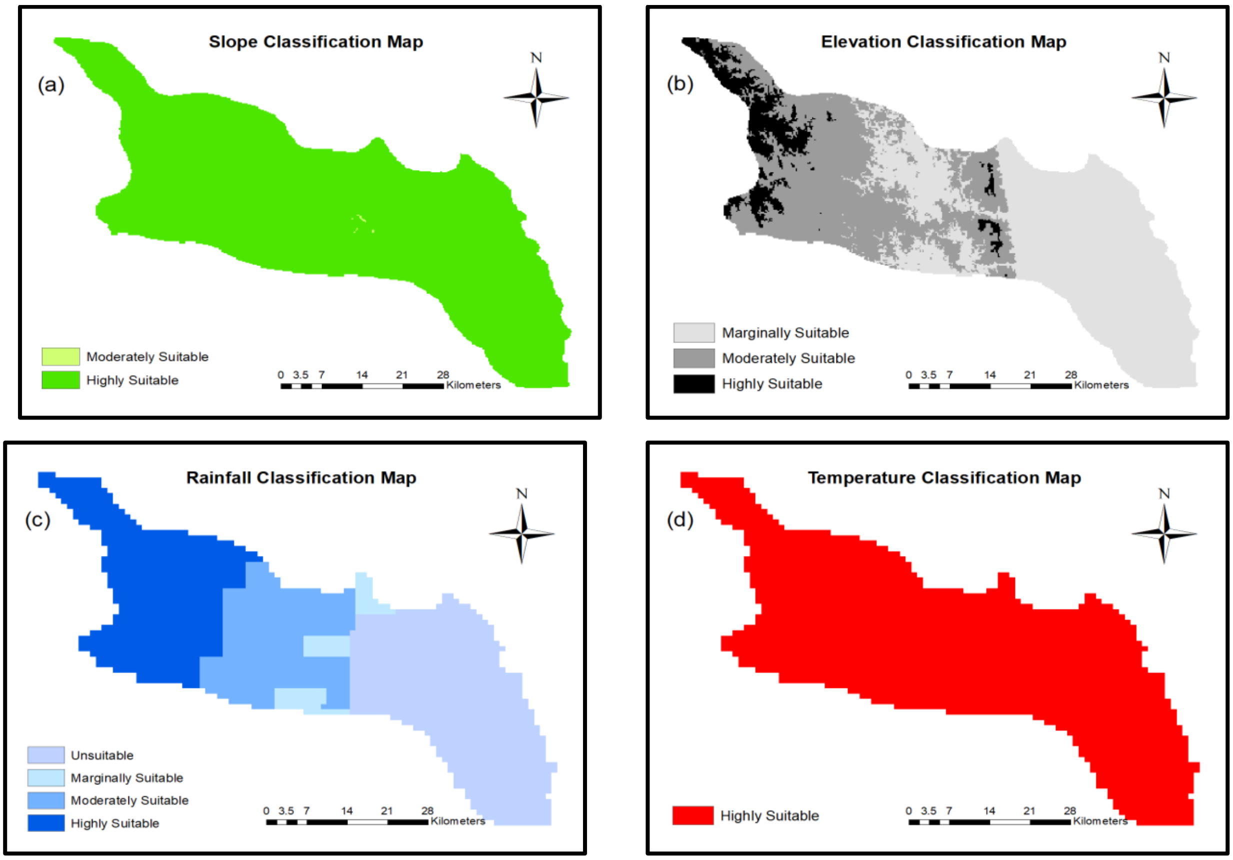
Figure 3 Seven different variable maps of the study area: (a) slope, (b) elevation, (c)rainfall, (d) temperature, (e) soil pH, (f) soil depth, and (g) soil texture

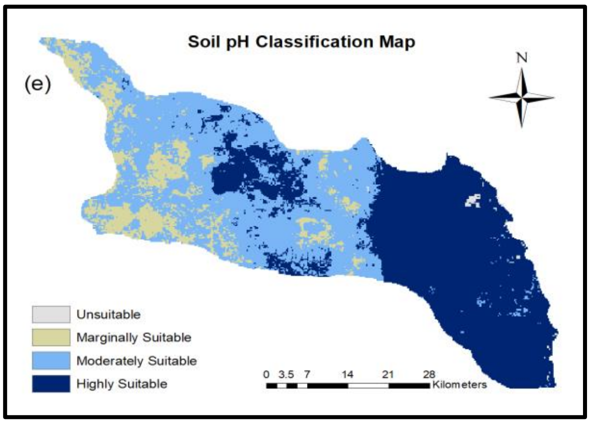
2.4.2 Reclassification

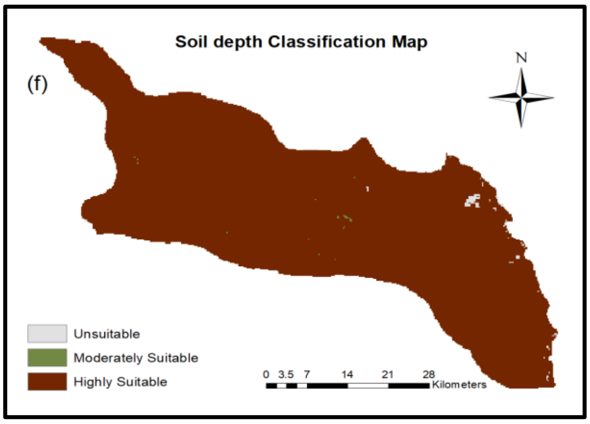
As discussed previously, we used the FAO matching technique to evaluate the suitability site for teak plantation (FAO, 1984). Therefore, the attributes of seven variables (i.e., slope, elevation, rainfall, temperature, soil pH, soil depth, and texture) were reclassified into four classes of suitability based on the FAO system and previous studies. These were: unsuitable (N1), marginally (S3), moderately (S2), and highly suitable (S1), they were as well assigned the ranking score of each suitable level as 0, 1, 2, and 3 respectively. The categorization of variables for suitability was based on literature (Htwe, 2016; Kaosa-ard, 1981; Meunpong *et al.*, 2017; Nicolay and Hokamp, 2014; Nugroho *et al.*, 2015). Ranking scores of each variable are shown in Table 2, while their spatial distributions are presented in Figure 4. Those with a higher score will be more suitable.

Table 2 Ranking score of seven variables

Variables	Ranking Score/ Suitability Level			
	0 (Unsuitable)	**1 (Marginally Suitable)**	**2 (Moderately Suitable)**	**3 (Highly Suitable)**
Slope	40->50% (21.8– >26.57°)	30 - <40% (16.7 – <21.8°)	20 - <30% (11.31 –<16.70°)	< 20% (< 11.31°)
Elevation (m)	700-900	0-200	200 -400	400 -700
Rainfall (mm)	<1000 (or) >2500	1000-1250 (or) 2250-2500	1250-1500 (or) 2000 - 2250	1500-2000
Temperature(°C)	16 - 20	20 - 25	30 - 35	25 - 30
Soil pH	<4.5	4.5-5.0	5.0-5.5	5.5-7.0
Soil depth	<75	75-100	100-150	>150
Soil texture	Gravel Sand, Clay, Silt	Loam sand, massive lit	Sandy Loam	Loam, Sandy clay loam, Silt loam, Clay loam, Sandy clay, Silty clay loam, Silty clay







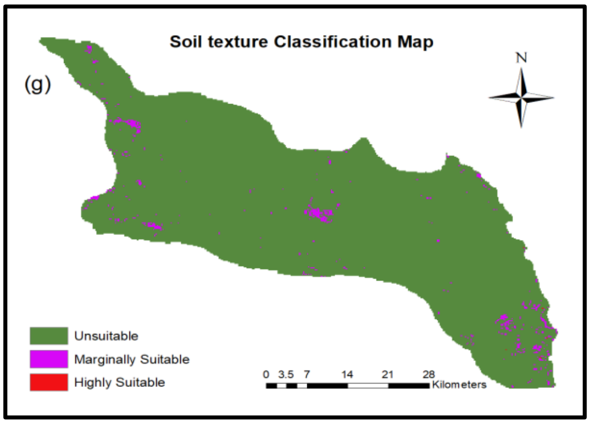


Figure 4 Reclassification map of all seven variables maps of the study area: (a) slope, (b) elevation, (c) rainfall, (d) temperature, (e) soil pH, (f) soil depth, and (g) soil texture

According to literature reviews, it was discovered that the maximum usable slope is 50%, and that slopes below 20% are the easiest to establish teak plantations on (Nicolay and Hokamp, 2014). The slope is one of the main limiting factors for teak plantations because the lesser the slope, the higher the moisture content of the slope is (Greulich *et al.*, 1985). Therefore, lesser slopes are more suitable. The maximum elevation limit for teak trees is about 900 m, and the most suitable value ranges between 400 m and 700 m, and suitability reduces at the minimum limit of 200 m. The limiting factor concerning elevation is the temperature (Nicolay and Hokamp, 2014). Teak can grow best under temperature ranging from 27 °C to 36 °C with the most suitable temperatures of 25 °C to 30 °C and the suitable rainfall is between minimum 1,000 mm to maximum 2,000 mm (Kaosa-ard, 1981). The range of soil pH in teak forests is 5.0 to 8.0 very wide, although the optimal soil pH is between 6.5 and 7.5. Teak can grow well in pH levels from 5.5 to 7.0 (FAO, 1998). The suitability sites have a soil depth of 75 cm or more, but soil depth lower than 75 cm is unsuitable for teak. Rock or deeper soils on gravel-based material are not so suitable for teak while in general, Luvisol and Leptosols are very suitable for teak plantations (Nicolay and Hokamp, 2014).

Regarding the slope variable, if the slope value is high, in the range of 40->50 % (or) 21.8–>26.57°, this range of slope is reclassified as unsuitable for teak plantations, while if it is below 20 % (or) below 11.31°, the area was reclassified into category 3, which is highly suitable for teak plantations. Similarly, other variables were applied in the same process and reclassified into four classes.

2.4.3 Ranking and weighting score of variables

Besides determining the ranking scores, we also assigned a weightage of each parameter. These seven variables are basically different in their dependence on land suitability (Kaosa-ard, 1981; Vaides-López *et al.*, 2019). The seven variables were grouped into three environmental groups, namely (1) topographic, (2) climatic, and (3) soil factors. We assigned the total (accumulated) weighting scores of 10. The more important for teak plantations the factor is, the higher weight is given to its contribution.

Out of the three parameters, the highest weightage was given to soil because soil property is the most crucial factor for teak distribution. Therefore, the soil factor was assigned a weighting score of 5, as presented in Table 3. And then, in the case of topography and climatic factor, slope and elevation are more sensitive factors for teak because teak cannot grow in all elevation gradients. Besides, the topography is recognized as a limiting factor for teak distribution. In Myanmar, teak is not found in areas of more than 914 m above sea level (Myint, 2012). Similarly, it is rarely seen in altitudes above 1,000 m in Thailand (Kaosa-ard, 1981). Thus, topography was assigned as the second most important factor (weighting score of 3). The weighting score for the climate was assigned as 2 because the study area is not very large, and teak can be found under a range of temperatures from 23°C to 35°C (Kanchanaburangura, 1976).

Table 3 Weighting score of three parameters

Factor	Weighting Score
Soil	5
Topography	3
Climatic	2
Total	**10**

2.4.4 Spatial analyses

After all variables were ranked and weighted, they were superimposed. Then, the cell-based algebra technique of spatial analytic tools was used to calculate the total scores of all pixels across the study area using the following equation.

$$\sum score = 3\left(\frac{slope + elevation}{2}\right) + 2\left(\frac{rainfall + temperature}{2}\right) + 5\left(\frac{pH + soil\ depth + soil\ texture}{3}\right)$$

Where the total of scores in a cell is the result of the calculation of parameter weights (Table 3) and average ranking scores from certain ranges of all variables (Table 2).

2.4.5 Site suitability mapping

The final step deals with suitable area mapping for teak plantations. The result of spatial analyses derived from the previous step determined the total scores. These scores were reclassified into three suitable classes: marginally suitable, moderately suitable, and highly suitable using mean and standard deviation (SD) values. It should be noted that suitable sites may be located either inside or outside the remaining forest cover (https:// rlcms-servir.adpc.net/en/landcover/). Therefore, the land cover dataset for the year 2018 was used to determine the areas promoted for teak plantations.

In the study area, there were 11 types of land cover. These include surface water, deciduous forest, orchard, and plantation, evergreen broadleaf, mixed forest, urban, and built up, cropland, rice, barren land, wetlands, and shrubland (Table 4). These types of land cover were grouped into three classes, including 1) forest areas, 2) potential conversion, and 3) constraints. The potential conversion or possible land use classes can be used for teak plantations include orchard and plantation, cropland, barren land, and shrubland. The total areas of these land use classes are 974.48 km^2. Orchard and plantation class is included because it mainly contains existing teak plantations, while fruit trees are minimal (Oo, 2019; https://rlcms-servir.adpc.net/en/landcover/). Other land use classes such as urban and build-up, wetlands and surface water are constraint factors for teak plantation. Conversion of these land use classes to teak plantations is most likely impossible. The potentially suitable sites to promote teak plantation contain moderately suitable and marginally suitable classes of the preliminarily suitable map, which are located inside the potential land use classes (Figures 5 and 6).

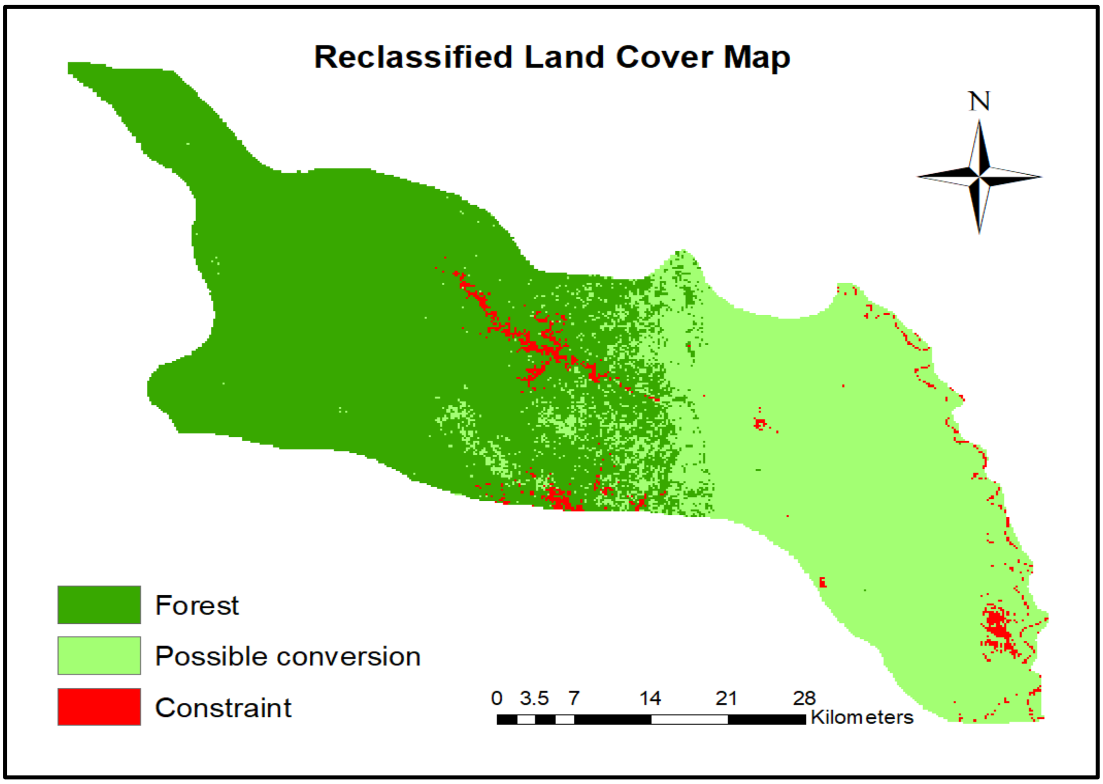


Figure 5 Reclassified land cover map in the study area (2018)

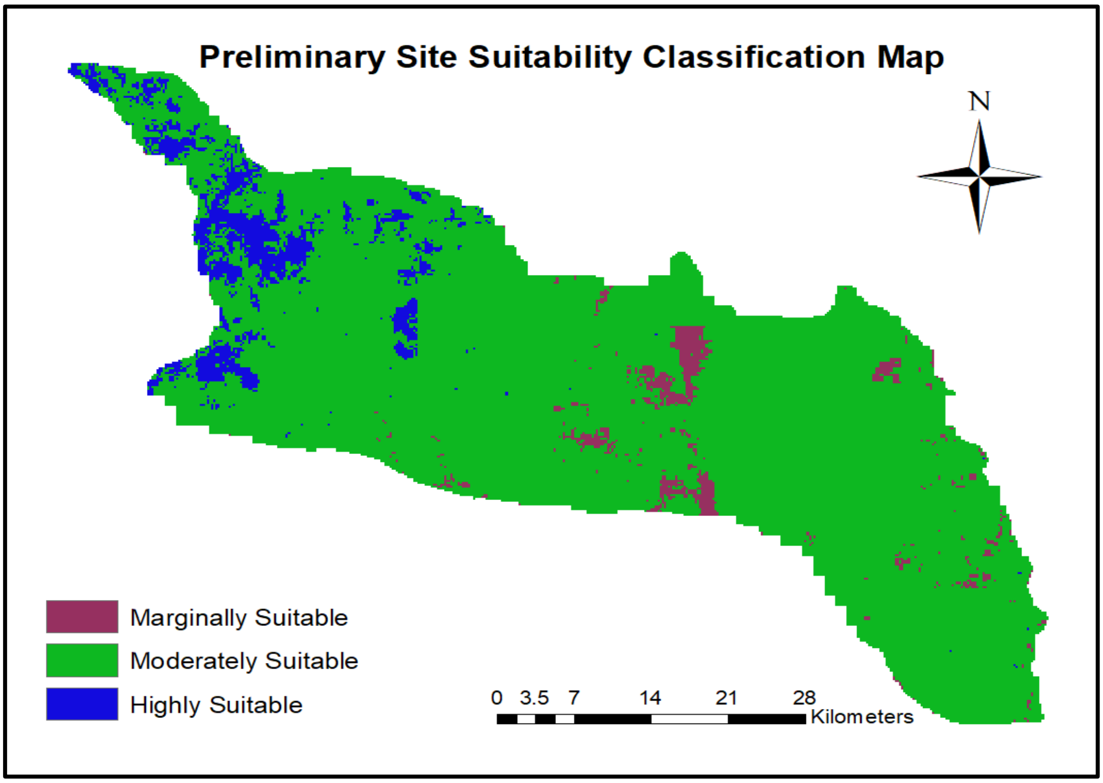


Figure 6 Preliminary site suitability classification for teak plantations

Table 4 Original and modified land use class and area of the study area

No.	Land use type	Modification	Area (sq.km)	%
1	Surface water	Constraint	33.20	1.51
2	Deciduous forest	Forest	850.80	38.73
3	Orchard and plantation	Possible conversion	141.52	6.44
4	Evergreen broadleaf	Forest	6.28	0.29
5	Mixed forest	Forest	321.48	14.63
6	Urban and built up	Constraint	1.60	0.07
7	Cropland	Possible conversion	829.60	37.76
8	Paddy field	Constraint	1.16	0.05
9	Barren	Possible conversion	0.52	0.02
10	Wetlands	Constraint	7.96	0.36
11	Shrubland	Possible conversion	2.84	0.13
	Total		**2196.96**	**100.00**

3. RESULTS AND DISCUSSION

3.1 Characteristics and distributions of environmental variables

The suitability classes of each variable resulted from the reclassification of all variables within their suitable ranges and were displayed in Figure 4. The proportion and area of each environmental variable can be seen in Table 5.

3.1.1 Slope

Slope value ranges between 0 % and 25 % (below 14°) in the study area. It was observed that the entire study area (2,195 km^2 or 99.5% of the study area) has a slope gradient of less than 20%, which falls into the highly suitable class, while only 0.05 % (1 km^2) has a moderately suitability class. Suitability decreases in steeper slope areas; therefore, the areas with lesser slopes are more suitable.

3.1.2 Elevation

Suitability is reduced with altitudes above 700 m, and the most suitable range lies between 400 m and 700 m. The topography of the study area ranges between 10 m and 569 m. Three suitability classes were found: marginally (1,193 km^2 or 54.33 %) in flat terrain on the east, moderately (821 km^2 or 37.39 %) in the middle area and high classes (182 km^2 or 8.29 %) in the hilly areas of the west.

3.1.3 Rainfall

Mean annual precipitation is ranging from 1,339 mm to 2,966 mm in the study area. Teak grows well in areas having annual rainfall between 1,000 mm and 2,000 mm with a sub-tropical climate. Highly (1,500 – 2,000 mm per year) and moderately (1,250-1,500 mm per year) suitable areas can be found in hillside area with a 708 km^2 (31.94 %) and 490 km^2 (22.10 %), respectively. All of the flat areas fall into unsuitable (913 km^2/41.18 %) or marginally (106 km^2/ 4.78 %) suitability classes.

3.1.4 Temperature

Teak is a light-demanding species. The suitable temperature sites (moderate-high) can be found between 25 °C and 35 °C. The entire study area lies in sites with temperatures between 25 °C and 28° C, which are highly suitable temperature classes for teak.

3.1.5 Soil pH

The range of soil pH in teak forests is 5.0 to 8.0 very wide, although the optimal soil pH is between 6.5 and 7.5. Teak can grow well at a pH level from 5.5 to 7.0, and its growth deteriorates at pH below 4.5. The study area has pH values from 4.7 to 6.8 in an area of all suitability classes, 13 km^2 (0.59 %) of unsuitable level, 249 km^2 (11.32 %) of marginally level, 935 km^2 (42.52 %) of moderately and 1,002 km^2 (45.57 %) of a highly suitable level.

3.1.6 Soil depth

Soil depth is ranging between 132 cm and 200 cm. The best sites for teak should have soil depth greater than 150 cm. Therefore, only 1 km^2 or 0.05 % of the study area is classified as a moderately suitable class, and 13 km^2 or 0.59 % are in unsuitable class, while most of the entire area (2,184 km^2 or 99.36 %) is classified as a highly suitable class.

3.1.7 Soil texture

Lateritic (Dystric Nitosols) and meadow alluvial soil (Eutric Gleysols) are major soil types of Phyu township (Figure 3g). The lateritic soil is dominant in the western part and is determined as not suitable for teak plantations. Meanwhile, a gleyic type derived from alluvial deposits contains a lot of clay particles, which is assigned as marginally suitable. Only a few patches (Luvisols) have sandy clay loam type and sandy loam soils, which are highly suitable for teak. Therefore, soil texture in the study area is mostly assessed into unsuitable with 2,159 km^2 (98.23 %), and 38 km^2 (1.73 %) in the marginally class and 1 km^2 (0.05 %) in the highly suitable class respectively.

Table 5 Proportion and area of each environmental variable

Variables	Ranking Score/ Suitability Level			
	0 (Unsuitable)	**1 (Marginally Suitable)**	**2 (Moderately Suitable)**	**3 (Highly Suitable)**
Slope	0	0	1 km^2/ 0.05 %	2,195/ 99.95 %
Elevation (m)	0	1,193 km^2/ 54.33 %	821km^2/37.39 %	182 km^2/ 8.29%
Rainfall (mm)	913km^2/41.18%	106km^2/4.78%	490km^2/22.10%	708km^2/31.94%
Temperature(°C)	0	0	0	2,217 km^2/100%
Soil pH	13 km^2/ 0.59 %	249 km^2/ 11.32 %	935 km^2 / 42.52 %	1,002km^2/45.57%
Soil depth	13 km^2/ 0.59 %	0	1km^2/ 0.05%	2,184km^2/ 99.36%
Soil texture	2,159 km^2/ 98.23%	38 km^2/ 1.73 %	0	1 km^2/ 0.05 %

3.2 Preliminary suitable classes

Total scores of the study area derived from grid-based analyses ranged from 9 to 25, with 6-9 for topography, 3-6 for climate, and 0-15 for soil characteristics. The mean value was 19.7, and the standard deviation value was 1.49. Using the mean and SD values, any pixels having the total scores from 9 to 17 (less than mean – SD) were classified as marginally suitable, 18-22 values (mean +/- SD) were classified as moderately suitable, and greater than 22 (mean + SD) as highly suitable. The preliminary suitability map is shown in Figure 6. The site suitability assessment showed a highly suitable class, an area of 130.12 km^2 (6.08 %) of the total area situated in the western hillside area. Similarly, areas occupied by marginally and moderately suitable lands were 61.24 km^2 (2.85 %) and 1,948 km^2 (91.07 %), respectively, as shown in the following Table 6. The marginally suitable areas are mainly located in the central part, while the large and contiguous suitable areas are found in the eastern part, and only small patches are scattered in the western part mainly due to its high altitude.

Table 6. Preliminarily suitability classes of the study area

Ranging of suitable score	Value	Suitability Class	Area (sq.km)	%
9 - 17	1	Marginally Suitable	61.24	2.85
18 - 22	2	Moderately Suitable	1,948	91.07
22 - 25	3	Highly suitable	130.12	6.08
Total			**2139.36**	**100.00**

Notes: mean = 19.7; SD = 1.49.

3.3 Final suitable site selection for teak plantations

All agricultural types of land were not a potential site to be promoted for teak plantation either because of physical constraints or high-cost investment. For example, the paddy field is recognized as traditional agriculture for the livelihood of local people. Conversion of paddy filed to teak plantation would be conflict on social, environmental, and economic impacts on local people (Barlow and Cocklin, 2003). However, if plantation forests were established on degraded or agricultural abandon lands, it can provide not only wood production but also substantial environmental benefits (Siry *et al.*, 2000). On the other hand, Myanmar Forest Policy 1995 aims to rehabilitate degraded forest lands and restore deforested areas by plantation establishment. By masking the moderately and highly suitable classes with the possible land use conversion class (Table 4), the total area of 932.24 km^2 or 42% of the study area could be promoted for teak plantations, including 120 km^2 of orchard and plantation, 808 km^2 of crop land, and 3 km^2 of degraded land area (Table 7).

Natural forest and existing plantations in the Bago Yoma range cover approximately 60 % of the study area. When the preliminary suitability map was masked by the reclassified land use map, it was evident that most agricultural areas (cropland, orchard, and plantation), degraded land, and built-up, and water surface areas fall into moderately suitable classes. Furthermore, forest areas can be seen by scattering in all suitability classes, in particular, moderately and highly suitable classes (Figure 7).

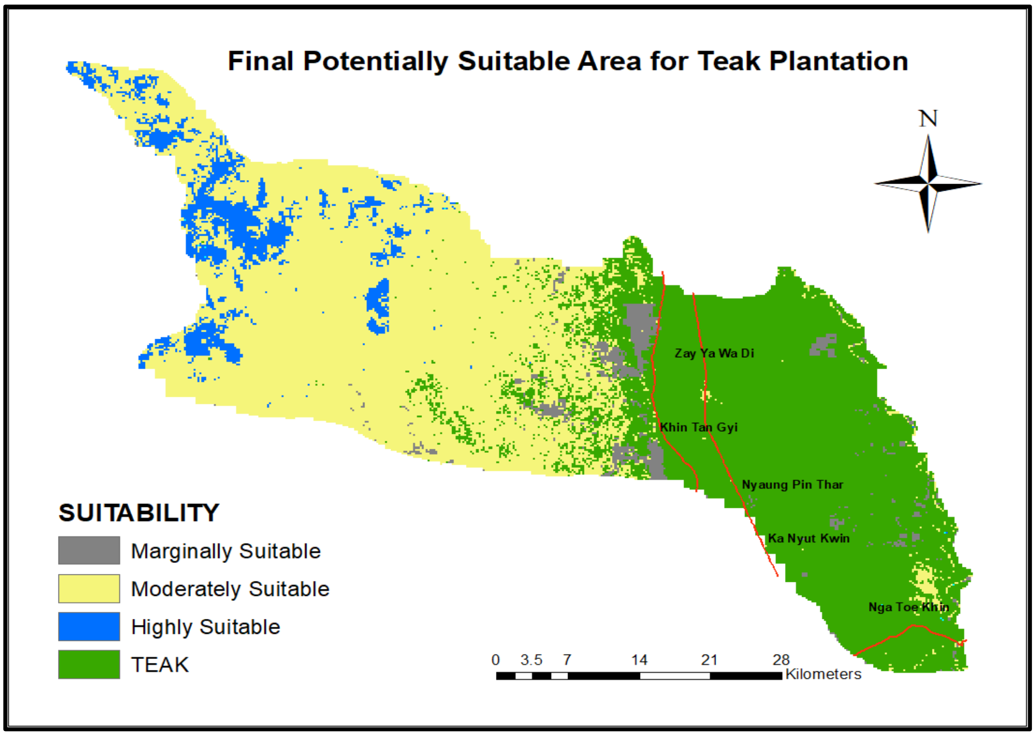


Figure 7 Final potentially suitable area for teak plantation in the study area

Table 7. Land use classes and preliminarily suitability classes of the study area (km^2)

Prelim. suitability	**Forest area**			**Possible conversion**				**Constraints**				**Total**
	Deciduous forest	Evergreen broadleaf	Mixed forest	Orchard & plantation	Cropland	Barren	Shrubland	Paddy filed	Surface water	Wetlands	Urban & built up	
Marginal	9.76	0.21	11.61	20.91	18.32	0.29	0.08	0.00	1.15	0.12	0.00	62.44
Moderate	755.27	6.42	266.07	**120.48**	**808.83**	**0.25**	**2.68**	1.07	30.46	8.15	1.19	2000.87
High	89.11	0.04	43.88	**0.04**	**0.45**	**0.00**	**0.00**	0.00	0.08	0.00	0.00	133.61
Total	854.14	6.67	321.55	141.43	827.59	0.54	2.76	1.07	31.69	8.27	1.19	2196.92

The existing forested lands would not be able to promote teak plantations because of the confrontation between forest conservation and forest development. In addition, the option of changing urban/ built-up and water surface areas into a new area for teak plantations is not feasible and too costly (especially water body). If teak plantations are established in this region, the socio-economic condition of local people and environmental assessments must be considered as well. Therefore, agricultural land areas should be considered as suitable site selection if compared with forest area, urban and water surface. However, all agricultural types will not be suitable for teak plantations. The existing agricultural areas, including rice and cropland and orchard and plantation, cover about 975 km^2 (44.39 %) of the agricultural land area. Out of 975 km^2, 142 km^2 (6.44 %) of orchard and plantation, 830 km^2 (38%) of cropland, and 3 km^2 (0.15%) of the degraded land area were identified as a potentially suitable site for teak plantation (Table 4). The final site suitable areas to promote or to convert agricultural lands into teak plantations cover approximately 932 km^2 (42%) located mainly in the east part and central parts of the township as in moderately suitable classes.

3.4 Discussion

The selection of suitable sites for forest plantations, especially teak plantations, is essential because of the long rotation period (Enters, 2000). Previous studies were conducted both at the specific area to asses site quality and for defining the growth performance in a single-species and even-aged stand (Pandey and Brown, 2000). On a broader scale, it is recommended to use soil-site measurement or the indirect method using GIS approach to determine land suitability to find the possible areas for new plantations, as well as to estimate growth and yield of plantations (Jumwong *et al.*, 2018). This study attempts to select suitable sites for teak plantations at Phyu township in the Bago Yoma region, Myanmar, recognized as the home of teak.

In fact, GIS has very distinct, powerful functions and can play an essential role in the decision making and planning process, and provide a great advantage to analyze multi-layers of data spatially and quantitatively (Kiran *et al.*, 2015). However, it is rarely used in Myanmar for selecting site suitability of teak plantations, even though Myanmar's government has implemented policies to promote teak plantations since 1998 to substitute forest concessions in natural forests (FD, 2000). The results of this research will accelerate Myanmar's forest plantation policy and the activities of the on-going ITTO Teak project in the Mekong (ITTO/BMEL, 2019).

Typically, forest officers use simple methods like soil sample classification at a national laboratory in advance of teak plantation establishment, and site surveys, and national forest inventory work when establishing teak plantations at the initial stages. In this research, we found out that applying GIS techniques can give reliable data in a short time. Therefore, Kiran *et al.* (2015) concluded that GIS could provide an excellent advantage for result data on accuracy and reliability, depending on the available spatial data.

In this study, the weight assigning or matching method was used based on three environmental factors including topography, climate and soil. Weighting score was created by the determination of priority/ importance for teak plantations, while ranking score was assigned for the attribute of variable according to its suitability. Although, these scores were given based on previous studies (e.g., De Camino *et al.*, 2002; Kaosa-ard, 1981; Pandey and Brown, 2000; Tanaka *et al.*, 1998). It is basically arbitrary. In addition, the research did not validate or comparison of the study result to other studies/projects. This is due to the fact that land suitability for teak plantation has never been applied in this study area. In addition, site quality cannot be used because teak plantations have been recently established. Other methods could be applied (e.g. pairwise comparison) for future research. Furthermore, the conditions of long-term teak plots (20-30 years old) can be shown the agreement or disagreement of suitability classes.

In addition, the research result determines the potential site for teak plantation largely based on physical variables. Final decision is also depending on land quality and economic return compared with other crops, as well as social conditions (FAO, 1984; Kaosa-ard, 1981). Myanmar still has rather limited and poor datasets. Many GIS layers were therefore downloaded from global dataset (e.g., climate and soil). To improve the quality of research results, we therefore highly encourage Myanmar's institutions (e.g., universities, Forest Department) to develop national datasets, especially for soil data, because some soil properties (e.g., shallowness, hardpans, waterlogging, compaction, or heavy clays) are identified as limiting factors for teak growth (Weaver, 1993).

The results of this study show that about 932 km^2 or 42% of study area is potentially promoted as teak plantations, which reflects the recognition Bago Yoma region as home of teak because of the good quality and geographical identity of natural teak wood (Keh and Aung, 1995; Midgley et al., 2015). The potential areas are currently occupied by orchard plantation (120 km^2) and cash crops (808 km^2) such as sugarcane and banana. Based on national statistics, the price of sugarcane is declining from USD 38 per ton in year 2015 to USD 32 per ton in year 2019 (LIFT, 2019). FAO (2009) predicted that the global wood demand will increase from 1,200 million m^3 in 2020 to over 1,800 million m^3 in 2030 or 50% from the baseline within 10 years. Nevertheless, Myanmar significantly reduced wood harvest from logging concessions (MRT: Myanmar Wood Based Industry - personal communication). Therefore, there are a lot of opportunities to convert croplands either for smallholder plantations or for large scale commercial teak plantations in Myanmar and the GIS technique used in this study is highly relevant and supporting.

Consequently, the research outputs will help in implementing Myanmar Forest Policy-1995 and 30-years forestry master plan (2001-2031), which aim to protect and extend reserved forests and protected public forests (PPF). Moreover, Myanmar Forest Policy 1995 stipulates up to designate up to 30% of total land area as reserved forest. Therefore, if poor productivity of cash crop and abandoned areas are substituted with teak plantations as an alternative way, local people will improve their socio-economic situation as a sustainable strategy. And Forest Department will quickly complete its national forest plantation target.

4. CONCLUSION

GIS could be effectively used as a management and analysis tool that facilitates the planning process. In this research the GIS approach, with a combination of the FAO matching technique, was used to evaluate three environmental factors, consisting of seven variables, to describe site suitability for teak plantations at Phyu township, Taungoo District, Bago Yoma Region. The preliminary suitability map, derived from the spatial analyses map, revealed that out of the study area about 61 km^2 (2.85 %) were marginally suitable, 1,948 km^2 (91.07 %) were moderately suitable, and about 130 km^2 (6.08 %) were highly suitable. When this map was masked by the recent land cover map to identify suitable areas for promoting teak plantations, about 932 km^2 (42 %) of the study area was obtained. Future research should incorporate land quality and economic conditions in the analyses. Validation with long-term teak plantation plots is also encouraged.

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