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Agricultural Land Evaluation Using GIS-Based Matching Method in Highland Areas for Oil Palm Cultivation

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Abstract

Oil palm (*Elaeis guineensis*) is one of the commodity crops and is mostly found in tropical lands. This study aimed to analyze the current and potential land suitability for oil palm using the geographic information system (GIS) technique. The study was conducted in the Ranau District, Sabah State, Malaysia. Field activity was carried out to collect soil samples and land information in the study area. Land suitability was then assessed using the matching method and GIS software was employed to produce a land suitability map for oil palm. The results indicated that the current land suitability classes in the study area were highly suitable (S1) with a total area of 99,118 ha (27.4%); moderately suitable (S2) with 110,108 ha (30.4%); marginally suitable (S3) with 109,533 ha (30.2%); currently not suitable (N1) with 2,728 ha (0.7%) and permanently not suitable (N2) with 40,693 ha (11.3%). Meanwhile, the potential land suitability classes showed 198,206 ha (54.7%) for S1; 123,281 ha (34%) for S2 and 40,693 ha (11.3%) for N2. Suitable areas that could be planted with oil palm included the gently sloping flank and the low gradient slope margin. Availability of nutrients and work capability were the dominant limiting factors in the study area. The outputs of this study recommend that the Ranau District has the potential for oil palm although it still needs land improvements for sustainable oil palm cultivation.

Keywords: agroenvironmental mapping; land suitability; limiting factors; spatial analysis; Ranau

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INTRODUCTION

Recently, the management of land use planning for agriculture or public sectors must be estimated quickly and efficiently. In other words, the development of land use projects should be firstly analyzed to avoid loss of money in the future. Therefore, land suitability or land evaluation is the best method in evaluating the potential of lands based on the analysis of their characteristics for a specific use, especially for agricultural functions (Rahmawaty et al., 2020). The primary aim of the land evaluation is to determine suitable areas for particular land use by calculating physical, social, economic and conservation of practice for sustainable land use (Karthikeyan et al., 2019). Land evaluation measures how the quality of land units fits the land use requirement. According to AL-Taani et al. (2021), it is found as the best agricultural land use for both rainfed agricultural and irrigated crops. Land evaluation has vital roles for potential agricultural efficiency and sustainable land use planning that analyzes land resources and

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suitability for each land characteristic. It is usually used to facilitate the land resources at a regional stage with specified land characteristics and land qualities as a land unit.

Generally, the land is a physical environment that consists of soil, climate, topography, water and plant. Interaction among these environmental factors can affect the land potential (Zhang et al., 2020). Furthermore, the land characteristic is highly associated with land quality, for example, soil texture and organic matter can govern the availability of water in soil (Senes et al., 2020). Land suitability can be measured by comparing the required land characteristics for specific land use. To analyze land suitability, the geographic information system (GIS) technique has been widely applied to evaluate land suitability in many studies (Maleki et al., 2017; Ostovari et al., 2019; Kome et al., 2020; Pilevar et al., 2020; Radočaj et al., 2020). With information and communication technology development, land evaluation analysis methods have been complemented using GIS and remote sensing. Several benefits of this technique are the rapid evaluation process and the presentation of land suitability outputs as shown in the map of spatial distribution (Hassan et al., 2017; Abdullahi and Pradhan, 2018). Also, the GIS can be used for collecting, classifying and overlaying values of land characteristics in the form of a raster map.

In Malaysia, the oil palm crop has contributed to the highest income for this country. At this moment, this country had more than five million hectares of the planted area of oil palm, and the government still makes an effort to increase the allocation of land for this commodity crop (Sahibin et al., 2019). Ranau is one of the district in the country with a low total of the planted area, which is around 1,849 ha. It was lower than other areas like Kinabatangan with a total planted area of about 279,108.4 ha (Department of Statistic of Malaysia, 2019). Based on the results of the previous studies, the soil properties in the Ranau District are suitable for oil palm cultivation (Sahibin, 1995; Simon et al., 2017), but limited works are available for land suitability analysis in this area because it is a highland region. Much of highland areas consist of stream-dissected high plateau and mountains that tend to drive complexity and variety of microclimates. Moderate soil erosion events indicate the Sabah's Ranau District because of long-term land degradation and many steep slopes surrounding the area (Roslee and Sharir, 2019). In the Ranau District, the population rises from year to year, leading to the decline of land productivity. Therefore, the agricultural production in the area has become unsustainable state because marginal lands have poor soil or other undesirable properties. It is important to assess the potential of the marginal lands such limitations and their suitability. The land evaluation aims to assure sustainable land use with the best management. Although the crop production technique in the Ranau District has been applied for many years, the potential and limitations of the land have not been assessed scientifically. Thus, the productivity level is still slightly low in the Ranau District. Therefore, in the present study, we aim to analyze the current and potential land suitability for oil palm cultivation in the Ranau District using the GIS technologies to supply scientific information that can be used for future sustainable land use development and planning. Furthermore, the local authority can also adopt the output of this study to increase the total planted area in the Ranau District.

MATERIALS AND METHOD

Study area

The Ranau District is located in Latitudes 5˚30’ to 6˚25’N and Longitudes 116˚30’ to 117˚5’E, covering a total area of about 3,612.8 km^2 (Figure 1). This is an administrative district in the Malaysian State of Sabah. It lies 108 km east of Kota Kinabalu as the main town. The Ranau covers hilly geographical areas or highland regions and is known as the largest producer of highland vegetables in this state. According to the geological history, the lithological study area is formed by a sedimentary rock from the crocker and trusmadi formations, and also there is an igneous rock intrusion from Mount of Kinabalu. The suitable temperature and soil of the Ranau District make it utilized to grow horticultural crops, such as cabbage, lettuce, tomato, carrot and capsicum. Strawberry is one of the famous fruits successfully planted in this area. Also, different species of flowers are cultivated for commercial functions. However, other commodity crops such as oil palm are not optimally planted yet in the study area. Currently, the total area with oil palm cultivation in the study area is only around ± 2,000 ha, recorded lower than other areas within this region.

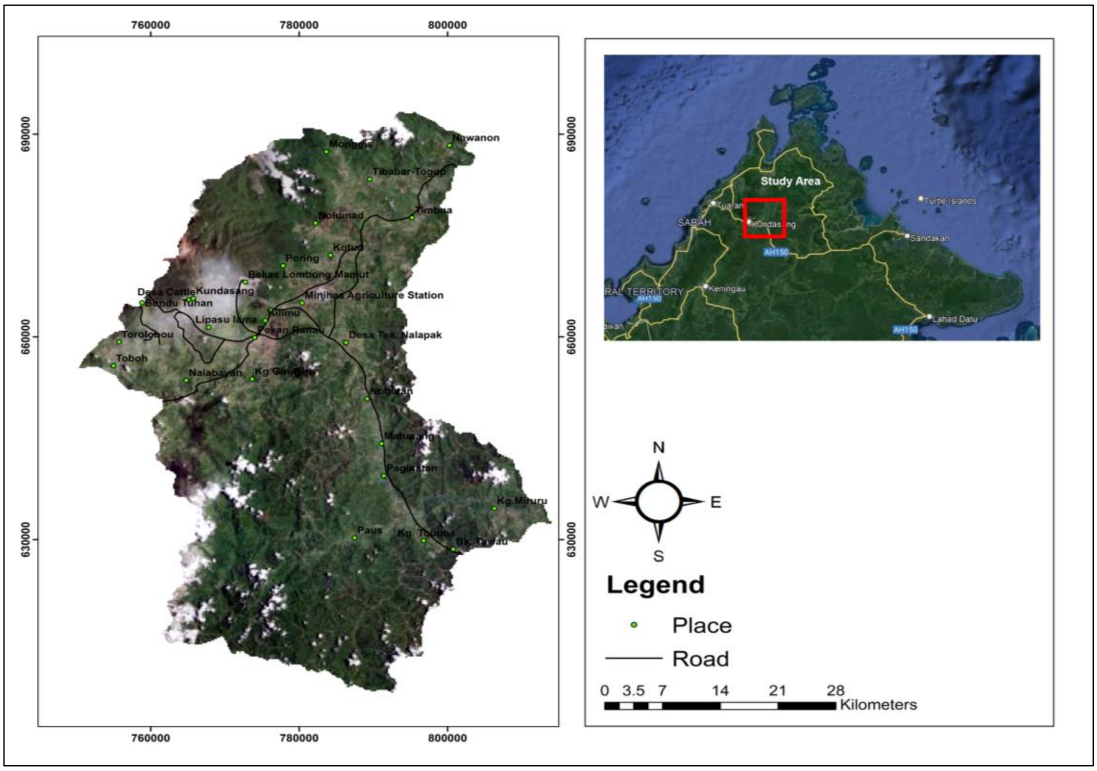

Figure 1. Location of the study area

Data collection

The data used in this study include data on soil, climate, topography and oil palm crop requirement. These data were collected from the field around June 2019. Field activity was carried out to collect soil samples and land information using the GPS Garmin Etrex 10 device. About 100 sampling points were collected for this study using a Dutch Auger at soil depth 0 to 10 cm. The soil samples were then brought to the laboratory for physical and chemical analysis, including pH, electrical conductivity, nutrient content, heavy metals and soil texture. The oil palm requirement data were obtained from the previous study (Sahibin, 1995). Climate data were obtained from the meteorological stations in the study area. Furthermore, topographical data were extracted from NASA's Shuttle Radar Topography Mission to generate the Digital Elevation Model (DEM) for the study area.

Data analysis

In this study, we used the matching technique to assess land suitability for oil palm. In general, land suitability analysis was conducted by matching the land characteristics (Table 1) with the crop requirements (Table 2). Leibig's law of the minimum was applied to analyze the limiting factors that governed the land suitability class (Ritung et al., 2011). This technique fitted the data from the laboratory and the field with the crop requirements. The land suitability analysis classified the land suitability into five, including highly suitable (S1), moderately suitable (S2), marginally suitable (S3), currently not suitable (N1) and permanently not suitable (N2) (Food and Agriculture Organization, 1976).

Table 1. The association between land qualities and land characteristics

Land qualities	Land characteristics
Water availability	Rainfall, dry month duration, soil depth, soil texture
Oxygen availability	Drainage, flood event, soil texture, rainfall
Nutrient availability	pH, available-P, available-K, available-Mg, soil texture
Work capability	Stone mass percentage, slope, elevation, drainage
Toxicity	Electrical conductivity, heavy metals

Table 2. Levels of land characteristics and land qualities for oil palm cultivation

Land characteristics/ land qualities	Level of limiting factors and land suitability classes				
	None	Slight	Moderate	Poor	Very poor
	S1	S2	S3	N1	N2
Water availability					
Rainfall (mm $year^{-1}$)	> 2000	2000-1500	1500-1250	-	< 1250
Dry month (month)	< 2	2-3	3-4	-	> 4
Soil texture	Clay loam, loam	Sandy clay loam	Loamy sand, sandy loam	Any	Any
Drainage	Well drained	Moderately drained	Imperfectly drained	Poorly drained	Very poorly drained
Soil depth (cm)	> 100	100-50	50-20	20-10	< 10
Nutrient availability (mg kg^{-1})					
Available-K	> 312.8	156.4-312.8	78.2-156.3	< 78.2	-
Available-Mg	> 54	36-54	18-35	< 18.	-
pH	5.6-7.0	7.1-8.0	4.5-5.5	4.1-4.4	-
Available-P	> 25	15-25	6-14	< 6	-
Oxygen availability					
Soil texture	Clay loam, loam	Sandy clay loam	Loamy sand, sandy loam	Any	Any
Flood event	None	Rarely	Occasionally	-	Frequently
Drainage	Well drained	Moderately drained	Imperfectly drained	Poorly drained	Very poorly drained
Work capability					
Stone mass (%)	0-15	16-30	31-55	-	> 55
Slope (°)	0-6	6-12	12-25	-	> 25
Toxicity (mg kg^{-1})					
Cd	0-1	1-3	3-8	-	> 8
Cr	0-50	50-75	75-100	-	> 100
Cu	0-30	30-60	60-125	-	> 125
Ni	0-15	15-25	25-50	-	> 50
Pb	0-50	50-100	100-250	-	> 250
Zn	0-80	80-150	150-300	-	> 300
Electrical conductivity (mS cm^{-1})	0-4	4-8	8-15	-	> 15

Source: Sahibin (1995)

RESULTS AND DISCUSSION

Spatial distribution map of land quality

The land suitability assessment could be used as a fundamental way for arranging land use planning and decision-making. Recently, the GIS method has been widely applied to analyze land suitability in many studies (Nurda et al., 2020; Radočaj et al., 2020). One of the most effective benefits of applying GIS was that the assessment and the presentation of its outputs could be done in spatial maps to describe the distribution of certain geographic objects (Habibie et al., 2019; Nguyen et al., 2020). The GIS was also used for data repository, management and analysis of all geographic objects. Many studies elaborated the evaluation of land suitability on conventional agriculture, farming and commodities crop, but limited studies were found for the oil palm cultivated in highland areas because the land capacity for oil palm cultivation would continuously reduce while the global demand for oil palm was still high. Thus, the expansion of the use of agricultural land, including marginal areas like highland, had the important key for escalating the total planted area.

Figure 2 shows a spatial distribution map of land quality in the study area, such as water availability, nutrient availability, oxygen availability, work capability and toxicity. The spatial map indicated the classifications of water availability into S2 (336,542 ha (93%)) and S3 (5,773 ha (1.5%)) (Figure 2a). Meanwhile, 19,865 ha (5.5%) of the area was classified as N2, including Mount of Kinabalu with a high mass of stone, shallow soil depth which made the soil in this area did not have water storage for agricultural purposes. Therefore, limiting factors affecting land suitability classes S2 and S3 were soil texture, soil drainage and rainfall distribution. Water availability was a prominent land quality for oil palm because it was an interaction between climate and soil parameters. The oil palms usually needed water in much quantity for their growth. Waite et al. (2019) revealed that soil water availability would affect palm height on the anatomy of oil palm fronds. However, based on the results of this present study, we assumed that the study area would be suitable for growing oil palm because almost 90% of the area had good water availability. In addition, the annual rainfall of the study area was more than 2,000 mm, making it possible to ensure water availability for the crop, especially in the area with a soil depth of more than 50 cm. This notion was consistent with that of other studies, assuming that the optimum value of annual rainfall for oil palm growth ranged from 2,000 to 3,500 mm and the dry month period was not more than two months (Rahmawaty et al., 2020). Rainfall would affect the number of fruits, bunch weight and oil palm production (Gunawan et al., 2020).

The oil palm was a perennial plant that grew well under appropriate climatic situations. However, to support its growth and production, it needed large amounts of nutrients such as nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg). Therefore, in this study, we analyzed the availability of macronutrients such as N, K, Mg and P in soil. The nutrient deficiency in the soil could be commonly improved by using standard fertilization. The nutrient content in the study area was found at a low level. It might due to soil erosion and leaching processes that frequently occurred in this area. The results of this study showed that about 339,587 ha (93.8%) of the area was classified as S3 for oil palm, while 2,728 ha (0.7%) was N1 and 19,865 ha (5.5%) was N2 (Figure 2b). Limiting factors affecting the land suitability belonging to classes S3 and N1 were pH value and the contents of P, K and Mg in the soil. The lowest content of macronutrients was observed at N1 class, this area consisted of the ex-mining area (Mamut copper mine). This area has been degraded with soil and nutrient losses. In addition, the low pH in the area contributed to high solubility of macronutrients. Kurniawan et al. (2018) explained soil texture played a significant role in controlling nutrient leaching losses, nutrient stocks, soil fertility and nutrient cycling in weathered soils.

The spatial map of oxygen availability showed that around 180,810 ha (50%) of the area was classified into S2, while 161,505 ha (45%) into S3 (Figure 2c). Limiting factors influencing the land suitability of classes S2 and S3 were drainage and soil texture. The combination of soil texture, flood events and drainage factors would determine the status of oxygen availability in soil for plant growth. Furthermore, Oktarita et al. (2017) assumed that soil water and the water-filled pore space were a benchmark of oxygen availability in the soil. In the Southeast Asian Region, the oxygen availability in the soil was quite good, as reported in the study by Harahap et al. (2019) that the availability of oxygen in Pakpak Bharat District of North Sumatera, Indonesia, was at a good level for oil palm cultivation. This result was consistent with the current study that obtained that more than 80% of the study area was considered suitable for oil palm cultivation. In general, the oil palm needed at least 30% of aeration in the soil to supply good oxygen availability for the crop. Flood-prone areas that did not have good drainage would cause increased soil saturation and decreased aeration in the soil. The best areas for oil palm cultivation based on this study were characterized with moderate drainage, moderate soil texture, and not flood-prone areas.

The spatial map of work capability disclosed that 147,123 ha (41.1%) of the area was classified into S2; 171,364 ha (47.6%) into S3 and 40,693 ha (11.3%) into N2 (Figure 2d). Dominant limiting factors contributing to the S2 and S3 classes were the degree of steepness and soil texture in the study area. Meanwhile, the N2 class was indicated by the limiting factors, such as degree of steepness, stone mass and soil depth.

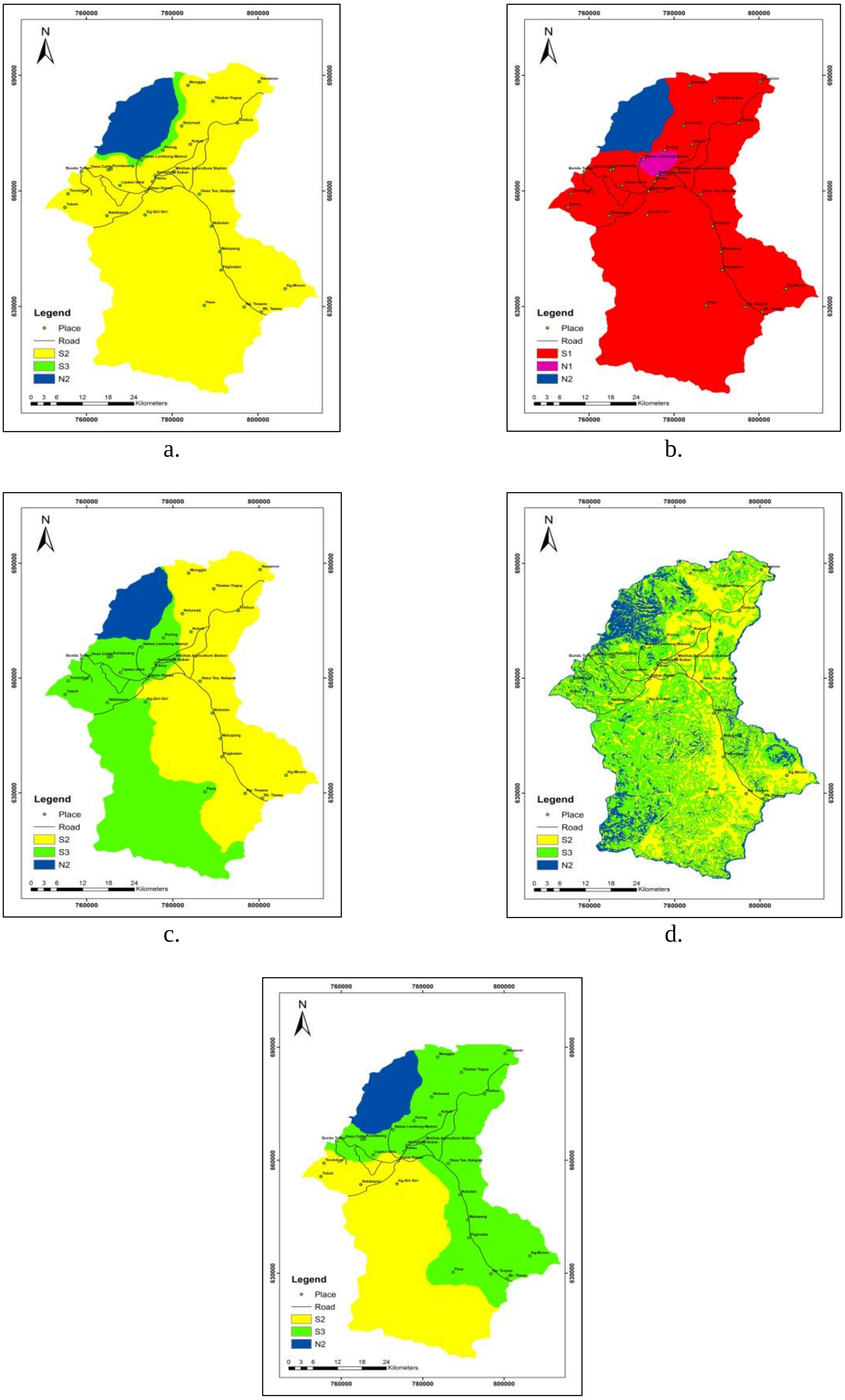

Figure 2. Map of land qualities for oil palm cultivation in the study area, (a) water availability, (b) nutrient availability, (c) oxygen availability, (d) work capability and (e) toxicity

A previous study by Montgomery et al. (2016) classified factors that affected work capability, including elevation, slope, soil texture, organic matter, depth to restrictive layer, available water, bulk density and drainage. The work capability was occasionally related to the capability of excavation machines employed in a particular area. The degree of difficulties of land preparation was affected by stone mass, slope and elevation of the proposed lands. For instance, the oil palm planted in the steep area would make it difficult for the workers to pick fruits. Therefore, Abd Aziz et al. (2019) assumed that the degree of steepness for oil palm cultivation should not be more than 25˚ for the plantable areas. Moreover, the spatial map of toxicity indicated that about 158,278 ha (43.7%) of the area was classified into S2, while 184,037 ha (50.8%) into S3 (Figure 2e). The limiting factors contributing to the S2 and S3 classes in the study area were high concentrations of Ni (352 mg kg^{-1}), Cu (130 mg kg^{-1}) and Cr (590 mg kg^{-1}) in the soil.

The presence of heavy metals in the soil could significantly decrease soil fertility for crop growth. The study by Tashakor et al. (2018) found the high content of Cu (1,650 μg L^{-1}) and Zn (134 μg L^{-1}) in the adjacent rivers from the ex-mining site. Van der Ent and Edraki (2018) concluded that the primary sources of the heavy metal pollution in the rivers were the Mamut copper mine and Cu-rich acid mine drainage that drained from the sites near the area.

Current land suitability for oil palm

The overlay analysis for all land qualities produced the current land suitability map for oil palm in the study area. Table 3 presents that about 99,118 ha (27.4%) of the study area was classified into S1; 110,108 ha (30.4%) into S2; 109,533 ha (30.2%) into S3; 2,728 ha (0.7%) into N1 and 40,693 ha (11.3%) into N2. Some areas with S1 classes for oil palm cultivation were shown at the northeast and the east then to the southeast parts of the study area (Figure 3). These areas were found at the lower elevation and gentler slope areas. In contrast, N1 areas were mostly found in the ex-mining area and its surroundings. This area was categorized into the N1 class because it had a limiting factor of nutrient availability problem. Meanwhile, N2 areas consisted of hilly areas with a steepness value of more than 25˚. The dominant limiting factor in this class was work capability, including steepness and elevation factors. These areas also covered reserved forest areas, which could not be developed for any human activities in the northwest and the southwest parts of the study area.

Table 3. The current and potential land suitability classes for oil palm in the study area

Land suitability analysis	Suitability classes	Limiting factors	Area	
			ha	%
Current land suitability	S1	-	99,118	27.4
	S2	na, to, oa, wc, wa	110,108	30.4
	S3	na, to, oa, wa, wc	109,533	30.2
	N1	na	2,728	0.7
	N2	wc	40,693	11.3
Potential land suitability	S1	-	198,206	54.7
	S2	-	123,281	34.0
	N2	wc	40,693	11.3

Note: na = nutrient availability; to = toxicity; oa = oxygen availability; wa = water availability; wc = work capability

Potential land suitability for oil palm

Potential land suitability analysis was performed by considering all limiting factors in the S3 and N1 classes, which were already improved and thus suitable for oil palm cultivation. For example, the nutrient deficiency was improved using standard fertilization technique, low pH with liming, poor drainage and aeration with organic amendment application (Jakkula and Wani, 2018; Baghbani-Arani et al., 2021). However, other permanent limiting factors such as work capability, which consisted of high mass of stone, steepness and elevation, could not be improved due to high cost, and therefore, the area under this condition remained in the N2 class. Figure 4 demonstrates a potential land suitability map for oil palm cultivation. There was an increase of S1 and S2 classes after improving land characteristics in the current land suitability map.

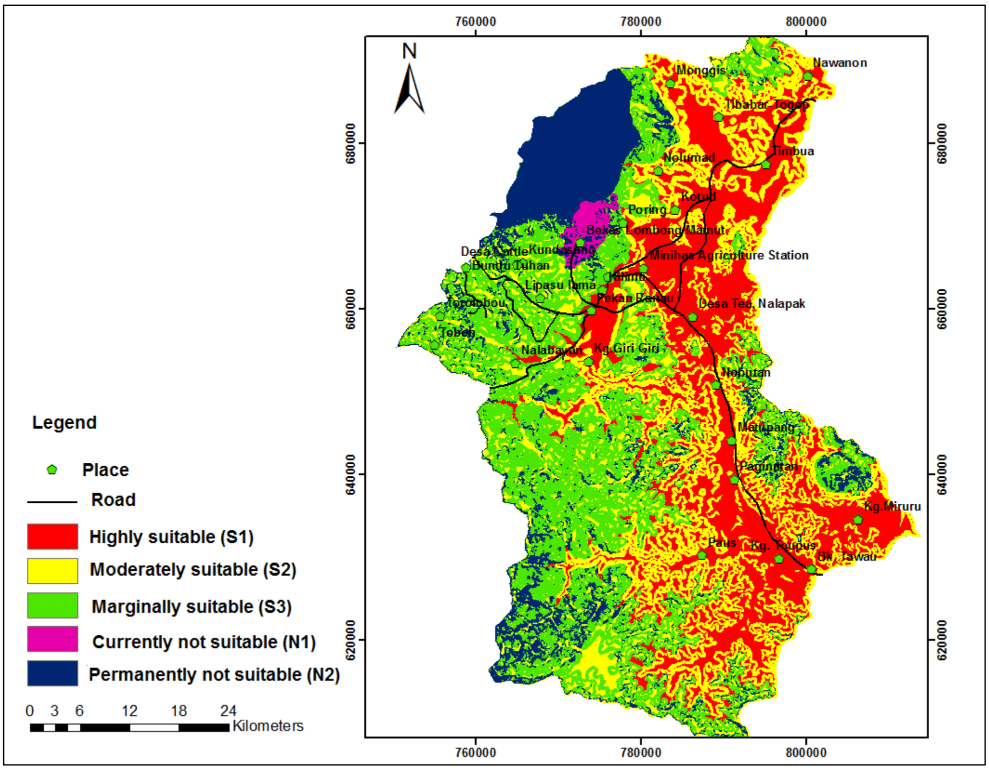

Figure 3. Map of current land suitability for oil palm cultivation in the study area

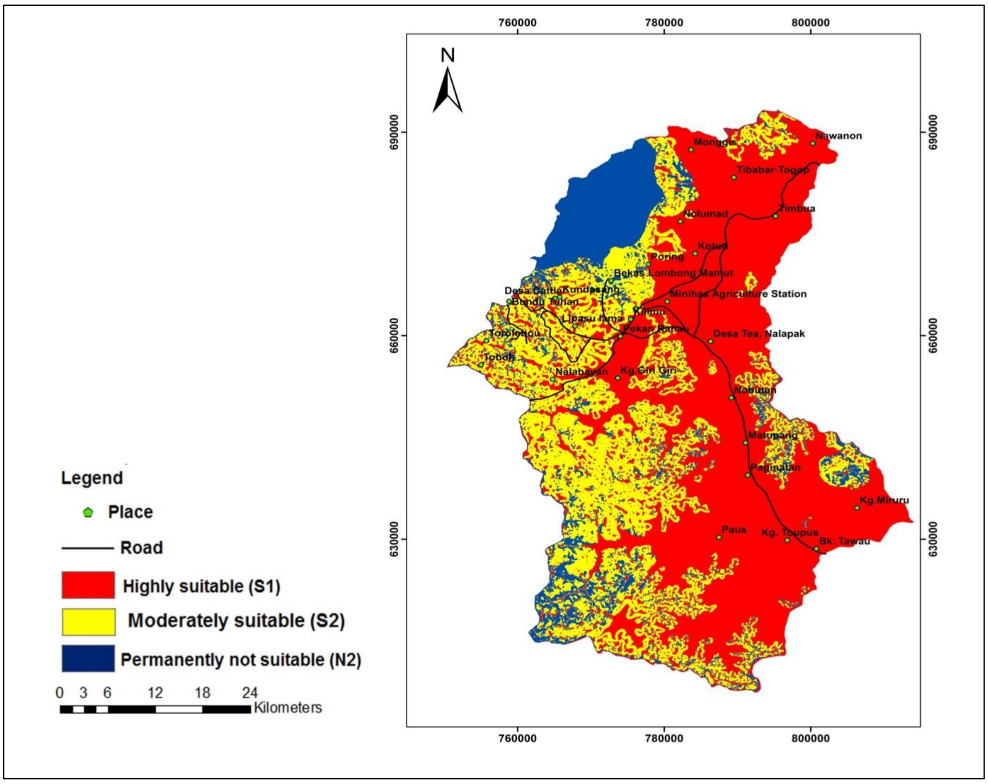

Figure 4. Map of potential land suitability for oil palm cultivation in the study area

As a whole, the results of potential land suitability analysis revealed that the S1 covered about 198,206 ha (54.7%) of the area, S2 about 123,281 ha (34%), while N2 around 40,693 ha (11.3%) (Table 3). This study suggested the assessment and selection of optimal land for oil palm by using a GIS-based matching method. Using this technique, the oil palm plantation owners could improve oil palm quality and decrease plantation expenses.

CONCLUSIONS

This study revealed that the total area of suitable classes in the current land suitability map was around 209,226 ha, while the potential land suitability map showed a higher total area of suitable classes around 321,487 ha. Hence, this study concluded that the study area was found very suitable for oil palm cultivation. The outputs of this study can be used by the local authority to determine the suitable areas for oil palm; thus, the land utilization can be carried out at maximum capacity.

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