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RESEARCH ARTICLE — OPEN ACCESS

Geospatial assessment of potential land suitability for oil palm (*Elaeis guineensis Jacq*) cultivation in the western parts of Ethiopia☆

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Abstract – Ethiopia is investing in Oil Palm cultivation to minimize palm oil imports from other countries. Our aim was to analyze the potential land suitability for oil palm tree cultivation by using geospatial technology with an analytical hierarchy process (AHP) in the Jejeba watershed, Western Ethiopia. Ten parameters such as, land use land cover (LULC), land surface temperature (LST), agro-ecological zone (AEZ), slope, rainfall, soil types, soil texture, soil drainage, soil depth and road were aggregated and reclassified according to their suitability to evaluate potential land for oil palm cultivation in the study. In the presnt study, ArcGIS 10.3, ERDAS 2015, and ArcSWAT software were used. Results show that about 36.7 km^2 (1.[illegible]%) was highly suitable for palm oil cultivation. Consiquentially,1780.5 km^2 (64.8%) was moderately suitable for oil palm cultivation whereas, about 25.2 km^2 (0.9%) of the study area was not suitable for oil palm cultivation. The southeastern part was highly suitable, whereas some eastern and northern parts of the study area were not suitable for oil palm cultivation. Therefore, government and non-governmental organizations should raise awareness among local communities to support oil palm cultivation in the study area. Further studies should be carried out, especially on the importance of soil PH, aspect and proximity to markets should be investigated to understand the most suitable areas for Oil Palm cultivation in the western parts of Ethiopia.

Keywords: Oil palm / AHP / overlay analysis / Jejeba watershed / geospatial technology

Résumé – Évaluation géospatiale de l'aptitude potentielle des terres à la culture du palmier à huile (Elaeis guineensis Jacq) dans les régions occidentales de l'Éthiopie. L'Éthiopie investit dans la culture du palmier à huile pour répondre à la demande de l'industrie et minimiser les importations d'huile de palme en provenance d'autres pays. Notre objectif était d'analyser l'aptitude du potentiel foncier à la culture du palmier à huile en utilisant une approche géospatiale *via* une analyse multicritère hiérarchique (AHP) dans le bassin versant de Jejeba, à l'Ouest de l'Éthiopie. Dix paramètres tels que l'utilisation des terres, la couverture terrestre (LULC), la température de la surface des terres (LST), les zones agro-écologiques

☆ Contribution to the Topical Issue: "Palm and palm oil / Palmier et huile de palme".

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(ZEA), la pente, les précipitations, les types de sol, la texture du sol, le drainage du sol, la profondeur du sol et les routes ont été regroupés et reclassés en fonction de leur aptitude à évaluer les terrains potentiels pour la culture du palmier à huile dans l'étude. Dans la présente étude, les logiciels ArcGIS 10.3, ERDAS 2015 et ArcSWAT ont été utilisés. Les résultats montrent qu'environ 36,7 km^2 (1,3%) étaient parfaitement adaptés à la culture de l'huile de palme. En revanche, 1 780,5 km^2 (64,8%) étaient modérément propices et environ 25,2 km^2 (0,9%) de la zone d'étude n'étaient pas adaptés à la culture du palmier à huile. La partie Sud-Est convenait parfaitement, alors que certaines parties Est et Nord de la zone d'étude n'étaient pas adaptées à la culture du palmier à huile. Par conséquent, les organisations gouvernementales et non gouvernementales devraient sensibiliser les communautés locales au soutien de la culture du palmier à huile dans la zone d'étude.
Des études complémentaires devraient être menées, notamment sur l'importance du pH du sol, de l'aspect, et la proximité des marchés doit être étudiée pour identifier les zones les plus appropriées à la culture du palmier à huile dans les régions Ouest de l'Éthiopie.

Mots clés : Huile de palme / AHP / bassin versant de Jejeba / géospatial / Ethiopie

1 Introduction

The Palm oil tree is originated to West Africa and is the tallest tree with larger evergreen leaves, slender, smooth trunk, and unbrached stem and has three natural forms: Dura, Tenera and Pisifera fruit. Taxonomically, this tree belongs to the Superorder *Lilianae*, Order *Arecales*, Family *Arecaceae*, Genus *Oil Palm* and Specie *African Oil Palm*. Globally, Indonesia and Malaysia are the leading palm oil tree producing countries, and account for about 85–90% of the palm oil production (Zuhdi *et al.*, 2021; Ng *et al.*, 2022).

Cameroon, the Central African Republic, Côte d'Ivoire, the Democratic Republic of the Congo and Gabon are the largest palm producers in Africa (Ouédraogo *et al.*, 2021). Oil palm is used as a source of income, source of human consumption, detergent, disease treatment agent and industrial input as raw materials (Dislich *et al.*, 2017). An edible oil palm contains 40% monounsaturated fatty acids, 10% polyunsaturated fatty acids, 45% palmitic acid and 5% saturated fatty acids that can be used in a variety of food applications (Dorni *et al.*, 2018). Diseases related to cardiovascular issues, cancer, kidney and injured body are treated with palm oil products (Zainal *et al.*, 2022). Similarly, sodium lauryl sulfate is produced from palm oil and used to clean household products. In addition, different industrial products such as fatty acids, soaps, cosmetics, waxes, resins, and methyl esters are obtained from palm oil production (Jeon *et al.*, 2019).

Since the 20th century, Palm oil cultivation has been practiced in some parts of Ethiopia by agro pastoralists in Afar, Somali, Gambella, Dire Dawa, Benishangul Gumuz and in some parts of the Oromia Regions as a new agricultural activity. Compared to other oil crops, Oil palm can provide the highest yield per hectare (Gutierrez *et al.*, 2018). According to the previous study by De Souza *et al.* (2010), about 4.17 tons of palm oil yield can be produced per hectare. However, the yield and productivity of this crops are correlated with land use capacity and suitability of cultivation land (Abdullah and Sulaiman, 2013). Land suitability evaluation plays an important role in adopting appropriate land resource management and proper allocation of arable land for oil palm production (Khatun *et al.*, 2017). The sustainability and productivity of farming activities can be improved through prior assessment of ecological parameters, including biophysical soil characters, infrastructural requirements, climatic data and agro ecological condition of cultivation land. Previous study by Bernhard *et al.*, (2018) stated that areas characterized with a sandy and silt clay soil texture, alkaline free soil, at least lm soil depth, hot temperature and steep slope are an ideal potential land for oil palm cultivation. Some scholars have studied the spatial distribution of potential land suitability for oil palm tree cultivation using geospatial techniques and Analytical Hearachy Process (AHP) in Africa, particularly in Northern Uganda, Ghana and Malaysia (Rhebergen *et al.*, 2016; Abraham and Bamweyana, 2022; Abubakar *et al.*, 2023a). Ethiopia is characterized by favorable climate and biophysical factors for several oil crops and tree production for industrial inputs, particularly oil palm cultivation. However, the practice of cultivating oil palm tree is not to the required standards due to a lack of sufficient information on assessing land suitability for oil palm tree cultivation, particularly in the western parts of Ethiopia. In addition, to date, little research has been done to analyze the suitability of land suitability for oil palm production. Geospatial technology is the most essential technology that used to map the spatial distribution and potential land extent, and provide clues to utilize the most productive land for oil palm tree cultivation. Therefore, this study aims to fill the existing research gap on assessing the potential land suitability for oil palm tree cultivation by using geospatial technology and Analytic Hierarchy Process (AHP) in the Jejeba watershed, western Ethiopia.

2 Materials and methods

2.1 Description of the study area

The Jejeba Watershed is located within the Dhidhessa River sub-basin in Oromia National Regional State, western parts of Ethiopia. Geographically, the study area is situated between 7^{0}59'30" to 8^{0}43'30"N and 36^{0}25'30" to 36^{0}58'30"E. The elevation of the Jejeba watershed ranges from 1275 to 2490 meter above sea level with a total area of 2747 km^2 (Fig. 1). The study area receives maximum rainfall during summer season (June to September) with 1329 mm to 1590 mm. In addition, the minimum and maximum temperatures of the study area was 18°C and 36°C, respectively. There are five (5) major soil types, including Eutric vertisols, haplic acrisols, haplic alisols, haplic nitisols and rhodic nitisols in the

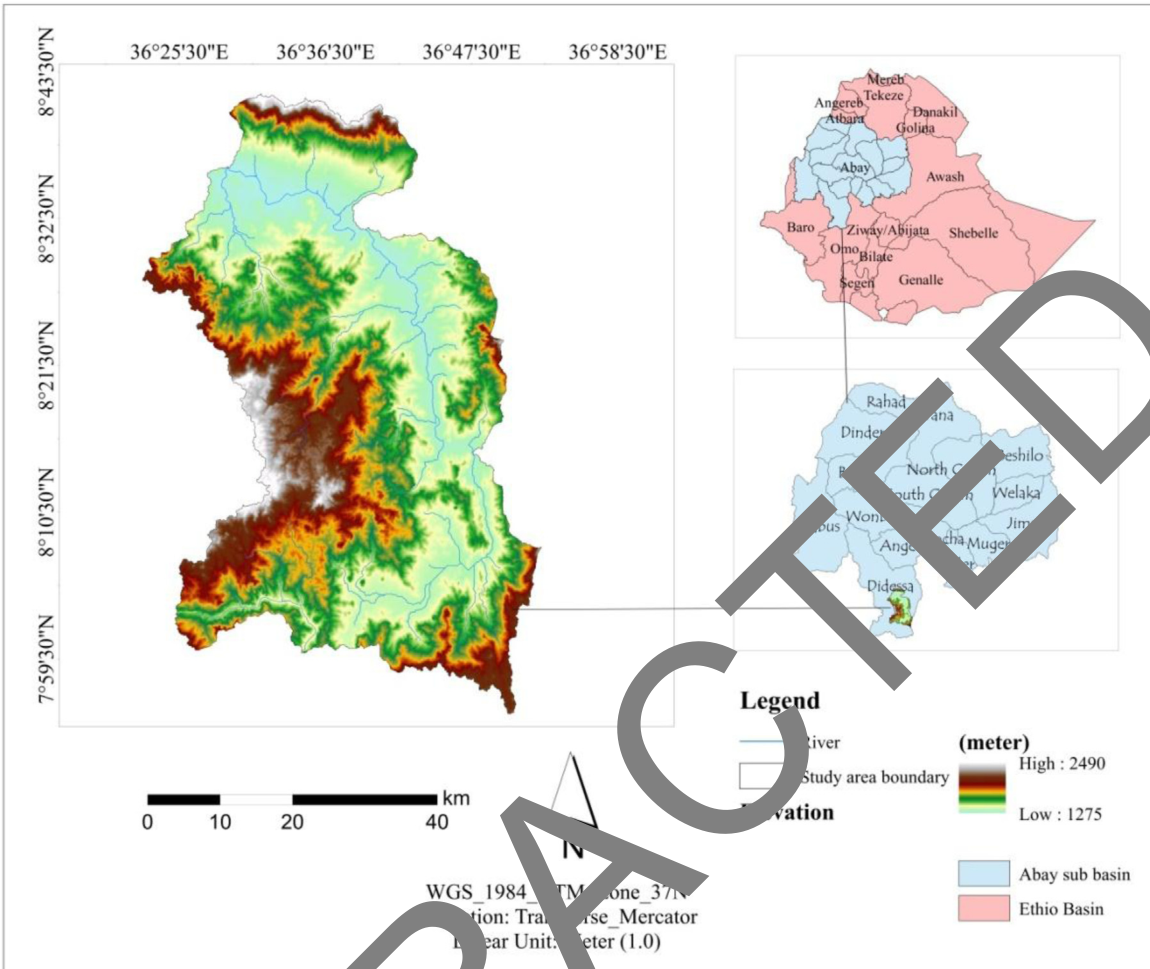

Fig. 1. Location map of the study area.

Table 1. Data sources and descriptions.

Data	Data type	Resolution(m)	Sources
Climate data	Rainfall data	30	NMA
Landsat OLI/TIRS	Land Surface Temperature, Land use land cover	30	USGS
ASTER DEM	AEZ, Slope	30	USGS
Soil data	soil drainage, soil depth, soil texture, soil types	30	MoWIE
Infrastructure data	Roads	30	EMA

Jejeba Watershed. Haplic alisols is the most dominant soil type with an area of 598.6 km^2, whereas haplic nitisols is the least dominant soil type with an area of 46.5 km^2.

2.2 Data sources and descriptions

Potentiality of the land for oil palm cultivation was analyzed by using appropriate geospatial data. The Landsat images of OLI/TIRS 2023 was downloaded from the USGS website the United States Geological survey (USGS) which is freely available to the users and was downloaded with little cloud cover (<10%) and during the dry season (January, February). Landsat OLI/TIRS was used for LULC classification and retrieval of land surface temperature (LST) retrieval. Similarly, rainfall data of the study area was obtained from Ethiopian Meterological Institute. Soil properties such as soil texture, soil drainage, soil depth and soil type were obtained from the Ministry of Water and Irrigation Engineering (MoWIE). Road data were extracted from the GIS data of 2018. Finally, ASTER DEM was downloaded from the USGS to generate surface slopes (Tab. 1; Fig. 2). Additionally, handle GPS, ArcGIS 10.3, Arc SWAT, ERDAS 2015 and IDRISI Selva 17 were used to analyze oil palm land suitability area.

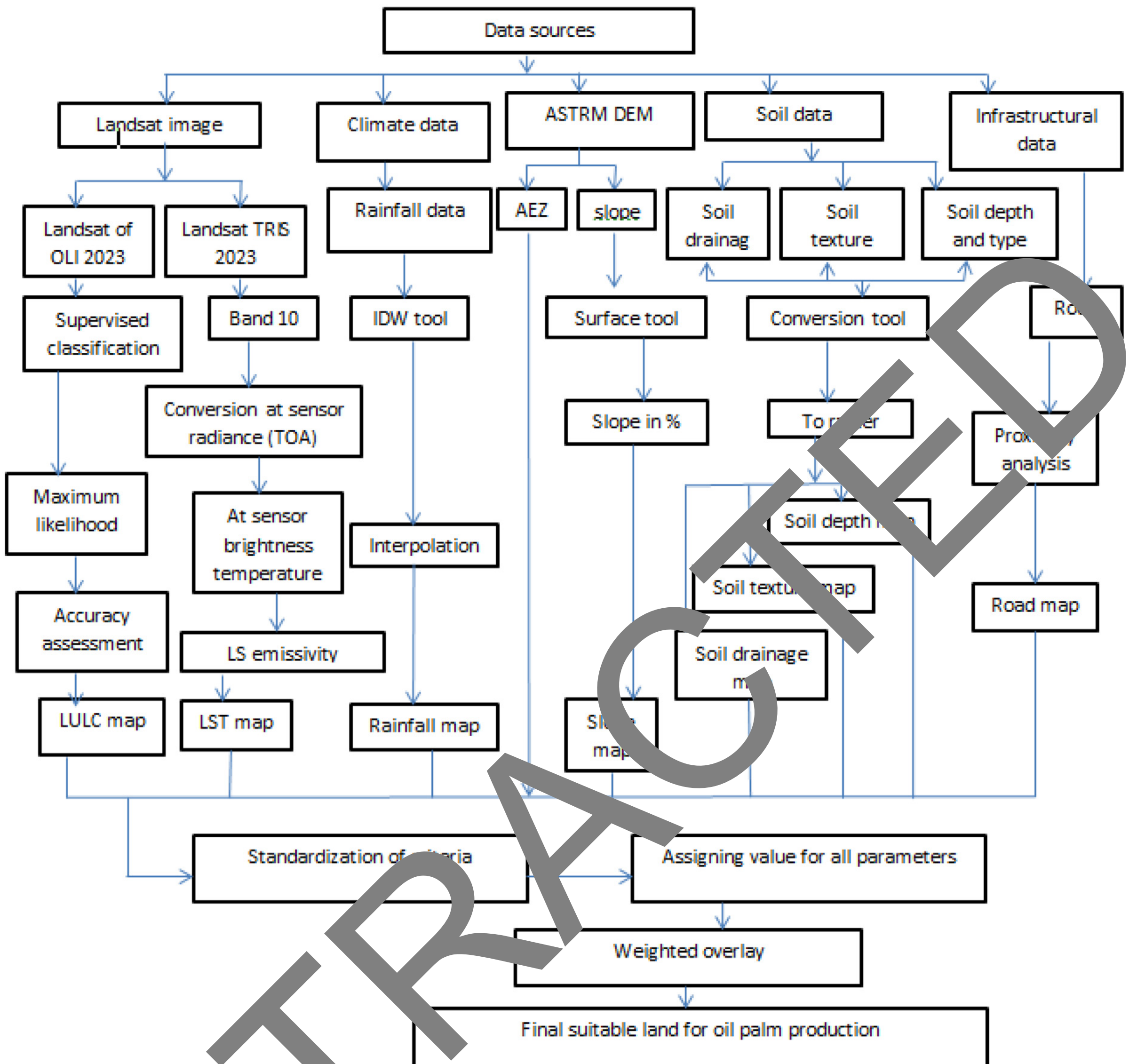

Fig. 2. Methodological flowchart.

2.3 Data analysis

The potential land suitability for oil palm tree cultivation was analyzed using geospatial technology. Transformation of vector data to raster data was applied for appropriate weighted overlay analysis. The AHP method was used to calculate the weighted importance value of each parameter in IDRISI selva 17 software for comparison of each parameters percent of influence for land suitability analysis. The final land suitability classes of the study area were classified based on the values of overlay analysis parameters. A pairwise comparison matrix was made to determine the weight and relative importance of each factor by normalizing the eigenvector of the factors by their cumulative total (Saaty, 1980). The weight of the factor was divided by the number of classes to determine classes' breakdown and Equal interval ranging techniques were used to distribute the total weights of the elements to the various degrees of appropriateness classes (Tab. 2).

2.4 Parameters used for oil palm land suitability analysis

2.4.1 Land surface temperature

Land surface temperature was calculated from the thermal band of Landsat OLI/TIRS 2023 for land suitability analysis and oil palm tree cultivation in the Jejeba watershed. LST measures the state of coldness or hotness of the cultivated land in the study area. Response of surface temperature variation of arable land to the existence of different land suitability classes for oil palm cultivation. According to Sabajo *et al.*, (2017), the temperature classification ranges from 36 to 30 °C, 26 to 30 °C, 20 to 26 °C, and <20 °C were highly suitable, moderately

Table 2. Rating parameters for oil palm tree cultivation land suitability analysis.

Parameters	Classification criteria and scale				
	Unit	Highly suitable	Moderately suitable	Marginally suitable	Not suitable
LST	°C	30–36	26–30	20–26	<20
Slope	degree	0–4	4–15	15–25	>25
AEZ	class	low land	middle land	–	high land
rainfall	mm	1329–1420	1420–1490	1490–1560	<1329; >1560
soil texture	class	CL,SCL	SL	L	LS
soil drainage	class	W	M	SWE, E	I
soil type	class	HN,RN	HA	HAl	EV
LULC	class	agricultural, grassland	forest land	1904–1943	wetland, bare land
soil depth	cm	>100	75–100	50–75	<50
Road	km	0–5	5–10	10–15	>15

CL = clay loam, SCL = sandy clay loam, SL = sandy loam, L = Loam, LS = Loamy sand W = well, M = moderate, SWE = somewhat excessive, I = imperfect HN = Haplic Nitisols, RN = Rhodic Nitisols, HA = Haplic Acrisols, Hal = Haplic Alisols, EV = Eutric Vertisols.

suitable, marginally suitable, and not suitable, respectively for oil plam tree cultivation.

2.4.2 Slope

Land suitability for oil palm tree cultivation can be influenced by the steepness of the landscape in the study area. According to previous studies (Satriawan *et al.*, 2016), land with a gentle slope is more suitable than land with a steep slope. The slope classes have been classified based on suitability. As a result, $0–4^0$, $4–15^0$, $15–25^0$ and $>25^0$ are highly suitable, moderately suitable, marginally suitable, and not suitable, respectively for oil palm cultivation.

2.4.3 Agro ecological zone

Agro-ecological zone (AEZ) is another environmental parameter that classifies the study area into highland, middle land, and lowlands. These agro-ecological variations are correlated with the existence of different land suitability classes for oil palm cultivation. This implies that all agro-ecological zones are not equally important for oil palm cultivation. Previous studies reported that low-land areas were more suitable than other ecological zones for oil palm production (Dossou *et al.*, 2017). As a result, the lowlands, middle land, and highlands are highly suitable, moderately suitable, and not suitable, respectively, for oil palm tree cultivation in the Jiicha watershed.

2.4.4 Rainfall

Rainfall refers to the water vapor that has condensed from the cloud in the atmosphere to fall in the form of liquids on the earth surface. It may show variation depending on the environmental condition of the study area. This variation classify the study area into different suitability classes for oil palm cultivation. Previous study by Abubakar *et al.*, (2023b) classified rainfall into four classes: (1329–1420 mm), (1420–1490 mm), (1490–1560 mm) and (>1560 mm) and categorizes as highly suitable, moderately suitable, marginally suitable and not suitable, respectively for oil palm tree cultivation.

2.4.5 Soil texture

Land suitability for oil palm cultivation influenced by the soil texture like sand, silt, clay and loam particles. Different soil textures have different suitability classes for oil palm cultivation. This means that various soil textures may classify the study area into different land suitability classes. Clay loam, sandy clay loam are highly suitable, sandy loam was moderately suitable, Loam soil is marginally suitable and loamy sand is not suitable oil palm tree cultivation. According to the previous studies, sandy and silt clay soil texture were highly suitable for oil palm tree cultivation (Adugna & Abegaz, 2015).

2.4.6 Soil type

Oil palm tree cultivation can be influenced by the soil types. The study area is characterized by different soil types, including eutric vertisoil, haphic vertisoil, haphic alisoil, haphic nitisol, and rhodic nitisols (Salamat *et al.*, 2021). Those variable soil types have various land suitability classes for oil palm cultivation.

2.4.7 Soil drainage

The degree to which the water moves across the soil profiles is described as soil drainage. This can be used to determine the capability of soil to hold water for a certain period of time. The soil water holding capacity may classify the study area into various suitability classes for oil palm cultivation. Well-drained soils drainage are highly suitable, moderately drained soils are moderately suitable, somewhat excessive and excessive were marginally suitable, and imperfect soil drainage was not suitable for oil palm production. According to Moisa *et al.*, (2022a), well and moderate soil drainage is more suitable, while somewhat excessive and imperfect soil drainage is ranked as marginally and not suitable for oil palm cultivation, respectively.

2.4.8 Land use and land cover

Land use and land cover (LULC) types of the study area were classified by Landsat 8 of OLI 2023 by using a supervised

Table 3. Relative importance value of parameters.

Intensity of parameters importance value	Definition	Description
1	equal importance	both parameters have equal influence
3	somewhat more important	impact of one parameter slightly favors the other
5	much more important	impact of one parameter strongly favors the other
7	very much important	impact of one parameter strongly favors the other and the impact demonstrated in practices
9	absolutely more important	impact of one parameter have highest possible value on the other
2, 4, 6, 8	intermediate importance	when comparison is required

classification method with the maximum likelihood algorithm. The LULC types in the study area were classified into agricultural land, grassland, forest, bareland, and wetland. Variation in land cover types causes different suitability classes for oil palm cultivation. According to Moisa *et al.*, (2023), grassland and cultivated land are more suitable than the other land cover types for oil palm cultivation.

2.4.9 Soil depth

Soil depth describes the root space and volume of the soil where the crop obtains water and nutrients for germination, growth, and other required life cycles. Hence, deeper soil can provide more nutrients than shallow soil for crop growth. These means of soil depth can classify the study area into different suitability for oil palm cultivation (Younis *et al.*, 2021). According to the classified soil depth, soil depths >100 cm, 75–100 cm, 50–75 cm and less than 50 cm were highly suitable, moderately suitable, marginally suitable, and not suitable.

2.4.10 Proximity to road

Since the oil palm tree is a major source for industrial input, accessibility of roads enabled the farm owners to transport the produced yield from the farm land to the market centers and factories. Based on this evidence, the cultivated land nearest to the road was more suitable than the farthest one. According to previous studies, the suitability of oil palm cultivation sites are based on proximity to road; site suitability classes range from >7 km, 4 to 7 km, 2 to 4 km, and 0 to 2 km, respectively (Shevade and Loboda, 2019).

2.5 Determining parameters weight and pairwise comparison

According to Saaty's nine-point weighing scale, an artificial hierarchy process of multicriteria evaluation was used to determine the precise importance value for each of the targeted parameters (Tripathi *et al.*, 2016). Finally, the relative importance of each parameter was calculated by normalizing the eigenvector of the factors. By using *a* pairwise comparison matrix, each factor was compared with the other factors, relative to its importance, on a scale from 1/9 to 9 as proposed by Saaty (2002) (Tab. 3). According to Deribew *et al.*, (2022) and Moisa *et al.*, (2022b) the pairwise comparison among all targeted parameters has been conducted based on their importance in deciding land suitability for oil palm tree cultivation (Tab. 4).

The realities of the parameter pair-wise comparison were evaluated based on the calculated value of consistency ratio (CR), which was expected to be less than 10% (Moisa *et al.*, 2023). The parameter pairwise comparison consistence ratio was determined as the ratio of consistency index (CI) to random consistency index (Eq1).).

$$CR = \frac{CI}{RI}, \tag{1}$$

where CI is consistency index and RI is random consistency index.

Consistency index is the measure of parameters consistency as the degree of consistency by using the following formula:

$$CI = \frac{\lambda max - n}{n - 1}, \tag{2}$$

where n indicate the number of parameters, λmax refers to is the principal eigen value of parameters that can be calculated from multiplication of the total horizontal summation of given intensity importance value and calculated weight value. Weighted value obtained by dividing the sum of the vertical importance value of all parameters to total sum of horizontal importance values of the parameters. Random consistency index is the constant number assigned for each targeted parameters based on their intensity importance scale (Tab. 5).

2.6 Overlay analysis for Oil palm cultivation

All reclassified factors were aggregated in the ArcGIS environment to assess the potential land suitability of oil palm tree cultivation in the study area. According to Rendana (2021), land suitability analysis for oil palm tree cultivation was classified as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N). According to Abebe *et al.*, (2023), land suitability for oil palm tree cultivation *was* calculated in (Eq_3)

$$S = \Sigma Wi * Xi, \tag{3}$$

where S is indicates suitability, Wi is the weight of the factor, and Xi is the criterion score of factors *i*.

Table 4. Pair wise comparison matrix of selected parameters.

Factors	LST	Slope	AEZ	Rainfall	Soil texture	Soil drainage	Soil type	LULC	Soil depth	Road	Weight
LST	1	2	2	2	3	3	3	4	4	5	0.18
Slope	1/2	1	2	2	2	3	3	4	4	5	0.17
AEZ	1/2	1/2	1	2	2	2	3	3	3	4	0.13
Rainfall	1/2	1/2	1/2	1	2	2	3	3	3	4	0.12
Soil texture	1/3	1/2	1/2	1/2	1	2	3	3	3	3	0.11
Soil drainage	1/3	1/3	1/2	1/2	1/2	1	2	3	3	4	0.1
Soil type	1/3	1/3	1/3	1/3	1/3	1/2	1	2	3	[illegible]	0.08
LULC	1/4	1/4	1/3	1/3	1/3	1/3	1/2	1	2	3	0.06
Soil depth	1/4	1/4	1/3	1/3	1/3	1/3	1/3	1/2	1	2	0.03
Road	1/5	1/5	1/4	1/4	1/3	1/4	1/3	1/3	1/2	1	0.02
Σ	5.2	5.87	7.7	9.2	11.83	14.36	19.16	23.8	26.5	34	1

$\lambda_{max} = (5.2*0.18) + (5.87*0.17) + (7.7*0.13) + (9.2*0.12) + (11.82*0.11) + (14.36*0.1) + (19.16*0.08) + (23.8*0.06) + (26.5*0.03) + (34*0.02) = 11.2138$, $n = 10$, $CI = 0.134$, $RI = 1.49$, $CR = 0.08$

Table 5. Random index value table.

Intensity importance	1	2	3	4	5	6	7	8	9	10
Constant number	0.00	0.00	0.58	0.90	1.12	1	1.32	1.41	1.45	1.49

3 Results and discusions

3.1 Land surface temperature

In the present study, LST was classified into highly suitable (30 to 36 °C), moderately suitable (26 to 30 °C), marginally suitable (18 to 26 °C), and not suitable (18 °C) land classes for oil palm cultivation in the Jejeba watershed. The northern, central, and southern parts of the Jejeba watershed were dominated by highly suitable and moderately suitable land classes. However, the eastern and southwestern parts of the study area are also occupied by marginally suitable and not-so-marginally suitable land classes for cultivating oil palm trees (Fig. 3a). Large-scale expansion of oil palm was evaluated by climatic factors to determine the current and future potential of oil palm production in Ghana (Rhebergen *et al.*, 2016; D[illegible]ifack *et al.*, 2021).

3.2 Slope

The slope indicates the landscape feature of the study area. The land feature could be flat or steep, which may create opportunit*ies* for the occurrence of different land suitability classes for oil palm farming activities. As a result, the slope of the Jejeba watershed was reclassified into highly suitable ($0–4^0$), moderately suitable ($4–15^0$), marginally suitable ($15–25^0$) and not suitable ($>25^0$) land classes for oil palm tree production. This finding shows that increasing the land slope is related to decreasing the suitability of the area for oil palm farming activities. Spatially, highly suitable land was located in the northern and southern parts, whereas the central parts of the study area were dominated by moderately suitable land. Similarly, some western and northern parts of the Jejeba watershed were covered by marginally suitable and not-suitable oil palm tree cultivation (Fig. 3b). Slope suitability in this study was more consistent with previous studies (Rhebergen *et al.*, 2016), where gentle slopes were more suitable than steep slopes for oil palm cultivation in the Ghana. In addition, *a*ccording to Rendana (2021) study, land with a gentle slope was highly suitable, whereas land with a low gradient slope was marginally suitable for oil palm cultivation.

3.3 Agro ecological zone

Elevation can classify the study area into highland (2300–3200 m), lowland (500–1500 m), and middle land (1500–2300 m) and be named an agro-ecological zone (AEZ). This zonation was characterized by different temperature*s*, rainfall, and soil condition*s* for assessing potential land suitability for oil palm cultivation in the study area. According to this finding, lowlands and middle land were highly and moderately suitable, whereas highland was not suitable for oil palm cultivation (Ranasinghe and Thimothias, 2012). Geographically, the north-east and south-east parts of the study area were highly suitable land, while moderately suitable land covered the central parts of the study area. However, some eastern and northern parts of the Jejeba watershed were not suitable land for oil palm cultivation (Fig. 3c).

3.4 Rainfall

Oil palm production and productivity were significantly influenced by rainfall scarcity. According to Figure 3d, the annual rainfall of the study area was reclassified into (1320–1420 mm), (1420–1490 mm), (1490–1560 mm), and (>1560 mm) and ranked as highly suitable, moderately suitable, marginally suitable, and not suitable, respectively, for oil palm tree cultivation. Low rainfall areas were classified

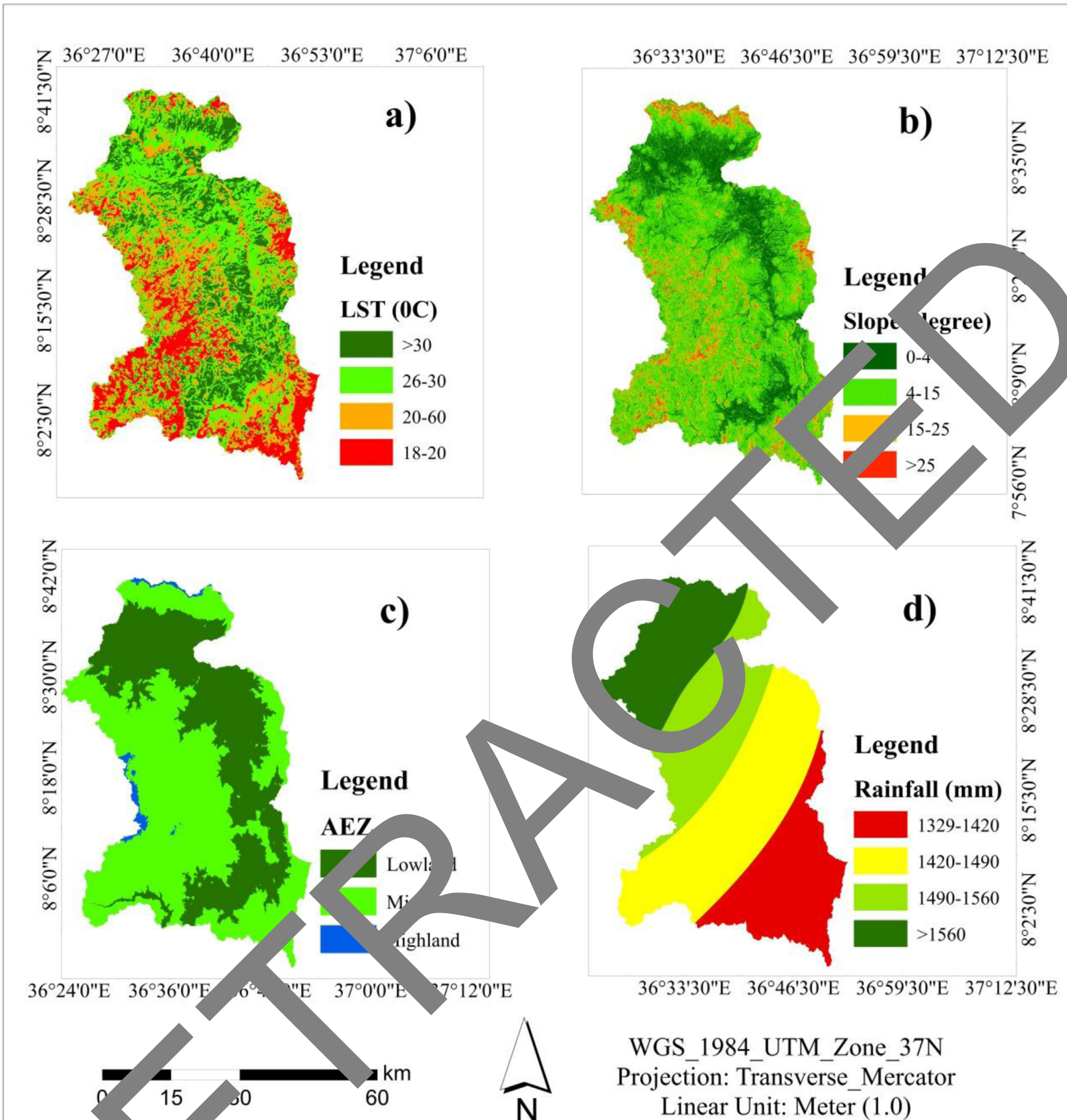

Fig. 3. LST (a), Slope (b), AEZ (c) and Rainfall (d).

as most suitable than high rainfall for oil palm tree cultivation. In addition, the southern part of the Jejeba watershed is highly suitable, the northern region is not suitable, whereas the central regions are moderately suitable and marginally suitable for oil palm tree production. Variability of climatic factors like rainfall and temperature has affected oil palm yield distribution in Peninsular Malaysia (Abubakar *et al.*, 2023b).

3.5 Soil texture

Soil texture implies various layers of soil, like sandy soil, clay soil, and loam soil profiles on the earth's crust. Different layers of the soil profile possess various suitability classes for oil palm production. The results show that the Jejeba watershed contains about 1261.4 km^2 (45.9%), 1189.6 km^2 (43.3%) and 296 km^2 (10.8%) of highly suitable, moderately suitable, and marginally suitable for oil palm cultivation (Tab. 6). According to Jaroenkietkajorn and Gheewala's (2021) soil quality in the southern region of India was most suitable for oil palm cultivation. Geographically, highly suitable and moderately suitable land for oil palm were distributed across the northern and southern parts of the study area, respectively. However, its central parts were marginally suitable for cultivating this oil palm (Fig. 4a).

3.6 Soil drainage

The movement of water across the soil profile may depend on the type of soil particle. It can be managed by the soil

Table 6. Soil texture classes and area coverage.

Soil texture	Area (km^2)	Area (%)
clay loam	17.0	0.6
sandy clay loam	1172.6	42.7
loam	12.0	0.4
sandy loam	1249.4	45.5
loamy sand	296.0	10.8
Total	2747.0	100.0

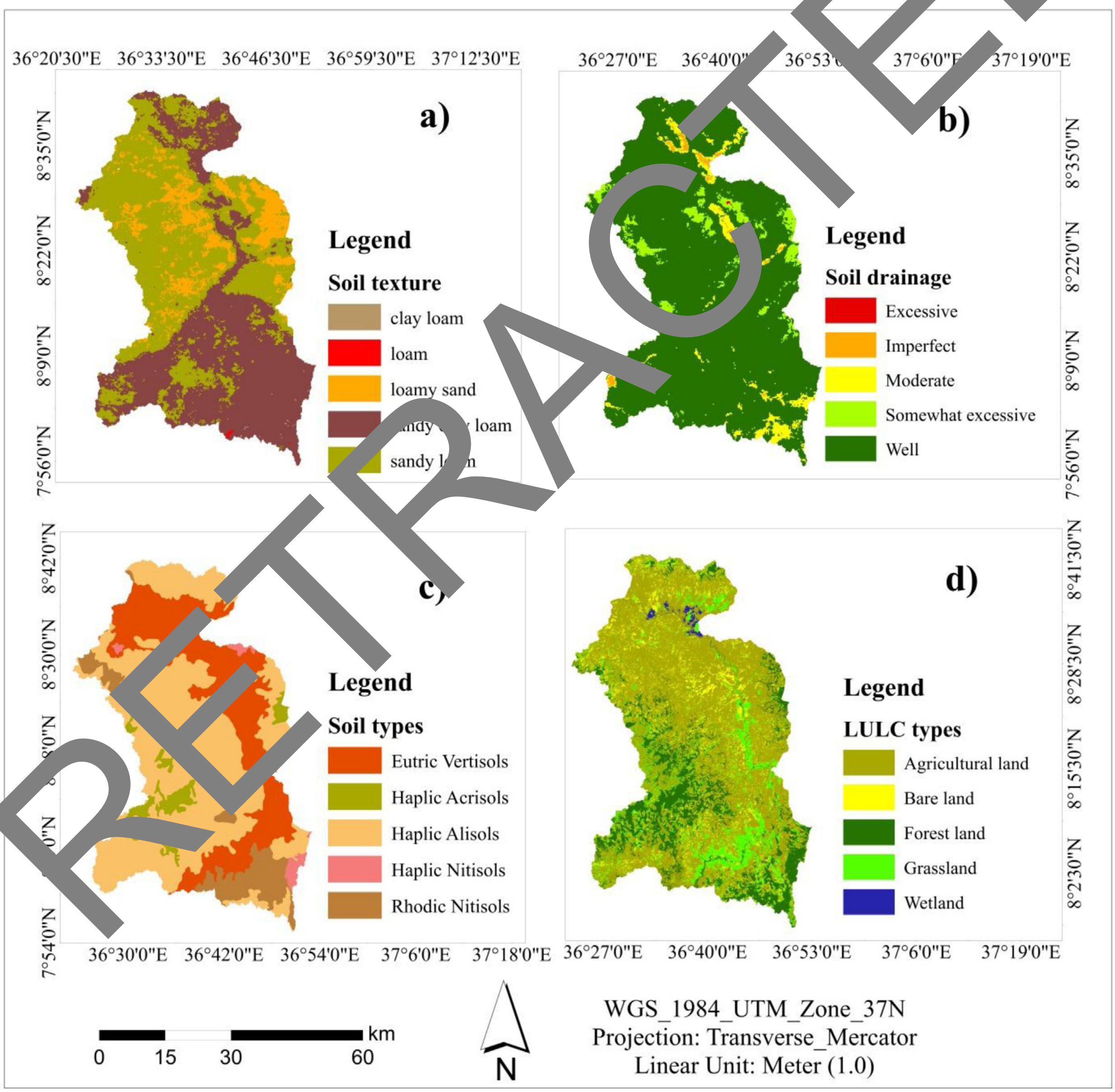

Fig. 4. Soil texture (a), soil drainage (b), soil type (c) and LULC (d) maps.

Table 7. Soil drainage and area coverage.

Soil Drainage	Area (km^2)	Area (%)
Imperfect	30.2	1.1
Moderate	132.0	4.8
Well	2428.7	88.4
Somewhat excessive	134.6	4.9
Excessive	21.5	0.8
Total	2747.0	100.0

Table 8. Soil types and area coverage.

Soil types	Area (km^2)	Area (%)
Eutric Vertisols	770.5	28.1
Haplic Acrisols	114.0	4.2
Haplic Alisols	1598.6	58.2
Haplic Nitisols	46.5	1.7
Rhodic Nitisols	217.3	7.9
Total	2747.0	100

particle size. Soil with a larger porous size was characterized by a higher drainage density, and vice versa. Soil drainage capability can classify the study area into various suitability classes for oil palm cultivation. The results revealed that larger parts of the Jejeba watershed were occupied by highly suitable (93.2%) land for oil palm production. Other remaining land was covered by moderately suitable (0.8%), marginally suitable (4.9%), and not suitable (1.1%) land classes for oil palm tree farming activities (Tab. 7, Fig. 4b). The study done by Harahap *et al.* (2019) shows the presence of soil drainage-based actual cultivated land suitability for oil palm tree cultivation in Sitellu Tali Urang Jehu subdistrict.

3.7 Soil types

Production and productivity of the oil palm tree were significantly influenced by the soil types. Variation in soil types is correlated with the existence of different land suitability classes for oil palm tree cultivation. In Table 8, there are about 86.3% of highly suitable, 9.6% of moderately suitable, and 4.2% of unsuitable for oil palm tree cultivation, respectively. Geographically, wider parts of the Jejeba watershed were occupied with highly suitable classes, except for some southern parts. However, some southern and western parts were not suitable land for oil palm tree cultivation (Fig. 4c). The result of this finding was more consistent with the study done by Jaroenkietkajorn and Gheewala (2021), which identified soil type suitability for oil palm tree cultivation in Thailand.

3.8 Land use land cover

The Jejeba watershed is covered by forest land, grass land, bare land, farm land, settlement land, and wetland land cover classes. The occurrence of various land cover types were

Table 9. LULC types and area coverage.

LULC types	Area (km^2)	Area (%)
Agricultural land	1718.9	62.6
Bare land	234.5	8.5
Forest land	437.4	15.9
Grassland	339.7	12.4
Wetland	16.5	0.6
Total	2747.0	100.0

responsible for the presence of different land suitability classes for oil palm tree cultivation. Results revealed that highly suitable areas accounts about 75%, while moderately suitable and unsuitable land cover classes represents 15.9 and 9.1%, respectively, for oil palm tree cultivation (Tab. 9). The geographical distribution of highly suitable areas dominated the central and some northern parts of the study area. However, the western and other northern parts were dominated by moderately suitable and not suitable land cover classes for oil palm tree cultivation, respectively (Fig. 4d). This finding is in line with work done in rainfed conditions in India, which identified 0.95 Mha *as* highly suitable, 1.08 Mha as moderately suitable, and 2.2[illegible] Mha as marginally suitable for oil palm tree cultivation out of 4.237 Mha total study area of 4.237 Mha (Shibendu *et al.*, 2022).

3.9 Soil depth

The productivity of oil palm tree cultivation is correlated to soil depth, which may limit the capability of cultivated trees to absorb nutrients from underground. This phenomenon results from the existence of various oil palm tree cultivation suitability classes. According to Kietkajorna and Gheewala (2021), soil depth*s* >100 cm, 75–100 cm, 50–75 cm, and <50 cm were classified as highly suitable, moderately suitable, marginally suitable, and not suitable for oil palm cultivation, respectively. The result revealed a distribution of highly suitable land classes across all parts except the southern and northeastern parts of the Jejeba watershed, which are occupied with moderately and marginally suitable classes. However, some northern parts of the watershed were not suitable for oil palm tree cultivation (Fig. 5a). The result was more consistent with the study conducted by Abraham and Bamweyana (2022) in northern Uganda, which improved the suitability of the deepest soil over the upper soil for oil palm tree cultivation.

3.10 Road proximity

Road proximity was used to assess which land was suitable for oil palm tree growth. It was the determinant factor for transporting input materials for cultivation and other produced goods to the market center for exchange. A higher priority was given to land nearest to the road when deciding land suitability classes for oil palm tree cultivation. According to the result defined in Figure 5b, the western and southern parts of the Jejeba watershed were highly and moderately suitable,

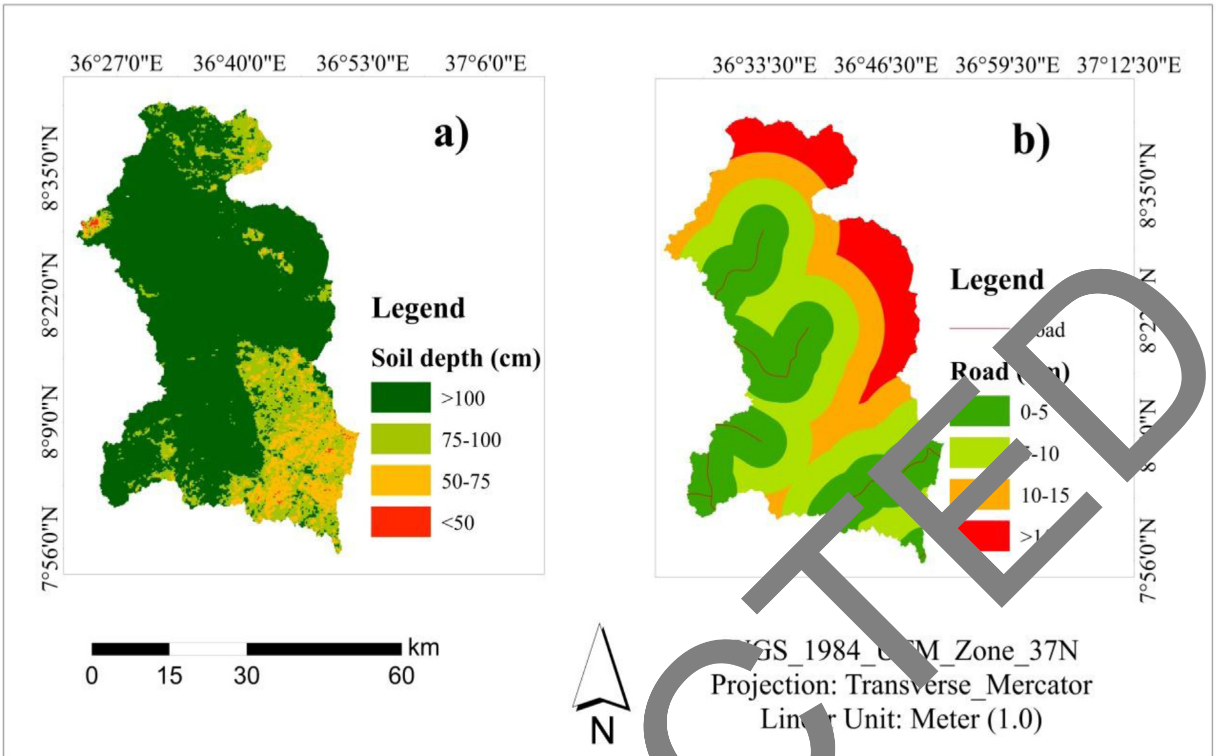

Fig. 5. Soil depth (a), road proximity (b) map.

Table 10. Potential land suitable for oil palm cultivation.

Suitability classes	Area (km2)	Area (%)
Highly suitable	36.7	1.3
Moderately suitable	1780.5	64.8
Marginally suitable	904.6	32.9
Not suitable	25.2	0.9
Total	2747.0	100.0

whereas the northeast parts were not suitable for oil palm tree cultivation, respectively. According to Moisa *et al.*, (2022c), agricultural land closest to road access was more suitable than others.

3.11 Potential land suitability for oil palm cultivation

The final land suitability for oil palm cultivation was aggregated from ten parameters by using the integration of geospatial technology and AHP in the Jejeba watershed. The result shows that about 36.7 km^2 (1.3%) was highly suitable for oil palm tree cultivation in the study area. Consequently, the study area was highly dominated by moderately suitable areas, with an area of 1780.5 km^2 (64.8%) out of the total study area. However, due to the limited constraints used in the study, about 25.2 km^2 (0.9%) were not suitable for oil palm tree cultivation (Tab. 10). Geographically, the southeast part of the Jejeba watershed was highly suitable for oil palm tree production due to the existence of conducive environments like a warm climate, lowland areas, agricultural land use types, and suitable soil properties. According to Abubakar *et al.*, (2022), soil, climate, and land use types were the main parameters used to assess the suitability of oil palm production in Peninsular Malaysia. In addition, the central, south, and northern parts of the study area were dominated by moderately suitable areas, whereas whereas, western and eastern parts of the study area were captured by marginally suitable and not suitable areas, respectively, for oil palm cultivation in the study area (Fig. 6). Cultivation of the oil palm was very essential to solving the scarcity of medication for several diseases and ensuring food security in developing countries, particularly Ethiopia. According to Abraham & Bamweyana (2022), about 38.18% and 35.54% were highly suitable and moderately suitable for oil palm and cultivation, respectively in northern Uganda.

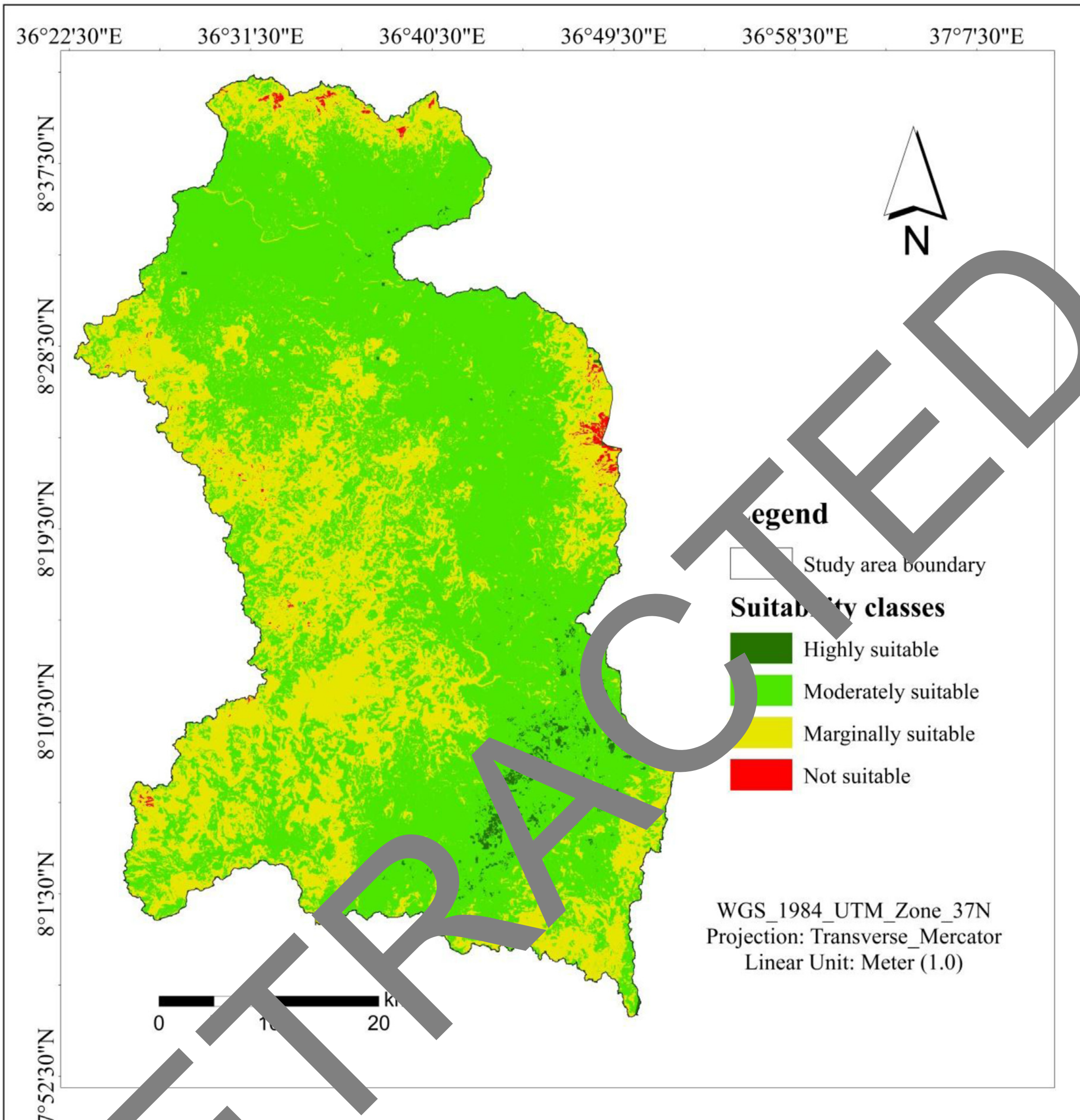

Fig. 6. Potential land suitability for oil palm cultivation.

4 Conclusions

Environmental conditions such as climate and topography are favorable indicators for the cultivation of different types of crops. The Jejeba watershed in western Ethiopia is characterized by a warm climate and lowland that were ideal for growing oil palms. The potential for land to be exploited for oil palm agriculture was assessed using geospatial technology and AHP. In this study, various biophysical, ecological, infrastructural, and climate-related environmental factors were used. The result revealed that highly suitable and moderately suitable areas dominated with an area of 36.7 km^2 and 1780.5 km^2, respectively, whereas 25.2 km^2 was not suitable for oil palm cultivation in the study area. Oil palm cultivation can significantly contribute to the development of industries, with the potential to generate foreign exchange on the one hand and solve the problem of food insecurity in Ethiopia on the other. We suggested that the local community, investors, and governmental and non-governmental organizations can play a significant role in cultivating oil palm in the Jejeba watershed. To influence decision makers additional studies on land suitability analysis for oil palm tree cultivation can be conducted by considering different parameters such as soil PH, aspect, and proximity to market parameters.

Conflict of interest

The authors declared no conflict of interests.

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Author's contributions

MMG and MBM participated in research design, document analysis and manuscript writing. LHB, GGN and FST participated in data collection, methodology, data analysis and interpretation. KTD, ZRR and DOG participated in research design, literature review, data analysis and final draft edition. All authors read and approved the final manuscript for publication.

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