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Research article

Application of geospatial technology on land suitability analysis for wheat and maize farming: In a case of Guder sub-watershed North West Oromia, Ethiopia

Fayera Gizawu Garbaba *, Bayisa Negasa Wolteji

Department of Earth Sciences, College of Natural and Computational Sciences, Wollega University Nekemte Campus, Ethiopia

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ABSTRACT

Cereal crops like wheat and maize are crucial to providing food security in rural areas of Ethiopia. However, due to population growth, agricultural practices for these cereal crops have been expanded to vulnerable areas, and increasing land degradation. Geospatial technologies are essential for decision-making to reduce land degradation and ensure sustainable agriculture activities. In the Guder sub-watershed, Oromia regional state of Ethiopia, where land degradation has been a persistent issue, agricultural suitability study is crucial. This study is focused on the Guder sub-watershed, which aimed to analyze the land suitability based on ten controlling parameters, including elevation, slope, soil texture, soil depth, soil PH, soil drainage, proximity to the road, temperature, rainfall and land use/land cover, for the two most significant cereal crops (wheat and maize). All of these factors were weighted in accordance with the relative importance of each component for the appropriateness of wheat and maize land suitability using MCDA and AHP method, based on the recommendations of numerous writers and expert opinions. The findings of the study showed that 6 %, 50.58 %, 23.26 %, and 20.26 % of the total study area were highly, moderately, marginally and not suitable for wheat cultivation, respectively, whereas 5.1 %, 57.3 %, 17.3 %, and 20.3 % of the study area were highly, moderately, marginally and not suitable for cultivating maize crop respectively. This result support decision makers to develop land use planning thereby improve productivity and minimize land degradation.

1. Introduction

The majority of the population in Ethiopia has been participating in farming activities to address the issue of food insecurity. The main food crops for ensuring food security are cereal crops. Cereal crops, which compensate for 68 % of all agricultural production, are the main focus of agricultural activities. These include oats, barley, wheat, maize, sorghum, and millet [1–3]. In rural Ethiopia, wheat and maize cultivations are the most crucial necessities [1]. However, Ethiopia's agricultural productivity has not kept up with population growth, and the nation currently has worse nutritional conditions than it did 30 years ago [4–7]. For instance, food production has increased by about 2.5 % per year, whereas population growth has increased by more than 3 % annually [8].

The expansion of agricultural activity onto vulnerable land as a result of population growth has worsened land degradation. Overexploitation and degradation have a potentially fatal downward spiral that is accelerated by the negative effects of climate

* Corresponding author.
E-mail address: gfayegis@gmail.com (F. Gizawu Garbaba).

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change. This spiral causes natural resource availability to decrease and productivity to decline, endangering food security and escalating poverty [9]. Additionally, farmers in rural areas evaluate their farmland based on regular observations and shared experiences instead of advanced technologies. This information is insufficient for farmer communities to comprehend the appropriateness of optimal conditions, management techniques, and land-use decisions [10,11]. Agricultural production should be conducted in a way that promotes ecological preservation and biodiversity in order to secure food security [12]. Since agriculture contributes to around 46.3 % of Ethiopia's GDP, 83.9 % of its exports and 80 % of its labour force, resource management in the context of agriculture is crucial for emerging nations like Ethiopia [13,14].

Crop-land suitability analysis is a smart way to use land resources and a requirement for getting the most out of the already-available land for sustainable agricultural output [15]. Land appropriateness, according to Ref. [16], is the capability of a particular type of land for a specific use. The assessment and grouping of certain portions of land with respect to their appropriateness for a specified use is the process of land suitability classification [17,18] Interpreting data about soils, vegetation, terrain, climate, etc. to the extent that these affect the possibility of land use is involved in this. For example, to access land suitability site for cereal crop several studies have been classified suitability rank of individual factor and combined them. These factors having potential to control land capability for cereal crops include; temperature, rainfall, altitude, slope, soil texture, soil depth, organic matter, soil pH, soil drainage, land use/land cover and proximity to road [19,20]. Therefore, assessing land capability for agriculture is a complex, multi-criteria process that examines topography, climate, soil capabilities, and other socioeconomic factors such as roads [21]. These multi-dimensional factors call for appropriate decision support tools, such as the multi-criteria decision analysis (MCDA) approaches. GIS and MCDA are the best methods of overcoming the problems in defining the relative weights of several criteria involved in decision-making on land suitability and getting precise results, thereby developing a plan on how agricultural land is used in a sustainable way [19,22,23]. Numerous MCDA methods, like the ordered weighted average, outranking method, simple additive scoring, logic scoring of preferences, and analytical hierarchical processes, have been used to access land suitability for farming practices [24–26]. Of these methods, the analytical hierarchical process is one of the approaches to decision-making that is most often mentioned. Its ability to manage both objective and subjective aspects, as well as the way that it causes alternate scores and criteria weights through the creation of a comparison pair-wise matrix, accounts for its widespread popularity [27,28].

Although land degradation and the assessment of land suitability have been examined in developing nations, a recent study in the central region of Ethiopia revealed that land degradation has seriously affected environmental resources, while few studies have been conducted on the assessment of land suitability for cereal crop cultivation. For example, land degradation assessment in the Guder watershed in the central region of Ethiopia revealed that very high (4.96 %) and high (67.48 %) soil severity had been detected using the Revised Universal Soil Loss Equation (RUSLE) model [29]. According to a comparable assessment, the watershed's degraded status was classified as catastrophic, extremely severe, and severe for 426ha, 46764 ha, and 60055 ha, respectively [30]. Likewise [31], reported that as the population grows, soil erosion in the Guder watershed also rises. They estimated that the watershed had total soil loss in the years 1973, 1995, and 2015 of 198 Mt yr-1, 221 Mt yr-1, and 239 Mt yr-1, respectively, due to changes in land use and cover driven by population growth.

Guder Sub watershed is where the study is taking place, and the farmers there have been growing a variety of crops without taking

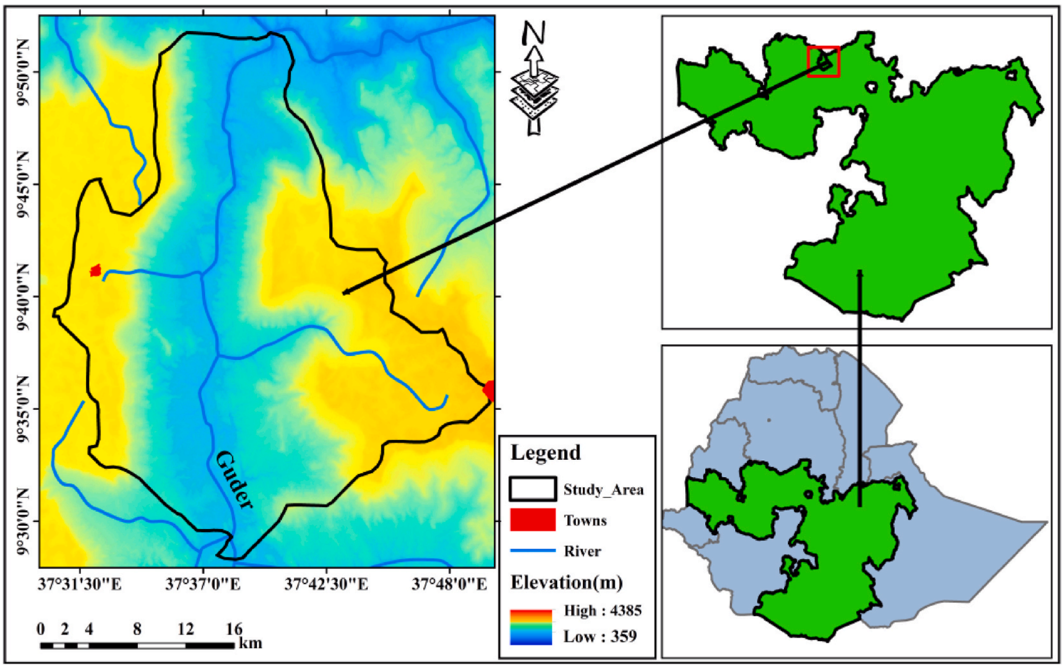

Fig. 1. Location of the study area.

into account the land's potential in terms of its qualities, characteristics, governing factors, and crop requirements. As the result land degradation become series problems in the watershed. Therefore, land suitability evaluation is important for the region giving the following consideration; (1) to increase agricultural productivity to meet growing demand. (2) To decrease environmental resource degradation through sustainable land resource use and management. (3) To identify priority area for rehabilitation of degraded land. This study aimed at assessing land suitability for maize and wheat cultivation using GIS and MCDA to support decision-makers, thereby boosting food security and minimizing the land degradation mentioned above in the Gudar sub watershed.

2. Materials and methods

2.1. Description of the study area

This study was carried out in the Guder Sub-watershed, Oromia Regional State, Ethiopia, which is located about 210 km from Addis Ababa, capital city of Ethiopia to northwest. It is located between 37°30′00″ and 37°50′00″ east longitudes and latitudes of 9°29′00″ to 9°52′00″ north (Fig. 1). The sub-watershed in the study region covers an area of about 822 km^2 and is elevated between 934 and 2568 m above mean sea level (msl). Because the majority of the study area's environment is flat, it is suitable for raising crops and caring for animals. The topography has a significant impact on the sub watershed's rainfall and temperature distribution. For ten years (2011–2021), the region has had 21 °C annual temperatures and 1498.75 mm of precipitation on average. The majority of farmers in the study area used a mixed farming technique.

2.2. Data types and source

In this study, many types of data were used to analyze the physical land suitability for the production of both maize and wheat. The National Meteorological Agency of Ethiopia provided the climate data (rainfall and temperature), while OWWDSE provided the soil properties (soil texture, soil pH, soil drainage, and soil depth). Sentinel2B January/2023 data, and Digital elevation model data was downloaded from USGS (United States Geological Survey) website (https://www.usgs.gov). Additional data like distance to the road, spatial boundaries of Ethiopia, and study area sub-watershed were obtained from the Ethiopian Mapping Agency. Information about data sources is listed in (Table 1).

2.3. Software and tools

To achieve the objective of the study, software like ArcGIS 10.3, ERDAS IMAGINE 2015, Google Earth 2021, TerrSet (AHP Plugin), and handheld GPS were used.

2.4. Data analysis

The land suitability area and its contributing variables can be studied and evaluated using a variety of ways. In this study, the Multi-Criteria Decision Analysis (MCDA) method was utilized to overcome the land suitability for particular cereal crops as proposed by Ref. [32]. The two most well-known multi-criteria analysis techniques used in this study were weighted linear combination (WLC) and analytic hierarchy processes (AHP). The possible thematic layers that may be found using the MCDA method are slope, soil texture, soil pH, soil drainage, soil depth, land use/land cover, proximity to the road, temperature, and rainfall. The next section has detailed explanations for each factor.

Using the ArcGIS 10.3 conversion tool, each vector layer was converted from a vector to a raster. Based on the international and national guidelines derived from various literatures, reclassification and rating of classes for each criterion was presented in (Table 2). Each factor that was taken into consideration was resampled at 30 m resolution to ensure uniform pixel size and prepare for overlay analysis. All factors were reclassified following [9] guide line in to four suitability rank such as: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N1) for crop production.

2.5. Factors used for land suitability evaluation

2.5.1. Topographic factors

The elevation factor has a significant impact on the distribution and activity of microorganisms, soil organic matter, and the growth

Table 1
Data types and source.

No.	Data type	Data Source	Data format	Scale	Purpose
1.	Study area boundary and Road data	EMA	Shapefile		Delineate study area and road proximity map
2.	DEM (ASTER)	USGS	Raster	30 m	To extract slope factor
3.	Climate data	NMA	Tabular		Rainfall and temperature
4.	Soil data	OWWDSE	shapefile	1:50,000	Soil map
5.	Sentinel2B January/2023	USGS	Raster	10 m	Extract Land use/Land cover factor

Table 2
Land suitability evaluation factors and their classification ranges.

Crops	Factors	Highly suitable (S1)	Moderate suitable (S2)	Marginally suitable (S3)	Not suitable (N1)	Source
Maize	Elevation (m)	<1000 m	1000–1500	1500–2000	>2000	[33–36]
	Slope (^{0})	0–7	8–15	16–24	>24	
	Rainfall (mm/yr)	1300–1400	1401–1500	1501–1600	>1600	
	Temperature (^{0}C)	21.1–22	20.2–21	19.1–20.1	17.9–19	
	Soil texture	Loam	clay loam	clay (light)	–	
	Soil depth (m)	>120	–	30–90	<30	
	Soil pH	5.5–6.2	5–5.5	–	2.9–5	
	Soil drainage	–	Moderately Well	–	Imperfectly	
	Distance from road (km)	0–2	2–4	4–7	>7	
	Land use land cover	Agriculture	Grass Land	Shrub land and Bare land	Settlement/Forest/Water body	
Wheat	Elevation (m)	>2000	1500–2000	1000–1500	<1000	[33–36]
	Slope (^{0})	0–7	8–15	16–24	>24	
	Rainfall (mm/yr)	>1600	1501–1600	1401–1500	1300–1400	
	Temperature (^{0}C)	17.9–19	19.1–20.1	20.2–21	21.1–22	
	Soil texture	Loam	clay loam	clay (light)	–	
	Soil depth (m)	>120	30–90	<30	–	
	Soil pH	5.5–6.2	5–5.5	–	2.9–5	
	Soil drainage	–	Moderately Well	–	Imperfectly	
	Distance from road (km)	0–2	2–4	4–7	>7	
	Land use land cover	Agriculture	Grass Land	Shrub land and Bare land	Settlement/Forest/Water body	

of some crops. Additionally, rainfall and soil erosion that are either directly or indirectly related to agricultural output have a greater impact on topographical altitudes [37,38]. Maize grows better in the Lowlands, whilst wheat does better in the Uplands [33]. In determining whether a piece of land is suitable for crop cultivation, slope is crucial [39,40]. For example, the slope can affect soil nutrients and minerals like other environmental variables do. Soil depth and slope affect local changes in soil nutrients, minerals, and agricultural productivity [41]. Using Arc Map Software, elevation and slope data were analyzed and categorized based on existing literature (Table 2).

2.5.2. *Climate factors*

The physical explanation of surface energy and water balance processes at the local to global scale depends heavily on temperature and precipitation. For instance, crop stress (such as water, weeds, and nutrients) affects the temperature of the canopy, which may be evaluated throughout key phonological phases and used to plan and optimize agricultural inputs and activities [42].

Precipitation is also in charge of changing the vegetation on Earth due to interactions between the vegetation and the atmosphere. It also has a significant impact on water availability, which is considered to be the primary regulator of ecosystem structure and the engine for biological processes on more than 40 % of the earth's natural vegetated surfaces [43]. The four closest rain gauge stations in/near the study area namely, Shambu, Busa, Dejen, and Debre-markos, were chosen for this paper's continuous surface generation. Because the inverse distance weighted technique is intuitive and effective, as advised by Ref. [44] it was utilized to interpolate rainfall and temperature data based on station data. ArcGIS geostatistical analysis was used to extract and reclassify this climate data based on previously published works of literature (Table 2).

2.5.3. *LULC factor*

Data on land use and land cover are essential when creating environmental impact statements and predicting how they will affect environmental quality in the future [45]. LULC factor map of the study area was extracted from sentinel 2B image of Jan/2023 which contains 10 m spatial resolution. Supervised classification technique with maximum likelihood algorism was utilized to classify land use/land cover types. Furthermore, representative points were recorded using handheld GPS to represent the various land use/land cover classes during field observation in accessible places. Additionally, high resolution Google Earth image was used as a guideline to identify the representative land cover classes. For image classification, accuracy assessment was calculated to tell how the land use/land cover maps were classified accurately using ERDAS Imagine 15 accuracy assessment tool. Accordingly, 133 points were collected from the ground truth by handheld GPS using random stratified method. The overall classification accuracy was computed as the below equation.

$$\text{Total (overall) Accuracy} = \frac{\text{Number of correctely plot (value)}}{\text{total number of plot (value)}} \times 100 \qquad \text{Equation 1}$$

The user and producer accuracy were calculated using equations (2) and (3) bellow respectively.

$$\text{UAC} = \frac{\text{Xij}}{\text{X} + \text{i}} * 100 \qquad \text{Equation 2}$$

$$PAC = \frac{Xij}{Xi+} * 100 \quad \text{Equation 3}$$

where: UAC = User accuracy, PAC = producer accuracy, Xij = the diagonal values, Xi+ = the column total, and X + i = row total, r is the number of categories. The image classification accuracy is further assessed by calculating Kappa coefficient 'k'. Kappa analysis generates a kappa coefficient and the values of which range between 0 and 1.

Kappa coefficient (Khat) is a measure of the agreement between two maps staking into account all elements of error matrix. It is defined in terms of error matrix as given below equation.

$$K_{hat} = \frac{Obs - Exp}{1 - Exp} \quad \text{Equation 4}$$

where: Obs = Observed correct, it represents accuracy reported in error matrix (Overall accuracy) and Exp = Expected correct, it represents correct classification.

Seven LULC classes were consequently identified: agriculture, grassland, barren land, shrubland, settlement, forest, and water body.

2.5.4. Road accessibility factor

Road networks are essential for moving goods from production locations to points of final consumption, as agricultural products are the key economic driver for farmers. The Euclidean distance tool in the ArcGIS software is utilized to calculate for each pixel the shortest distance to road. Using Arc Map software distance to road was classified based on its appropriateness rank, as used by Ref. [34].

2.5.5. Soil factors

The physical base for crop roots and the source of nutrients for crops are provided by soils [46]. The physical and chemical characteristics of the soil, such as its depth, organic content, and pH levels, are crucial for determining the crop needs [47]. For instance, soil texture and organic matter content affect the soil's ability to retain water and allow plant roots to circulate. Using ArcMap software, soil data were categorized and ranked in this study according to their suitability for a particular crop based on available literature (Table 2).

2.5.6. Assigning factor weights using AHP

Analytic Hierarchy Process is the most known method of multi-criteria evaluation that making comparisons between possible pairs in a matrix to give a weight for each element. In this study to drive the factor weights based on the percentage of influence for the analysis of land suitability, the AHP approach presented by Ref. [48] was used to determine the weights for each factor. The procedure is creating a matrix where each criterion is ranked from 1 to 9 point continuous scale in terms of importance and compared to the others. A score of 1 indicates that two criterion layers are equally important, whereas a score of 9 indicates that one criterion layer is greatly preferred over the other. Accordingly, weight for each criterion was established based on expert judgment and literatures using AHP plugin in IDRISI software (Table 3). The greater weight means the greater influencing factor on a land's suitability. To determine whether the judgment is rational or not, the consistency ratio must be calculated after the weight has been determined (Eq. (1)). The CR assessment is necessary for judgment improvements since it facilitates the identification of errors. According to Ref. [48], if the CR value is much higher than 0.1, the pairwise comparison results are inaccurate since they are too close to be random.

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

Table 3
Pairwise comparison matrix of the selected factors for the study.

Criteria	EL	SL	RF	TMP	ST	SD	SpH	SDR	DR	LULC	Weight (%)
EL	1										0.233
SL	1/2	1									0.185
RF	1/2	1/2	1								0.152
TMP	1/3	1/2	½	1							0.109
ST	1/3	1/3	½	1/2	1						0.092
SD	1/3	1/3	1/3	1/2	1/2	1					0.071
SpH	1/4	1/3	1/3	1/2	1/2	1/2	1				0.057
SDR	1/4	1/4	¼	1/3	1/3	1/2	½	1			0.042
DR	1/5	1/4	¼	1/3	1/3	1/3	½	1/2	1		0.034
LULC	1/5	1/5	1/5	1/4	1/4	1/3	1/3	1/2	1/2	1	0.026
Total											1.000

Consistency ratio = 0.03 Consistency is acceptable.
Where, EL-elevation, SL-slope, RF-rainfall, TMP-temperature, ST-soil texture, SD-soil depth, SpH-soil pH, SDR-soil drainage, DR-distance to road, and LULC-land use/land cover.

where, CR-consistency ratio, CI- consistency index and RI is random consistency index and to calculate CI

$$CI = \frac{(\mu \max - 1)}{n - 1} \quad (2)$$

where μmax is the principal Eigen vector and n is the number of factor considered.

2.5.7. Land suitability analysis based on weighted overlay

The ability of GIS is to integrate spatial analysis of data from several sources of datasets. To resolve spatial complexity in suitability analysis and site selection, the weighted overlay analysis is essential [49–53]. In this study wheat and maize land suitability was assessed by aggregating all considered factors using the weighted overlay method based on AHP and MCDA procedures. The criteria weights of the standardized factor were multiplied by the cell values [54–56]. The weighted overlay method in ArcGIS 10.3 spatial analysis tool was employed to combine all the factors that were taken into account for wheat and maize suitability analysis and this was performed based on (Eq. (3)).

$$LS = \sum_{i=1}^{n} WiXi \quad (3)$$

where LS is land suitability, Wi is the weight value of parameter i; Xi is the criterion score of parameter i and n is the number of parameters. The general methodology follow diagram of the study was discussed in (Fig. 2).

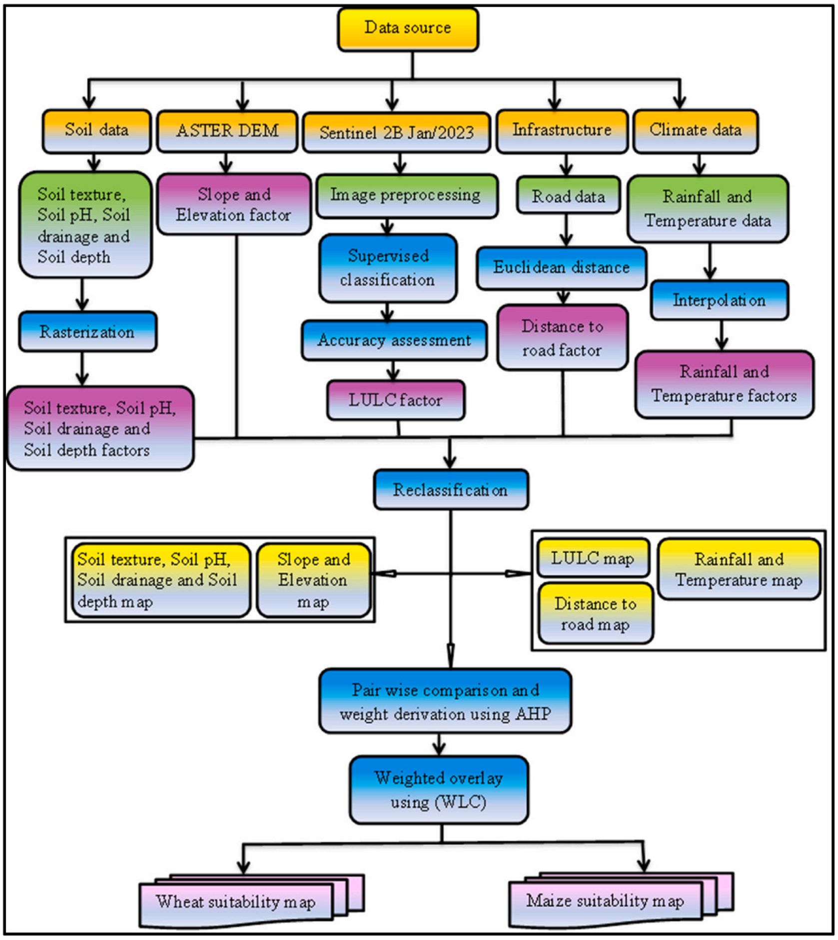

Fig. 2. General methodology follow chart.

3. Result and discussion

3.1. Result

3.1.1. Elevation

As indicated in (Table 4) land suitability in terms of elevation factor exceeding 2000 m (36 %) and below 1000 m (27.4 %) of the study area was very appropriate for growing wheat and maize, respectively. while 6.6 % and 30 % were moderately suitable, 30 % and 6.6 % were marginally suitable for wheat and maize respectively. Thus, lowland sub-humid regions are ideal for cultivating maize, whilst highland areas are better suited for growing wheat (Fig. 3a).

3.1.2. Slope

Concerning with slope sub suitability class is the same for wheat and maize. Accordingly about 7.5 % of the total areas categorized as highly suitable. About 14.6 %, 29.7 %, 48.2 % were ranked as moderately suitable, marginally suitable, and not suitable respectively for both crops production (Table 4). This highly suitable portion is cover western, eastern and central (below escarpment) of the watershed. Not suitable site mostly cover central region of the watershed (Fig. 3b).

3.1.3. Rainfall

About 16.5 %, 40.3 %, 32.5 %, and 10.5 % of the watershed was categorized as highly suitable, moderately suitable, marginally

Table 4
Parameter suitability classes and area coverage for the study.

Criteria	Suitability	Class	Area (ha)	Area (%)
LULC	Highly suitable	Agriculture	20451.97	24.9
	Moderate suitable	Grass Land	38102.67	46.3
	Marginally suitable	Shrub land and Bare land	10251.27	12.5
	Not suitable	Settlement/Forest/Water body	13409.09	16.3
	Total		**82215**	**100.0**
Elevation (m)	Highly suitable	>2000	29560.20	35.95
	Moderate suitable	1501–2000	5411.15	6.58
	Marginally suitable	1000–1500	24699.54	30.04
	Not suitable	<1000	22544.10	27.42
	Total		**82215.00**	**100.00**
Soil depth (cm)	Highly suitable	>120	59031.87	71.8
	Marginally suitable	30–90	12303.82	15.0
	Not suitable	<30	10879.31	13.2
	Total		**82215**	**100.0**
Soil pH	Highly suitable	5.5_6.2	61076	74.3
	Moderate suitable	5_5.5	8813	10.7
	Not suitable	2.9_5	12326	15.0
	Total		**82215**	**100.0**
Soil drainage	Moderate suitable	Moderately Well	61086.24	74.3
	Not suitable	Imperfectly	21128.76	25.7
	Total		**82215**	**100.0**
Soil texture	Highly suitable	Loam	12326	15.0
	Moderate suitable	clay loam	8813	10.7
	Marginally suitable	clay (light)	61076	74.3
	Total		**82215**	**100.0**
Temperature (C°)	Highly suitable	17.9–19	22093.4319	26.9
	Moderate suitable	19.1–20.1	12684.4036	15.4
	Marginally suitable	20.2–21	24892.0726	30.3
	Not suitable	21.1–22	22545.0946	27.4
	Total		**82215.0028**	**100.0**
Rainfall (mm/yr)	Highly suitable	1300–1400	13546	16.5
	Moderate suitable	1401–1500	33148	40.3
	Marginally suitable	1501–1600	26749	32.5
	Not suitable	>1600	8772	10.7
	Total		**82215**	**100.0**
Slope (degree)	Highly suitable	0–7	6193.08	7.5
	Moderate suitable	8 _ 15	11982.67	14.6
	Marginally suitable	16 _ 24	24428.56	29.7
	Not suitable	>24	39610.69	48.2
	Total		**82215**	**100.0**
Distance to road (km)	Highly suitable	0–2	13006.941	15.8
	Moderate suitable	2 _ 4	19634.2531	23.9
	Marginally suitable	4 _ 7	24090.1376	29.3
	Not suitable	>7	25483.6711	31.0
	Total		**82215.0028**	**100.0**

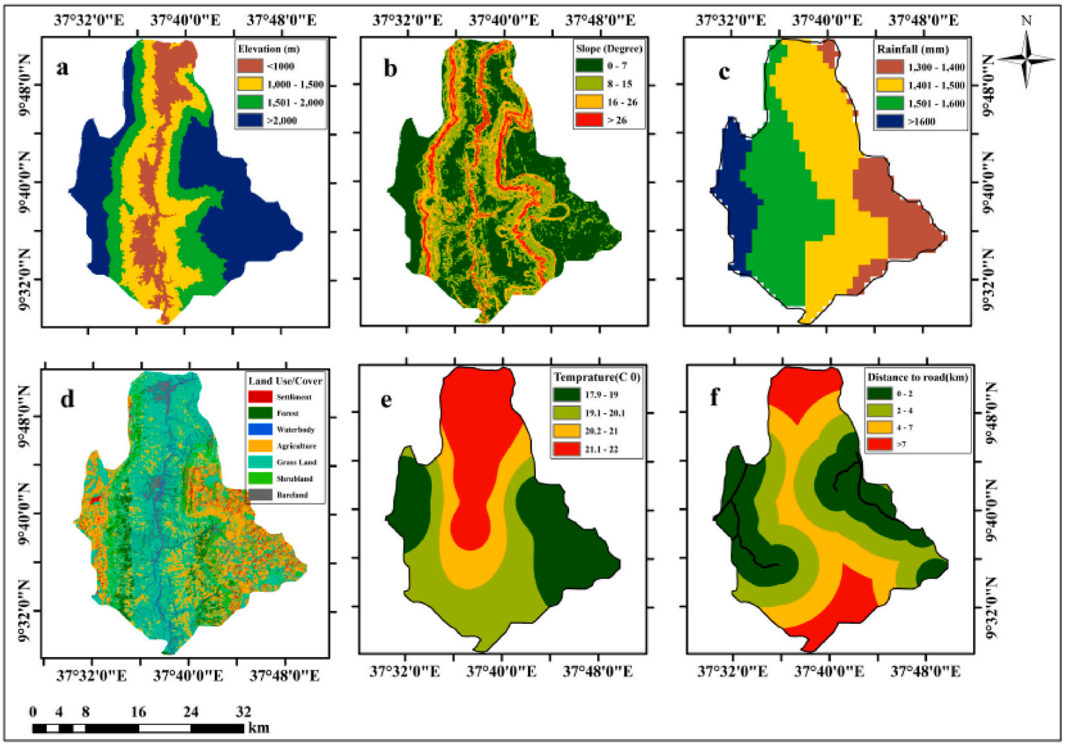

Fig. 3. a) Elevation, b) slope, c) rainfall, d) land use/land cover, e) temperature, and f) distance to road map.

suitable, and not suitable respectively for maize cultivation while 10.7 %, 32.5 %, 40.3 %, 16.5 % of the watershed was highly suitable, moderately suitable, marginally suitable, and not suitable respectively for wheat cultivation (Table 4). In the watershed eastern portion receive low amount of rainfall which favorable for maize growth while western portion receive high amount of rainfall which favorable for wheat cultivation (Fig. 3c). Thus, maize cultivation suitability decrease from eastern to western direction while wheat production decrease from western to eastern direction.

3.1.4. Temperature

The studied area's temperature ranges from 17.9 to 22 °C, as shown in (Fig. 3e). About 26.9 %, 15.4 %, 30.3 %, and 27.4 % of the study area was ranked as highly suitable, moderately suitable, marginally suitable, and not suitable for maize cultivation, respectively whereas, about 27.4 %, 30.3 %, 15.4 %, and 26.9 % were categorized as high, moderate, marginal, and not suitable for wheat cultivation, respectively (Table 4). Though their sub-suitability percent relatively similar in terms of temperature, spatially they are vary over the watershed. For example, 27 % of highly suitable for wheat cultivation dominate western portion the study area which received low temperature, while northern direction receives high temperature thus 26.9 % of highly suitable for maize farming (Fig. 3e).

3.1.5. Land use land cover

Seven LULC classes were identified with 87.2 % of overall accuracy assessment and 0.85 kappa coefficients. According to the findings, the study area's LULC was primarily made up of farmland (24.9 %) and grassland (46.3 %), which are both highly and moderately suitable for growing wheat and maize, respectively, while shrub land plus bare land (12.5 %) are marginally suitable. The remaining settlement, forest, and water body (16.3 %) were restricted when overlay analysis was performed for both crops (Table 4, Fig. 3d). This is due to the fact that turning a vegetated area into an agricultural area reduces biodiversity, and removing settlement also raises costs and adds extravagance.

3.1.6. Distance to road

As computed distance to road for each pixel, about 15.8 %, 23.9 %, 29.3 %, and 31 % of the study area were categorized as highly suitable, moderately suitable, marginally suitable, and unsuitable for both wheat and maize farming respectively (Table 4). Western and eastern portion have high road accessibility while northern to southern portion have less road accessibility (Fig. 3f).

3.1.7. Soil texture

Three types of soil texture were found in the study area: clay (light), clay loam, and loam (Fig. 4d). According to (Table 4), the loam soil texture class covers about 15 % of the study area and is highly appropriate for the cultivation of wheat and maize. Wheat and maize

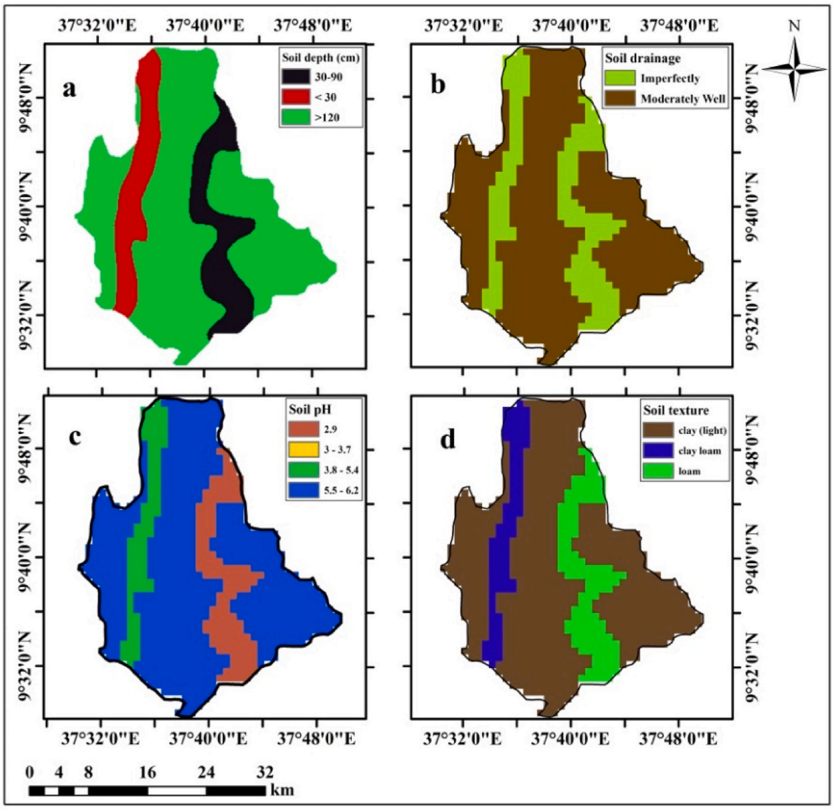

Fig. 4. a) Soil depth, b) soil drainage, c) soil pH and d) soil texture map.

crops did reasonably well in clay loam and clay light soil texture classes, which cover about 10.7 % and 74.3 % of the study area, respectively.

3.1.8. Soil depth

The soil depth which account for 71.8 % of the watershed ranked as highly suitable. About 15 % and 13.2 % were ranked as marginally suitable and not suitable for both crops which lay on escarpment on some part of eastern and western portion as shown in (Fig. 4a, Table 4).

3.1.9. Soil drainage

As shown in (Fig. 4b), the study area's soil drainage was divided into two categories moderately well and imperfect. Most of the study area under investigation, exhibit moderately well soil drainage which covers about 74.3 % of the total region, while the remaining 25.7 % have imperfect soil drainage. Imperfect soil drainage can result in waterlogging, compaction, nutrient leaching, and decreased oxygen availability for plant roots. This can result in decreased crop yields, poor crop quality, increased susceptibility to diseases, and overall reduced profitability for farmers. Therefore, based on (Table 2) moderately well soil drainage was assigned as moderately suitable for both crop types, while imperfect soil drainage is not suitable (Table 4).

3.1.10. Soil pH

The presence of phytotoxic substances in crops is indicated by the soil's pH, which is a determining factor in a plant's adaptability and growth. It influences the availability of nutritional anions and cations, controls the solubility of metal ions like Al, Mn, Fe, Cu, Zn,

Table 5
Land suitability for wheat farming and area coverage.

Crop	Suitability	Area (ha)	Area (%)
Wheat	High Suitable	4936.15	6.0
	Moderate Suitable	41538.24	50.5
	Marginally Suitable	19101.2	23.2
	Not Suitable	16639.41	20.2
	Total	**82215**	**100.0**

and Mo, and determines soil fertility [57]. The Gudar sub-watershed's soil PH value ranged from 2.9 to 6.2 (Fig. 4c) and was categorized into three ranges: high suitable (2.9–5%), moderately suitable (5.5–6.2 %), and not suitable (5.5–6.2 %). Highly suitable, moderately suitable and not suitable covers about 74.3 %, 10.7 % and 15 % of the study area respectively.

3.1.11. Land suitability evaluation for wheat production

In the present study, 6 % of the total study region were identified as very suitable for cultivating wheat crop, while the remaining 50.58 %, 23.26 %, and 20.26 % were moderately, marginally, and not suitable, respectively (Table 5). The result of the study shows that the majority of the area was highly and moderately suitable for wheat production which covers about 56 % of the total study area. The western and some eastern parts of the region are very suited, as seen in (Fig. 5). Furthermore, south central, north central and most parts of the central regions are moderately suitable for wheat cultivation.

3.1.12. Land suitability evaluation for maize production

The study's findings indicate that, of the studied area, 5.1 % and 57.3 % were highly and moderately suitable for maize cultivation, respectively, while 17.3 % and 20.3 % were marginally and not suitable (Table 6). As shown in (Fig. 6), the northern, eastern, and central regions of the study area were dominated by highly suitable areas, whereas moderately suitable areas were widespread throughout the region. This shows the majority of Guder sub watershed is preferable for maize crop farming. In other hand, some locations in the western, eastern, and northwestern were marginally suitable for maize production, while others are not.

3.2. Discussion

Land suitability analysis for wheat and maize farming in Gudar sub watershed was carried out by integrating information from different sources such as; slope, soil properties (texture, pH, drainage and depth), land use/land cover, proximity to road, temperature and rainfall. The weight for each criteria was calculated in AHP method and the assigned weights were used in the weighted overlay analysis to prepare land suitability for wheat and maize farming in the study region. Thus, the weight for each parameter were assigned from the highest to lowest percentage of influence as elevation, slope, rainfall, temperature, soil texture, soil depth, soil pH, soil drainage, distance to road and land use/land cover respectively for both crops (Table 3). This might be the case because elevation affects crop diversity since it controls the amount of water in the soil and the fluctuation of the climate, including precipitation, radiance, and temperature [39]. Slope factor was weighted as the second influencing factor next to elevation having 18.5 % of influence. This is due to the fact that slope can have an impact on the quantity of soil nutrients and minerals, and those local differences in soil nutrients, minerals, and agricultural productivity change with soil depth and slope [41]. Moreover, considering these

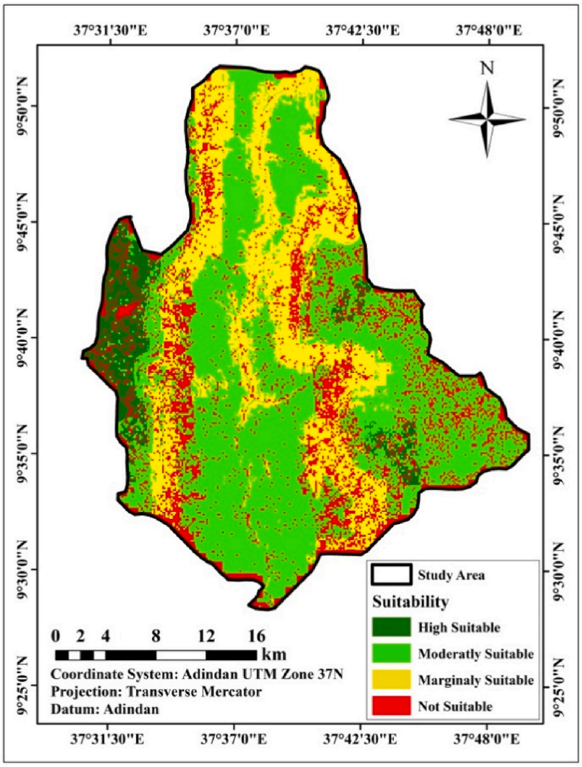

Fig. 5. Land suitability for wheat production in Guder sub-watershed.

Table 6
Land suitability and area coverage for maize farming.

Crop	Suitability	Area (ha)	Area (%)
Maize	High Suitable	4182.55	5.1
	Moderate Suitable	47137.89	57.3
	Marginally Suitable	14190.76	17.3
	Not Suitable	16703.8	20.3
	Total	**82215**	**100.0**

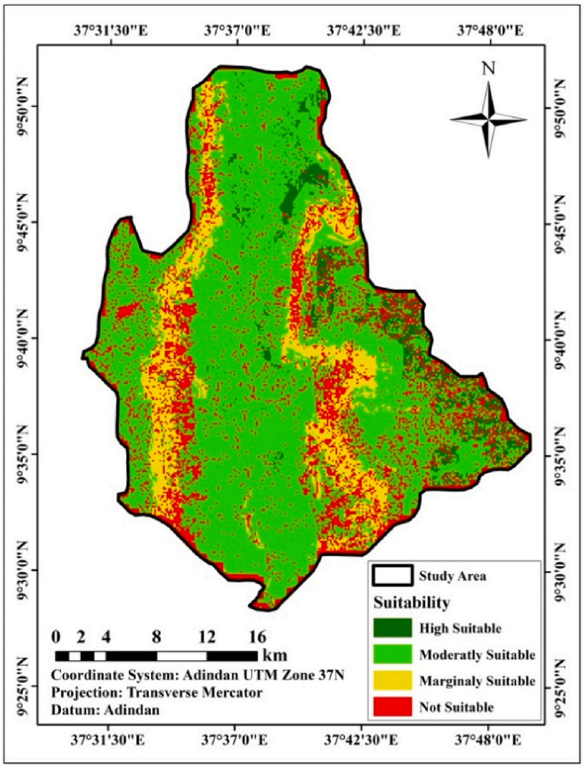

Fig. 6. Land suitability for maize production in Guder sub-watershed.

topographic factors as the major controlling variables in cereal crop cultivation is essential for tackling agricultural expansion toward fragile land that accelerate land degradation in the region. Similar study have been identified topographic variables as major influencing factor to determine land suitability for cereal crops [36] Accordingly, the lowest weights were assigned to soil depth, soil pH and soil drainage. Distance to road and LULC were considered as a little influencing factor (Table 3).

The result of the suitability shows that the western part of the region is very suited, for wheat cultivation. This can be the case since the area was dominated by the main crop need factors. For instance, this region was occupied by 35.95 %, 16.5 %, 7.5 %, and 74.3 % of an appropriate elevation, precipitation, slope, and soil properties, respectively. As shown by Ref. [33], such parameters are crucial in determining wheat/crop production. This result is in agreement with the study conducted by Ref. [34] in the Debo Hana district, southwest Ethiopia, which found that 8.6 % of the area is highly suitable for wheat crop cultivation. Some western, eastern and central parts of the region were not suitable for cultivating wheat crop. These areas were characterized with elevation >1000 m, slope exceed 24°, imperfect soil drainage, far from road and an area which are occupied with settlement, forest and water body. [58], found that in the Jello watershed, Eastern Ethiopian highlands, 61 % of the land was unsuitable for growing wheat, 33 % was marginally suitable and 6 % was moderately appropriate. The northern, eastern, and central regions of the study area were dominated by highly suitable areas for maize crop, whereas moderately suitable areas were widespread throughout the region. The characteristics of highly suitable areas were subjected with an elevation ranges of up to 1000 m, slopes of 0 to 7°, annual rainfall between 1300 and 1400 mm, temperature variations between 17.9 and 19 °C, and soil texture classes of loam and clay loam. This finding is inline with study conducted by Ref. [59], which found that maize crop production is better suitable for lowland areas with high land surface temperatures and low rainfall than wheat cultivation. Moreover, moderate suitable to not suitable observed in the watershed for both crop may be because of land degradation severity which has happened as reported by previous studies [31].

4. Conclusion and recommendation

An important step in ensuring sustainable land usage and maximizing profit from the property is conducting a land suitability analysis for cereal crops. In this study, topography, climate, soil qualities, environmental, and infrastructure aspects were taken into consideration when analyzing the feasibility of the site for cultivating wheat and maize in the Guder sub-watershed, Ethiopia. The pairwise comparison matrix result revealed that ten criteria were compared to one another and graded using a Saaty scale. Elevation, slope, rainfall, and temperature had the most influences, with corresponding influence weights of 23.3 %, 18.5 %, 15.2 %, and 10.9 %. In order to combine several layers of thematic data for the evaluation of land suitability for wheat and maize crops, geospatial and multi-criteria evaluation methodologies have been determined to be quite useful. The findings of the study revealed that 6 %, 50.58 %, 23.26 %, and 20.26 % of the total studied area were highly, moderately, marginally and not suitable for wheat production, respectively, while 5.1 %, 57.3 %, 17.3 %, and 20.3 % of the total studied area were highly, moderately, marginally and not suitable for producing maize respectively. The study's findings are helpful for future land management, and the local communities in the study area are advised to take the required steps to put the potential land in highly and moderately suitable locations to use. Furthermore, additional research must be done in places that are marginally suitable and unsuitable for the cultivation of other crops.

Consent for publication

The authors agreed to publish this manuscript for publication.

Data availability statement

Data will be made available on request.

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CRediT authorship contribution statement

Fayera Gizawu Garbaba: Writing – review & editing, Writing – original draft, Validation, Investigation, Data curation. **Bayisa Negasa Wolteji:** Software, Methodology, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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