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# Evaluation of Barley and Wheat Crops Land Suitability Using GIS and Remote Sensing Technologies: The Case of Duna District, Central Ethiopia Region, Ethiopia

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

The assessment of the suitability of arable land for sustainable intensive agriculture sustainable agricultural production using GIS and RS methods is becoming increasingly important. Therefore, the ultimate aim of this study was to evaluate the land suitability analysis of wheat and barley crops using GIS and remote sensing techniques in Duna district, southern Ethiopia. This study used secondary data types (land use, land cover, topography, soil, climate, and management factors. A weighted cumulative overlay analysis was then used to assess the crop produced to determine the suitability map in a GIS environment. The factors/criteria were evaluated in five classes from very suitable, up to permanently not suitable. The result of the determination showed that 115 km$^2$ (51.7%), 120, 6 km$^2$ (54.2%) and 95.4 km$^2$ (43.84%), 18.3 km$^2$ (8.22%) and 14.6 km$^2$ (6.7%) and 75.5 km$^2$ (33.9 %) of the study area were predominantly well suited, suitable and conditionally suitable for barley and wheat production, which exceeded 60% of the study area. Based on the analysis, there was extensive land suitable for wheat and barley cultivation in the district based on the current situation (factors). According to the result, it is concluded that favorable climate, suitable

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soil characteristics, suitability of existing arable land, better elevation, slope, and others were responsible for land suitability for the crops. For this reason, for the sustainability of land productivity and crop production, various incentives should be set by the concerning bodies and various stakeholders to improve the usability of the land according to the suitability assessment of this study.

*Keywords: GIS; irrigation; land requirement; land suitability assessment; MCDE.*

## 1. INTRODUCTION

### 1.1 Background of the Study

Land resources are gradually becoming scarce as world population pressures increase on natural resources that require careful and appropriate use, which is critical to achieving optimal productivity and ensuring environmental sustainability for future generations [1]. According to FAO [2], agricultural yields have stagnated over the three decades of agriculture in sub-Saharan Africa due to the loss of agricultural land suitability. According to the FAO [3], the food situation in Africa is set to continue to deteriorate. East Africa, including Ethiopia, also has extensive fertile agricultural land, a temperate to a mild climate, and a large labor force pool. Despite this potential, however, Ethiopian agriculture has remained underdeveloped due to poor land management and traditional agriculture.

Wheat and barley are among the staple crops grown on a large scale in Ethiopia, especially at the higher elevations. It is the largest wheat producer in sub-Saharan Africa with 1.8 million ha annually [4]. However, according to FAO [2], in Ethiopia, wheat and barley are cultivated on an area of 1.7 and 0.9 million hectares, with an annual production of 4.8 and 2 million tons, which is an average yield of up to 20 qui/ha equals less than worlds bring 40 qui/ha each. Due to the low yield, the country cannot meet the high demand and remains a net importer despite its good potential for wheat production [5].

The increasing demand for agricultural products and land to meet non-agricultural needs is leading to rapid changes in land use. These changes have led to a critical examination of real estate valuation (ibid., 1978). Land assessment is an essential prerequisite for rational land use planning, which must be based on knowledge of available and suitable land resources. The FAO [6] Framework for Land Evaluation was developed for the suitability of soil sites for different land-use types and was used to assess soil suitability for different crops and to establish cropping patterns [7-14].

According to Rabia and Terribile, [15], soil suitability is a multi-criteria problem affecting the number of parameters; Therefore, the assessment requires a multi-criteria approach. The availability of GIS and multi-criteria decision analysis (MCDM) methods makes it possible to combine knowledge from different sources to support land use planning and management [16].

### 1.2 Statement of the Problem

Ethiopia's arable farming system remains a backward system dominated by traditional agriculture, which accounts for almost three-quarters of all arable land and more than 90% of the food supply (Seyoum, 2008). Thus, much of the increase in crop production over the past decade is due to the increase in acreage. Demand for grain continued to increase due to population pressures, mainly due to drought, poor land management, and government agricultural policies that adversely affected crop production, which is a major importer of grain (CSA, 2008).

Rain-fed agriculture in the highlands of Ethiopia has a better climate but is often fragmented, producing mainly for subsistence and generating only a small marketed surplus [17-23]. Current grain yields are low by international standards, indicating growth potential (CSA, 2008). The study area (Duna District) also has a biophysical advantage for crop production; however, the area does not score very well in the assessment of its suitability and is not yet assessed and evaluated for better productivity. It is densely populated and has long been settled with a population that exhausts the low soil fertility status and limits the areas characteristic of crop production. The risk of soil erosion from runoff, frequent farming, traditional farming, land fragmentation, and seasonal variation in rainfall are among the main crop productivity issues in the study area. Improving soil fertility, assessing and identifying suitability have a significant impact on mitigating the problem [24-30].

No study was conducted in the study area to assess the suitability of land for crop production using GIS and RS methodology, while most studies assessed farmers' awareness of land degradation and practice of soil and water conservation measures using other methods - based research such as the study by Zenebe Admasu, [31] investigated how measurements were used. This study aims to evaluate soil suitability for wheat and barley crops by integrating GIS and MCA methods in Duna District, Hadiya Zone. Soil, climate, and topographical characteristics, the most important factors affecting crop demand, were considered in the study. Characteristics such as specific land-use type, slope, elevation, temperature, rainfall, and soil organic and inorganic properties were evaluated and identified the areas suitable for wheat and barley crops.

## 2. MATERIALS AND METHODS

### 2.1 Description of the Study Area

This study was conducted in Duna Woreda, Hadya Zone, about 274 km south of Addis Ababa or about 210 km west of Hawasa, the capital of SNNPR. Geographically, Woreda is located at 714-728 north latitude and 3732-3746 east longitude (Fig. 2). The relief of the study area was characterized by some plains, plateaux, cliffs, and ridges, which were generally highland areas from 1719 m to 2931 m above sea level with a large part of the moderate slope. Most of the study area is highland, which offers climatic conditions with 11°C and 18°C in an annual mean of the minimum and maximum temperature and 1400-1800 mm annual precipitation. (ibid., 2019). The most important soil types are loamy soil (34.6%), loamy soil (33.3%), and vertisol soil (32.1%). The main livelihood of the Woreda study population was mixed farming, which mainly depends on seasonal rainfall. The main annual crops grown in the study area were cereals: wheat, eragrose, teff, little and some corn; Legumes (WARDO, 2019).

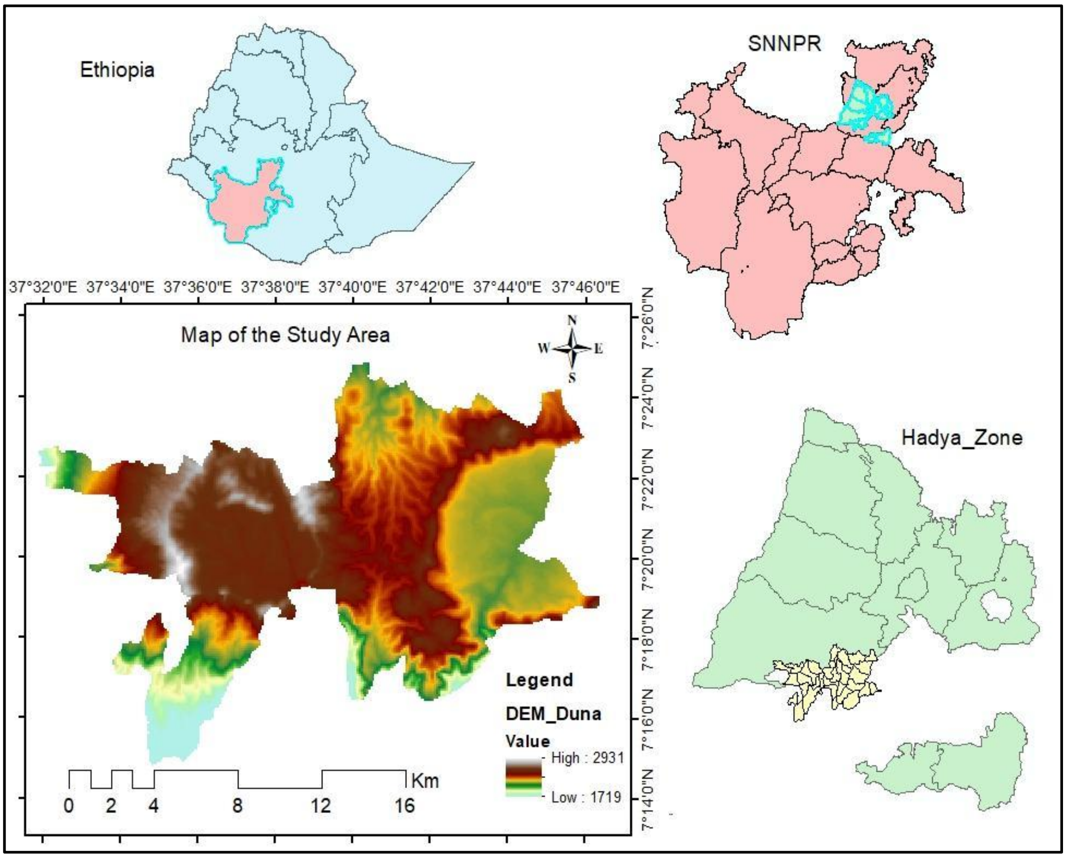



**Fig. 1. Map of the study district**

## 2.2 Source of Data and Collection Tools

The study was mainly based on spatial data types such as Land Sat, DEM, soil data, climate data and GPS points from various sources. The data types and sources used throughout the research activities are listed in (Table 1).

**Table 1. Materials used in the study**

| Types of images | Time of acquisition | Source | Resolution | Intended uses of the images |
|---|---|---|---|---|
| Landsat-8/OLI | February 2021 | Earth explorer web site | 30 | To produce the land use land cover map of the respective years |
| ASTER DEM | 2021 | USGS | 30 | To analyze the topographic features of the study area |
| Climate data (T$^o$ and RF | 2021 | Worldclima | -- | To evaluate its requirement for the crops |
| Soil data | 2021 | FAO data portal | | To evaluate its suitability for the crops |
| Google earth image | 2021 | Google earth | 2.5 | For accuracy assessment and for generation of control points |

The diverse data used for this study were collected from various sources. Topographic, soil, climate and management factors were used to assess the country's performance. These were selected based on agronomic knowledge of local experts and review of existing literature such as the FAO Framework for Land Assessment (FAO, [32], [33], 2007b). These criteria are soil depth, soil texture, soil drainage (permeability), soil chemistry (OC and PH), slope and climatic parameters (temperature and precipitation), and LULC map by classifying satellite imagery of 2021 Landsat-8/OLI data abtained in February according to the FAO land-use classification scheme. The slope map was created on Arc GIS 10.8 using DEM data. All of this data was converted to raster format, reclassified and subjected to weighted overlay analysis, using different weighted values in different parameters according to their importance. Mainly ERDAS Imagine 2015, Arc GIS 10.8 and Elshayal Smart Software were used to collect, organize, process, analyze and create the end result of the study.

## 2.3 Methods

The overall methodology used in the study is shown in Fig. 2. Multi-criteria decision-making was used using input data such as current land use, topography, soil properties and climate parameters. Use of MCE criteria in the form of relevant grids (layers), integrated multi-criteria area evaluation and GIS. The suitability map was classified based on its land-use quality priority for the specified land use requirements. According to FAO, [32] land suitability classes (very suitable to permanently unsuitable) are based on the parameters of crop-specific soil, climate and topographical data Analysis guidelines for identifying suitable areas for agricultural development.

The table of requirements was created through a review of experimental results and literature on parameters such as plant phonology and morphology, growth cycle length and ripening time, and specific climatic and soil physical and chemical requirements. The weighted overlay is an intersection of standardized and differently weighted layers in suitability analysis [34]. The weights quantify the relative importance of the suitability criteria considered. All criteria considered for the analysis of arable land suitability have been standardized based on the FAO Guide to Classification and Characterization of Soils for Agricultural Suitability.

The weights from the pairwise comparison for the criteria were based on a ratio number (reciprocal matrix) pairwise comparison technique (Saaty, 1980) developed as part of a decision-making process, in which each factor is compared relative to the other criteria to its importance on a scale of 1 to 9 (Saaty, 2004) on the importance of each criterion, as suggested by Saaty (2004), scale (19), for example, 1 means equally important and 9 means extremely important. Consequently, possible pair comparisons were carried out. Finally, the priority weights were calculated from the paired comparison matrix and the eigenvector values based on the formula below.

$$\text{Eigen vector} = A_{ij} = \frac{\sum^{n} i\_1(w1/w1 \times w1/w2 \times \ldots :x\ w1/wn)^{1/n}}{\sum(\sum^{n} i\_1(w1/w1 \times w1/w2 \times \ldots \times w1/wn)^{1/n}}$$

Where wi is the sum of row for pairwise comparison and n is the size of the matrix.

n – 1

## 2.4 Integrated Data Analysis Method (Study Design)

After standardizing and calculating the weight of each criterion using the FAHP, the WOA was performed. Each criteria raster layer was assigned a weight in the suitability analysis. The differently weighted layers were classified on a common suitability scale of 1 to 5 from very suitable (S1) to permanently unsuitable (N2). These layers were then overlaid and the weighting of each raster layer in the overlay process controls the influence of various criteria in the suitability model.

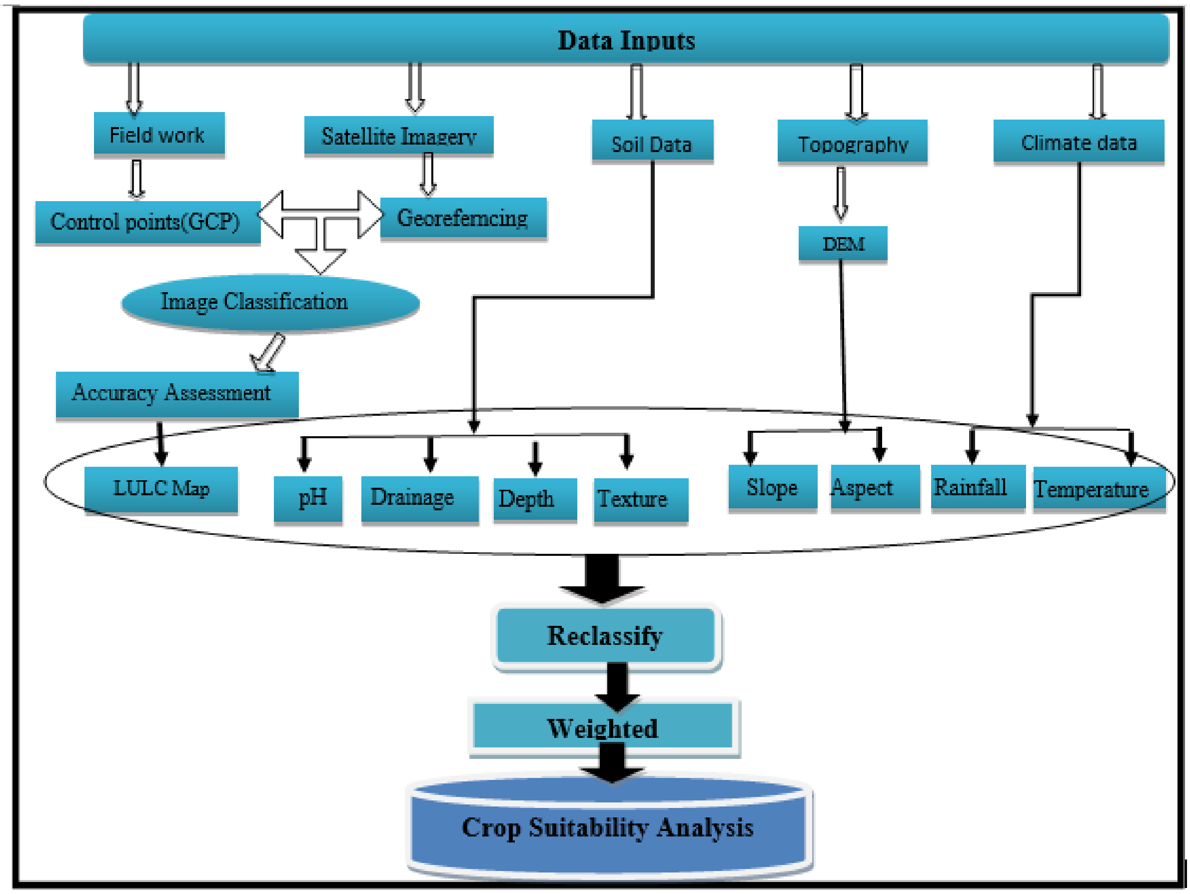



**Fig. 2. Methodological flow chart of the study**

## 3. RESULTS AND DISCUSSION

### 3.1 Crop Suitability factors

The results of spatial land suitability for wheat and barley crops were prepared after analyzing selected evaluation criteria such as soil physical properties (texture, drainage and soil depth), soil chemical properties (pH and OC), topographical factors (slope and elevation), climatic factors (temperature and precipitation) and existing LULC.

#### 3.1.1 Topographic factors

The propensity for the land assessment study has an immense impact on labor efficiency, erosion control practices, and plant adaptability [35]. The topographical feature of the study area, indicated by elevation and slope, ranges from 1719 to 2931 m asl, distributed in Woyna Dega (1719-2300 m) and Dega (2300-2931 m) with 78.84% and 21.86% of the area, respectively. As shown in (Table 3), the slope of the study area ranges from very gentle (< 3 degrees) to very steep (> 40 degrees). The area was a gentle slope.

#### 3.1.2 Soil physical and chemical characteristics

Soil properties are fundamental factors to determine the suitability of land for particular crop growth [36]. The physical properties of the soil and the chemical property; (Soil Depth, Soil Texture, Soil Drainage and Soil PH) are listed in the table below. As shown in (Table 3), the soil depth of the study area ranges from very shallow <30 cm to very deep (100 cm). (Endalkachew et al., 2020) also stated that almost 65% of the area has sandy loam soil and 33% has sandy loam soil and 41% of the area is well-drained, while 6% is ideally the best in terms of PH Beko Waterhsed.

#### 3.1.3 Climate factors

(Table 2) presented the spatial distribution of climate characteristics and evaluated the suitability of precipitation and temperature for barley and wheat crops according to their requirements. Soil suitability also depends on the suitability factor, as reported by the FAO (2007b). Average annual rainfall for the growing season of the Andit Tid watershed ranges from 76.32 to 186.31 mm and annual temperature varies from 11.32 to 12.80°C [35]. Accordingly, the mean annual precipitation for the two crops in the study area ranges from 1187 to 1334.6 mm and the annual temperature varies from 16 to 19°C (Table 2).

#### 3.1.4 Land use land cover factor

Duna district includes about 207.8 km2 of arable land, 5 km2 of bare and open area, 3.2 km2 of forest and woodland, and 8.6 km2 of residential areas. Analyze in percentage and set classification level with percentage (Fig. 3 h1).

### 3.2 Land Suitability Analysis of Factors for Wheat and Barley Crops

The suitability classes for wheat and barley cultivation are shown in (Fig. 3a-i). The study area has 47.98% very suitable and 32.66% suitable slopes with 55.56% sandy loam soil and 26.98% structured loam soil. Sandy clay loam and clay loam are considered optimal for growing wheat and barley. Most of the land in the study area was suitable and suitable soil Ph, with 43.14% being unsuitable for cultivation. The pH values varied from 2.9 to 6.6; this indicates that the soil of the study area was moderately acidic. As [35] the OC of the soil range between 0.03 and 0.05 in Andit Watershed. 22.97% of the study area has a very suitable soil depth and 77% has a suitable soil depth. There was also a higher annual rainfall of 74.78% and moderate to very suitable temperatures throughout the study area and 100% well to moderately well-drained to risk erosion, which is important for cultivation overall. There were no areas that were permanently unsuitable for any of the factors in the study area.

This section evaluated the suitability of the main crops (wheat and barley) grown during the summer season in the study area. According to Table 7, of the total area of the study area of 222.45 km2, around 173 km2 (77.82%) and 137.5 km2 (61.84%) were suitable or moderately suitable in their altitude for barley and wheat cultivation. A large part of the study area was very well suited and suitable for main crop cultivation. According to (Fig. 3a & b), 106.75 km2 (48%) and 150.8 km2 (71%) of the study areas had very suitable slopes, which are important for barley and wheat cultivation.

The highly suitable class of elevation for wheat ranges from 2,000 to 2,600 m a.s.l, whereas for barley it extends from 2,000 to 3,000 m a.s.l [36]. Wheat and barley prefer slopes less than 8% for the highest productivity (Sys et al., 1993). As shown in (Table 3), the slope of the study area ranges from very gentle (< 3 degrees) to very steep (> 40 degrees). This reduces soil depth, drainage and nutrient availability, and slows the rate of soil formation with increasing steepness [37]. Most of the soil (77%) and 56 (%) of the soil was very deep, which is very suitable for both crops. In terms of soil texture, sandy clay loam (123.6 km2) and clay loam (60 km2) were predominant in the study area. Approximately (55.5%) and (76%) of the soil was a very suitable texture for the crops evaluated (Fig. 3d).

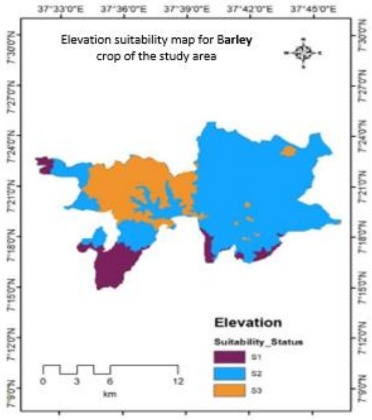
Based on (Fig. 3), moderately drained soil (S2) dominated the study area with (74%) and

(89.9%), and well-drained soil (S1) covered 25.87% and 10.3% of the soil for barley or wheat crops. This shows that the soil drainage of the study area was effective for growing crops. Soil chemical property (Ph value) and its spatial distribution of Duna district soil are shown in (Table 3 and Fig. 3f). The pH suitability of the soil ranges from very suitable (S1) to not suitable (N1). 11.68%, 45% and 43% and 48%, 37% and 14% of the district soil pH were very suitable, suitable and not suitable for barley and wheat production, respectively). If the soil has an OC < 2, it is considered negligible for most crops [38].

Using the available rainfall and temperatures in the study area, the suitability of the factors for barley and wheat crops is discussed below. Of the total of 25% and 76% of the land was suitable (S2) rainfall and 74.8% and 24% less suitable (S3) for growing barley and wheat respectively (Table 3 and Fig. 3g). Temperature suitability also ranged from very suitable (S1) to less suitable (S3) with 15% and 27% to 55% and 15% respectively for both crops (Table 3 and Fig. 3i). Wheat and barley have temperature preferences in the range of 15°C to 20°C and 812°C, respectively, for maximum production and productivity [39].

**Table 2. Land Suitability Analysis of Factors for Wheat and Barley Crops**

| Criteria | Class | Barley | | Wheat | | Total |
|---|---|---|---|---|---|---|
| | | Area coverage (km2) | Area coverage (%) | Area coverage (km2) | Area coverage (%) | |
| **Elevation** | S1 | 0.70 | 0.3 | 84.18 | 37.84732 | 222.45 |
| | S2 | 173.08 | 77.82 | 137.56 | 61.84696 | |
| | S3 | 48.63 | 21.86 | 0.68 | 0.305728 | |
| **Slope** | S1 | 106.75 | 47.98 | 150.88 | 71.2202 | 222.45 |
| | S2 | 72.65 | 32.66 | 23.39 | 11.04083 | |
| | S3 | 29.89 | 13.44 | 26.17 | 12.35308 | |
| | N1 | 13.14 | 5.9 | 11.41 | 5.385886 | |
| **Depth** | S1 | 171.35 | 77.02 | 125.83 | 56.56552 | 222.45 |
| | S2 | 51.1 | 22.97 | 96.62 | 43.43448 | |
| | S1 | 123.61 | 55.56 | 169.55 | 76.2228 | 222.45 |
| | S2 | 60.02 | 26.98 | 25.73 | 11.56716 | |
| **Texture** | S3 | 38.83 | 17.45 | 27.16 | 12.21003 | |
| **Drainage** | S1 | 57.56 | 25.87 | 22.89 | 10.28949 | 222.45 |
| | S2 | 164.89 | 74.1 2 | 199.57 | 89.71051 | |
| **PH** | S1 | 26.11 | 11.68 | 107.62 | 48.37941 | 222.45 |
| | S2 | 100.37 | 45.12 | 83.33 | 37.4601 | |
| | N1 | 95.98 | 43.14 | 31.50 | 14.16049 | |
| | S2 | 56.1 | 25.22 | 169.12 | 76.02266 | 222.45 |
| **Rainfall** | S3 | 166.35 | 74.78 | 53.34 | 23.97734 | |
| **Temperature** | S1 | 33.96 | 15.26 | 60.07 | 27.00504 | 222.45 |
| | S2 | 65.72 | 29.55 | 128.65 | 57.83582 | |
| | S3 | 122.78 | 55.19 | 33.72 | 15.15914 | |
| **LULC** | S1 | 207.88 | 93.26 | 207.88 | 92.49388 | 222.45 |
| | S2 | 5 | 2.24 | 4.47 | 2.224694 | |
| | S3 | 3.27 | 1.46 | 7.14 | 1.45495 | |
| | N1 | 8.6 | 3.87 | 12.91 | 3.826474 | |
| **Total** | 100% | | | | | |

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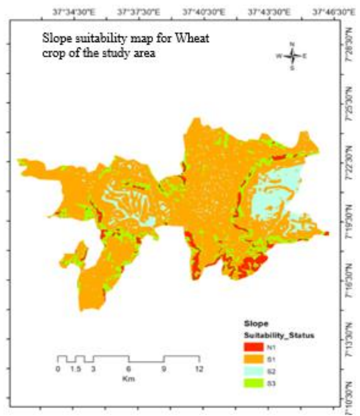
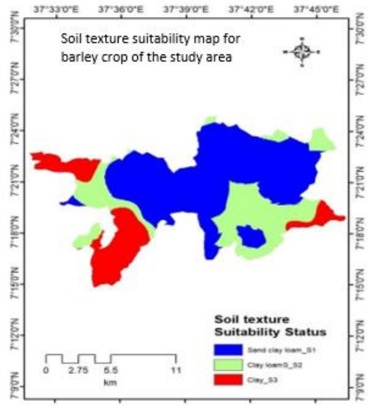



b2

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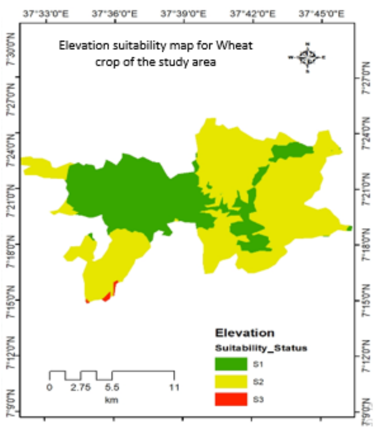


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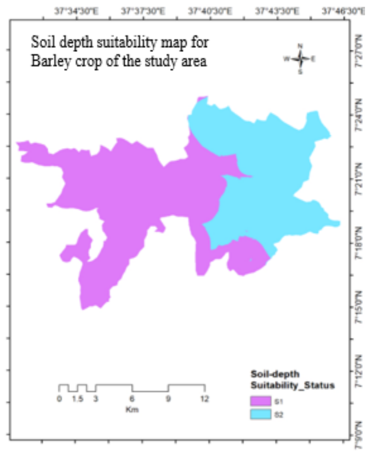
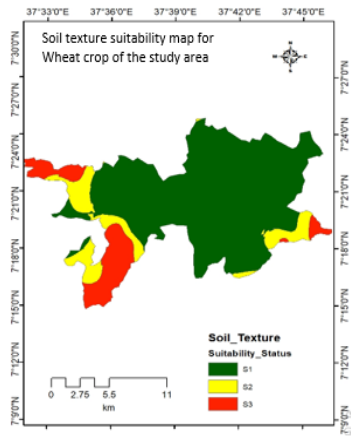



c1

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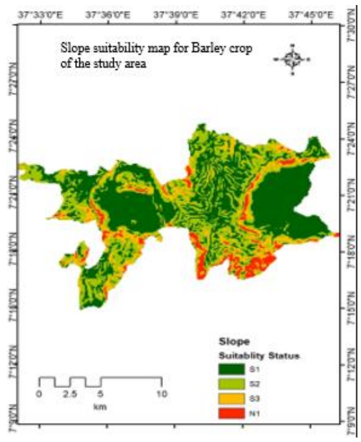


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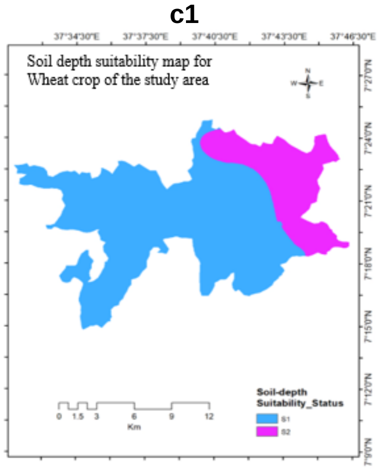
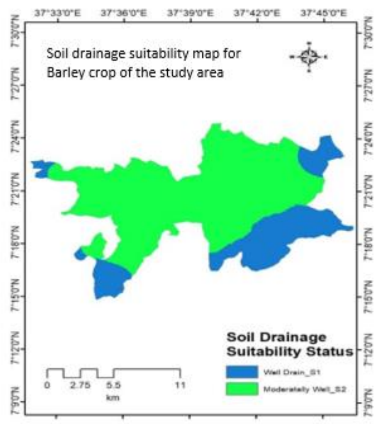



c2




e1

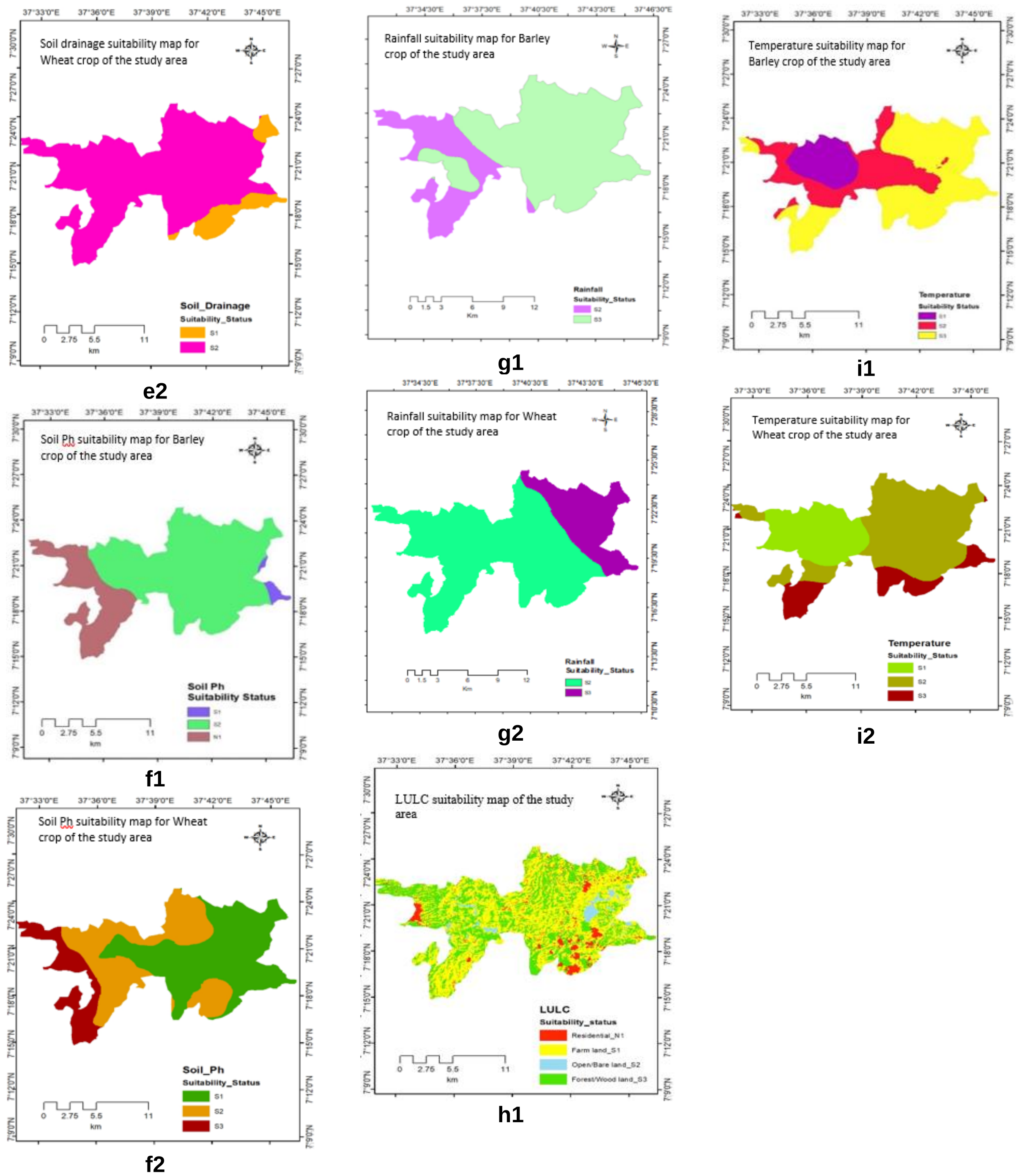



**Fig. 3. Factors suitability map for major crops (a) barley (b) wheat**

## 3.3 Overall Land Suitability Evaluation of Wheat and Barley Crops

Yield-influencing factors for important crops need to be assessed and the results obtained can be applied under scientific management practices for increased production of these crops through the appropriate use of similar soils found elsewhere in the same agroclimatic sub-regions (Khades et al, 1995). The overall suitability map for barley and wheat crops was created based on five layers of data: soil, topography, climate, LULC. (Table 3 and Fig. 4) shows the overall land suitability rating for barley and wheat crops. The unsuitable lands of the extreme west and south due to the residential area there.

Fig. 4 shows the map of the class of soil suitability for growing wheat and barley in the studied area. The results of the analysis showed that 115 km2 (51.7%) and 120.6 km2 (54.2%) of the study area were classified as highly suitable (S1) and 75.5 km2 (33.9%) as moderately suitable (S3) for barley grain and wheat crops were identified (Table 3 Fig. 4). [9] reported that 46% of the area in the Anjeni watershed is very suitable for barley and wheat crops. Girma et al. [1] reported that 61% of the land in the Jello watershed in the eastern Ethiopian highlands was unsuitable for wheat production and 6% was moderately suitable and 33% marginally suitable for wheat harvesting. In another study by Motuma et al. [40], in South Wello, 20.5% of the area was classified as moderately suitable and 79.5% as conditionally suitable for wheat. In this case, 36.68 ha (7.75%) of the land was assessed as conditionally suitable and less than 1% as unsuitable for wheat production.

On the other hand, the moderate and low suitability classes showed that the watershed is highly constrained in terms of various assessed factors such as elevation, slope, soil pH, soil OC, soil depth, temperature and LULC [39]. Therefore, the main limiting factors for wheat and barley crops identified in the study area were soil depth, texture, temperature and slope, and risk of erosion (Table 3). Only 3% of the land in Awulaelo district of Tigray is considered very suitable for wheat cultivation [15]. Hailu et al. (2015) estimated that 9.93% of the study area is marginally suitable, 51.39% of the study area was permanently unsuitable, and 38.68% is currently suitable for both wheat and barley production in the Kabe watershed in the South Zone Wello were unsuitable. Related to this study, Yohannes and Soromessa [41] reported that the grades were very suitable (0.70%), moderately suitable (91.07%), not very suitable (7.47%) and unsuitable land (0.76%) for barley production of 473.26 ha to the Andit Tid watershed. Similarly (Gizachew, 2015; Nahusenay & Kibebew, [42]) reported different class percentages of suitability for barley and wheat. Factors such as slope, temperature, soil texture, OC and soil PH have been mentioned for differences in the suitability of these plants in different areas (Girmay et al., 2018; Muhaimeed & Jaf, [43].

**Table 3. Land Suitability Area for barley and wheat crops cultivation**

| Suitability class | Barley | | | Wheat | | |
|---|---|---|---|---|---|---|
| | Area in (km2) | Area in (ha) | Area in (%) | Area in (km2) | Area in (ha) | Area in (%) |
| High suitable | 115 | 11531.75 | 51.7 | 120.6 | 12259 | 54.2 |
| Suitable | 18.3 | 1834.83 | 8.22 | 14.6 | 1459.5 | 6.7 |
| Moderate suitable | 75.5 | 7550.2 | 33.94 | 75.5 | 7550.2 | 33.94 |
| Not suitable | 13.64 | 1364.04 | 6.13 | 11.66 | 1166 | 5.2 |
| Permanently Not suitable | - | - | - | -- | -- | -- |
| Total | 222.45 | 22245 | 100 | 222.45 | 22245 | 100 |

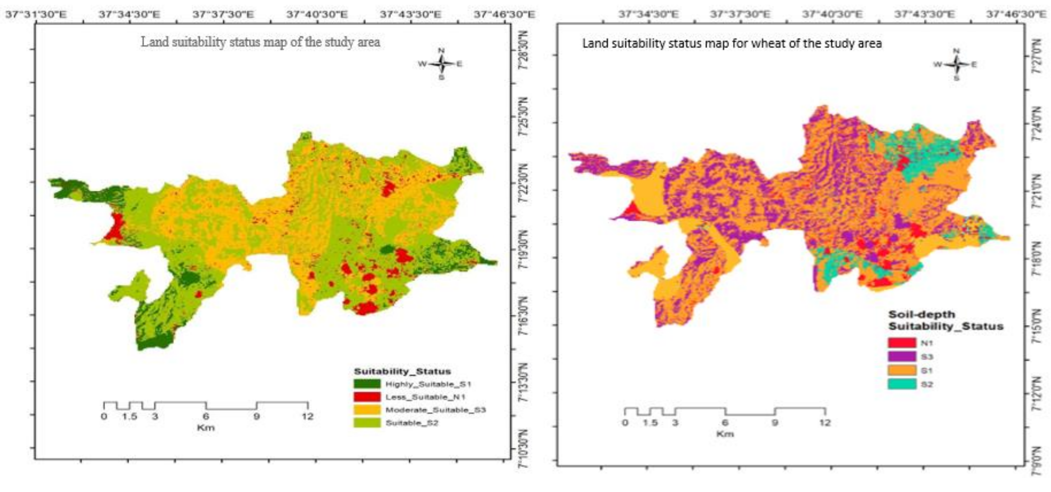



**Fig. 4. Land Suitability Area for barley and wheat crops cultivation**

The area's high suitability in all of the above factors is due to favorable soil characteristics, good elevation and slope of topography, favorable climate and appropriate existing cultivated land cover. The largest area in the suitable and moderately suitable for cultivation category has moderately steep slopes with moderate soil depth and less acidic soil reaction, good soil structure, better rainfall and favorable temperatures, and less erosion activity [44-53].

## 4. CONCLUSION AND FORWARDS

The study also incorporates topographical characteristics, soil physical and chemical characteristics, climatic factors, and existing land use land cover to assess the suitability of the land. At the end of the assessment, it was calculated that more than fifty percent of the study area was mostly very suitable for barley and wheat production. Only 13.64 km2 (6.13%) and 11.6 km2 (5.2%) of the study area were currently not suitable for growing barley or wheat. In any case, the problems of low production are caused by residential areas, geomorphological features such as very high elevations, a high degree of slope, lower soil moisture, the presence of bare rock and poor availability of the irrigation system.

Most of the poorly suited land, with severe limiting factors such as soil depth, texture, slope, temperature and erosion hazards, is located in the lower part of the watershed and is dominated by current agricultural land. This indicates that there is a mismatch between land use and suitability classes (requirement), which will deteriorate if current resource management practices continue without improvement. It is recommended to modify the current land use pattern according to its suitability classes and to plan land management measures accordingly [54-63].

In order to achieve successful land management, the introduction of alternative income generation mechanisms could help the poor farmers who have been completely dependent on fragile land for many years. Based on the prevailing factors, the local governments, agricultural experts and other stakeholders operating in the district should carry out biological and physical land remediation practices to improve the current crop productivity and production volume. The combination of scientific and local knowledge in soil suitability assessment based on GIS technology and weighted overlay methods has also proven itself as an assessment approach for soil suitability for intensive agriculture. Therefore, details and assessments, and studies should also be applied in other districts for other cultures that have better requirements.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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