GIS assisted suitability analysis for wheat and barley crops through AHP approach at Yikalo sub-watershed, Ethiopia

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Endalkachew Fekadu¹* and Ajanaw Negese¹

Abstract: Land suitability analysis is a fundamental system to identify the natural resource potentials and limitations of a given area that could help to provide decisions on the farming. Thus, for sustainable management of the land, suitability analysis for wheat and barley production was done on a watershed basis at Lay-Gayint District. The most important climatic, topographic and soil parameters were selected. Each parameter was subjected for pair-wise comparison following Analytical Hierarchy Process (AHP). The suitability of each factor for wheat and barley was generated and the overall suitability of the land was developed using weighted overlay tool of GIS software. The final output map showed that 83.21% (1945.17 ha) of the study area is moderately suitable, and 16.79% (392.52 ha) was marginally suitable for wheat cultivation. Likewise, it was observed that 86.14% (2013.61 ha) and 13.86% (324.08 ha) of the watershed was moderately and marginally suitable, respectively, for barley production. Soil pH, AWC, TN, and available
P were identified as the principal limiting factors. Integration of AHP with GIS was observed as a strong tool for suitability classification in a watershed.

**Keywords:** suitability; AHP; wheat; barley; GIS

1. **Introduction**

Ethiopia is a land of diversified agroecological areas that is favorable to produce different crops to feed the ever-increasing population. Despite this potential, Ethiopian agriculture has remained underdeveloped because of drought, poor economic base, low level of input use, limited application of technologies.

Ethiopian highlands have been severely degraded due to long years of cultivation, erosion, nutrient depletion, and soil acidity. As a result, the production and productivity of crops in a given land is getting low that led large numbers of households to rely on food aid to cover part of their household food gaps, even in normal years. Population increase in these areas will put additional pressure on the remaining natural resource base.

One of the critical challenges in these degraded areas is the mismatch of crops to land use requirements to insure reliable food supply. Thus, arable lands need to be evaluated for current and future agricultural uses. The sustained land use planning, therefore, involves the decision of land use so that available resources are put into use according to the assessed potentiality (Dula, 2010).

Land evaluation is a complex process involving multiple decisions that may relate to biophysical, socio-economic, and institutional/organizational aspects (Ali & Mohammad, 2011). Land suitability assessment measures the quality of land for a particular use. Land evaluation is a basic tool to identify the natural resource potentials and limitations that could provide alternative options to sustainable land use planning more efficiently (Qureshi et al., 2018). These will in turn, help decision makers such as land users, land-use planners, and agricultural organizations to develop a crop management which can overcome such constraints, and increase productivity (Rabia, 2012).

Physical land suitability focuses on the permanent aspects of suitability such as climate, landform, and soil qualities (Mathewos et al., 2018). According to Food and Agricultural Organizations (FAO), the standard technique to evaluate land takes in to account most relevant climate, soil requirements, and land terrains (including soil physical properties, soil fertility and chemical properties, soil salinity and alkalinity, topography, erosion hazard, and wetness) for each crop (Sys et al., 1991, 1993).

Land suitability analysis seeks the integration of multiple factors to come up with wise and acceptable decisions. Therefore, it becomes crucial to utilize analytical models and systems that could analyze these factors. The integration of Geographic Information Systems (GIS), Multi-Criteria Evaluation using Analytical Hierarchy Process (AHP) could provide a superior database and guide map for decision makers considering cropland in order to achieve better agricultural production (Singha & Swain, 2016).

Highlands in Lay-Gayint district receive a high amount of rainfall that allows the production of various cereals and pulses such as wheat, barley, triticale, and faba bean. However, due to soil nutrient depletion coupled with unpredictable climate variability, the productivity of crops is below the national and world average. Moreover, the ever-increasing population in the area demand for additional lands that is under degradation.
Agricultural activities in the watershed without adequate management practices, such as replenishment of nutrients using organic matter applications, rainwater harvesting, soil loss reducing measures further worsen the degradation of farmlands (Hailu, 2008). Farmers continue growing crops without having scientific-based information about the land use requirements, and use potentials. In the study area, there is no study about the resource potential of the area that could match with crop requirements. Hence, undertaking suitability analysis of the land for major crops will help to invest the scarce resource of smallholders on the best alternative agricultural commodity. This will, in turn, optimize the land resource potential in line with crop requirements. The objective of this particular study is to determine land suitability class for wheat and barley production in Yikalo sub-watershed at Lay-Gayint district.

2. Materials and methods

2.1. Description of the study area
The study was conducted in Yikalo sub-watershed of Lay-Gayint district, northwestern Ethiopia which covers an area of 2337.69 ha. Geographically, it is located between 11°43‘42"N and 11°46‘22"N latitude; and 38°14‘20"E and 38°19‘05"E longitude (Figure 1).

2.2. Agro-ecology and climate
Agro-ecologically, the district is divided into four elevation and temperature zones, namely: lowland (kolla) (12.5%), midland (woina-dega) (39.42%), highland (dega) (45.39%), and wurch (very cold or alpine) (2.71%). Based on the Ethiopian Ministry of Agriculture (Ministry of Agriculture [MoA], 1998) agro-ecological zonation, the watershed is found in the highland (dega), and wurch (very cold or alpine). According to climate data (1997–2016) obtained from the Ethiopian National Meteorological Service Agency (Ethiopian National Meteorological Service Agency [ENMSA], 2017), Lay-Gayint district receives a mean annual rainfall of 1020 mm. The main rainy season occurs between June and September, while the small rainy season extends between March and May. The mean minimum and maximum air temperatures of the district are 6.9 and 21.9 °C, respectively (Figure 2).
2.3. Topography, land use, and soils
The topography of the district is mostly characterized by a chain of mountains, hills, and valleys extending from Tekeze Gorge (1,500 m a.s.l.) to the summit of Guna Mountain (4,235 m a.s.l.). It is characterized by plain (10%), undulating (70%), mountainous (15%), and gorge and valley (5%) topographic features. The elevation in the watershed ranges from 2,967 to 3,902 m a.s.l (Addisu & Menberu, 2015). The major land-use patterns of the study area comprise cultivated land (44%), grazing land (14%), forest/bushland (5%), waterbody (2%), infrastructure and settlement (6%), and unproductive land (29%) (Addisu & Menberu, 2015). Hyperdystric Cambisols (Humic), Haplic Alisols (Humic), Cambic Umbrisols (Colluvic), Haplic Luvisols (Epidystric), and Pellic Vertisols (Mesotrophic) were the identified soil types in Yikalo sub-watershed of Lay-Gayint district (Endalkachew et al., 2018).

2.4. Farming system and vegetation cover
Mixed crop-livestock agriculture is the major farming system of farmers in the highlands of Ethiopia in general, and in the study district in particular. Crop production in most areas of the district is rain fall dependent. Major crops grown in the district include *Triticum aestivum* L., *Eragrostis tef* (Zuccagni), *Zea mays* L., *Sorghum bicolor* L., *Hordeum vulgare* L., *Cicer arietinum* L., *Vicia faba* L., *Phaseolus vulgaris* L., and *Solanum tuberosum* L. The area is covered with scattered vegetation of bushes and grasses. *Juniperus procera, Olea africana* and *Hajenia abyssinica* are the dominant tree species found around the churches while limited Eucalyptus plantation is observed in the sloppy lands.

Agriculture being the leading economic sector of the district is not productive even to satisfy the food need of the people. Among others, the decline in soil fertility, soil erosion, erratic rainfall, emerging diseases and insects together with poor natural resource and land use management exposed the area as one of the hot spot for food and nutrition insecure areas of the region.

2.5. Data collection
Slope and altitude were derived from the 30 m spatial resolution digital elevation model ASTE GDEM obtained from Aster Global Digital Elevation Map (http://gdex.cr.usgs.gov/gdex/) by using Spatial Analyst Tool in ArcGIS environment. Climate data was obtained from the Ethiopian National Meteorological Service Agency (Ethiopian National Meteorological Service Agency [ENMSA], 2017). The data for physical and chemical soil properties were taken from the previous soil characterization study of the watershed reported by Endalkachew et al. (2018). The soils were studied based on slope positions where a representative soil profile was opened in the upper slope, middle slope, lower slope and toe slope positions along the landscape.

2.6. Criteria for weight estimation
The selected climatic, topographic, and soil factors were subjected to pairwise comparison based on expertise view from long-term experience, and processed following AHP for decision-making by using IDRISI software. Based on the relative importance, values ranging from 1 to 9 were assigned to each
factor to construct AHP matrix as described by Saaty (1980). According to the scale 1 refers to equally important and 9 refers to extremely important. The matrix is then formed (Table 1) to calculate priority weights from the pairwise comparison matrix and eigenvector values as shown in the following formula.

$$\text{eigen vector } = \text{Aij} = \frac{\sum_{i=1}^{n} (w1/w1+w1/w2+\ldots+w1/wn)^1/n}{\sum_{i=1}^{n} (w1/w1+w1/w2+\ldots+w1/wn)^1/n}$$  \hspace{1cm} (1)

where w1 is the sum of row for pairwise comparison and n is the size of matrix.

The consistency ratio (CR) was calculated to verify the consistency of comparison as:

$$\text{CI} = \frac{\lambda_{\text{max}} - n}{n - 1}$$  \hspace{1cm} (2)

where CI is the consistency index, n is the number of elements being compared in the matrix, $\lambda_{\text{max}}$ is the largest or principal eigenvalue of the matrix

$$\text{CR} = \frac{\text{CI}}{\text{RI}}$$  \hspace{1cm} (3)

where CR is the consistency ratio, CI is the consistency index, RI is the random index

If the CR ≤ 0.10, it means that the pairwise comparison matrix has an acceptable consistency. Otherwise, If CR ≥ 0.10 it means that pairwise consistency has inadequate consistency (Bozdag et al., 2016). Following the criteria weight, the standardized criteria were aggregated by using weighted overlay, and suitability maps were then produced according to:

$$S = \sum_{i=0}^{n} (WiXi)$$  \hspace{1cm} (4)

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

2.7. Physical land suitability procedure

The land suitability procedure followed the guideline of Food and Agricultural organizations [FAO], (1976), where qualities/characteristics are matched with each specific crop requirements in order to find the suitability class of land for the same crop. Then, land characteristics such as climate, erosion hazard, wetness, soil physical properties, soil fertility and chemical properties, and topographical data were compared with wheat and barley crops requirements (Table A1) as described by Sys et al. (1991, 1993). The raster format in GIS environment was employed to analyze land suitability. The model is more appropriate due to grid cell-based structure that simplifies the delineation of suitable areas. Besides, raster data assists to carry out a weighted overlay on several layers. Raster suitability maps for each parameter for wheat and barley crops were developed by interpolation with a pixel size of 30 m, then reclassified to a common suitability levels using ArcGIS 10.4 software for the weighted overlay to drive final suitability maps for the crops.

3. Results and discussion

3.1. Pair-wise comparison and parametric weights

Fourteen parameters selected for the physical suitability of wheat and barley were compared following AHP, and the results are presented (Tables 1-3). From the soil parameters, the highest weights were obtained for soil pH (15.3%) and texture (13.9%) while the lowest was soil bulk density (3.1%). Topographically, slope (8.3%) followed by elevation were dominant factors to contribute the overall weights. The contribution of rainfall (8.3%) was equally important to affect
| Criteria | Rainfall | Temperature | Slope | Elevation | Soil Depth | Texture | Bulk Density | AWC | pH | OC | TN | Av. P | CEC | PBS | Sum |
|----------|----------|-------------|-------|-----------|------------|---------|--------------|-----|----|----|----|------|-----|-----|-----|
| Rainfall | 1        | 2.00        | 1.00  | 2.00      | 2.00       | 2.00    | 2.00         | 2.00| 2.00| 2.00| 2.00| 2.00 | 2.00 | 2.00| 12.50|
| Temperature | 0.50 | 1.00        | 1.00  | 0.50      | 0.50       | 1.00    | 0.50         | 0.50| 0.50| 0.50| 0.50| 0.50 | 0.50 | 0.50| 18.17|
| Slope    | 0.50     | 2.00        | 2.00  | 0.50      | 0.50       | 2.00    | 2.00         | 2.00| 2.00| 2.00| 2.00| 2.00 | 2.00 | 2.00| 14.00|
| Elevation| 1.00     | 2.00        | 2.00  | 0.50      | 0.50       | 2.00    | 2.00         | 2.00| 2.00| 2.00| 2.00| 2.00 | 2.00 | 2.00| 17.67|
| Soil Depth| 0.50 | 2.00        | 2.00  | 1.00      | 1.00       | 2.00    | 2.00         | 2.00| 2.00| 2.00| 2.00| 2.00 | 2.00 | 2.00| 15.50|
| Texture  | 0.50     | 1.00        | 1.00  | 0.50      | 0.50       | 2.00    | 2.00         | 2.00| 2.00| 2.00| 2.00| 2.00 | 2.00 | 2.00| 6.58 |
| Bulk Density | 0.50 | 1.00        | 1.00  | 0.50      | 0.50       | 2.00    | 2.00         | 2.00| 2.00| 2.00| 2.00| 2.00 | 2.00 | 2.00| 31.50|
| AWC      | 2.00     | 4.00        | 4.00  | 2.00      | 2.00       | 2.00    | 2.00         | 2.00| 2.00| 2.00| 2.00| 2.00 | 2.00 | 2.00| 21.83|
| pH       | 2.00     | 1.00        | 1.00  | 0.50      | 0.50       | 2.00    | 2.00         | 2.00| 2.00| 2.00| 2.00| 2.00 | 2.00 | 2.00| 6.28 |
| OC       | 0.50     | 0.50        | 0.50  | 0.33      | 0.33       | 1.00    | 1.00         | 0.33| 0.33| 0.33| 0.33| 0.33 | 0.33 | 0.33| 29.50|
| TN       | 2.00     | 1.00        | 1.00  | 0.50      | 0.50       | 2.00    | 2.00         | 2.00| 2.00| 2.00| 2.00| 2.00 | 2.00 | 2.00| 29.00|
| Av. P    | 0.50     | 0.50        | 0.50  | 0.33      | 0.33       | 1.00    | 1.00         | 0.33| 0.33| 0.33| 0.33| 0.33 | 0.33 | 0.33| 19.08|
| CEC      | 0.50     | 0.50        | 0.50  | 0.33      | 0.33       | 1.00    | 1.00         | 0.33| 0.33| 0.33| 0.33| 0.33 | 0.33 | 0.33| 10.00|
| PBS      | 0.50     | 0.33        | 0.33  | 0.33      | 0.33       | 1.00    | 1.00         | 1.00| 1.00| 1.00| 1.00| 1.00 | 1.00 | 1.00| 20.50|
| Sum      | 11.50    | 18.17       | 14.00 | 7.15      | 7.15       | 21.83   | 21.83        | 7.15| 7.15| 7.15| 7.15| 7.15 | 7.15 | 7.15| 7.15 |
| Criteria | Rainfall | Temperature | Slope | Elevation | Soil Depth | Texture | Bulk Density | AWC | pH | OC | TN | Av. P | CEC | PBS | Sum | Criteria Weight |
|----------|----------|-------------|-------|-----------|------------|---------|--------------|-----|----|----|----|-------|-----|-----|-----|-----------------|
| Rainfall | 0.080    | 0.110       | 0.143 | 0.057     | 0.129      | 0.076   | 0.063         | 0.092| 0.080| 0.068| 0.028| 0.105 | 0.069| 0.068| 1.167| 0.083           |
| Temperature | 0.040 | 0.055       | 0.036 | 0.057     | 0.032      | 0.051   | 0.063         | 0.092| 0.040| 0.068| 0.113| 0.157 | 0.069| 0.102| 0.974| 0.070           |
| Slope    | 0.040    | 0.110       | 0.071 | 0.113     | 0.129      | 0.076   | 0.063         | 0.092| 0.040| 0.068| 0.113| 0.105 | 0.069| 0.068| 1.157| 0.083           |
| Elevation | 0.080 | 0.055       | 0.036 | 0.057     | 0.032      | 0.076   | 0.095         | 0.183| 0.053| 0.068| 0.028| 0.026 | 0.138| 0.102| 1.029| 0.073           |
| Soil Depth | 0.040 | 0.110       | 0.036 | 0.113     | 0.065      | 0.051   | 0.063         | 0.092| 0.080| 0.034| 0.057| 0.105 | 0.069| 0.068| 0.981| 0.070           |
| Texture  | 0.160    | 0.165       | 0.143 | 0.113     | 0.194      | 0.152   | 0.095         | 0.183| 0.159| 0.102| 0.170| 0.105 | 0.103| 0.102| 1.946| 0.139           |
| Bulk Density | 0.040 | 0.028       | 0.036 | 0.019     | 0.032      | 0.051   | 0.032         | 0.023| 0.032| 0.017| 0.019| 0.026 | 0.017| 0.068| 0.439| 0.031           |
| AWC      | 0.040    | 0.028       | 0.036 | 0.014     | 0.032      | 0.038   | 0.063         | 0.046| 0.080| 0.102| 0.113| 0.105 | 0.069| 0.068| 0.833| 0.059           |
| pH       | 0.160    | 0.220       | 0.286 | 0.170     | 0.129      | 0.152   | 0.159         | 0.092| 0.159| 0.136| 0.170| 0.105 | 0.103| 0.102| 2.141| 0.153           |
| OC       | 0.040    | 0.028       | 0.036 | 0.028     | 0.065      | 0.051   | 0.063         | 0.015| 0.040| 0.034| 0.019| 0.026 | 0.017| 0.017| 0.478| 0.034           |
| TN       | 0.160    | 0.028       | 0.036 | 0.113     | 0.065      | 0.051   | 0.095         | 0.023| 0.053| 0.102| 0.057| 0.052 | 0.069| 0.068| 0.970| 0.069           |
| Av. P    | 0.040    | 0.018       | 0.036 | 0.113     | 0.032      | 0.076   | 0.063         | 0.023| 0.080| 0.068| 0.057| 0.138 | 0.102| 0.898| 0.064|                |
| CEC      | 0.040    | 0.028       | 0.036 | 0.014     | 0.032      | 0.051   | 0.063         | 0.023| 0.053| 0.068| 0.028| 0.013 | 0.034| 0.034| 0.517| 0.037           |
| PBS      | 0.040    | 0.018       | 0.036 | 0.019     | 0.032      | 0.051   | 0.016         | 0.023| 0.053| 0.068| 0.028| 0.017 | 0.034| 0.034| 0.470| 0.034           |
the production of wheat and barley. The CR of pair-wise matrix comparison for the evaluated criteria of this study was 0.069 indicating that the comparisons were consistent.

### 3.2. Climatic suitability classes

Yikalo watershed receives 1020 mm mean annual rainfall. The cropping cycles for wheat and barley occurs from mid-June to September in which the area receives a high amount of rainfall (Figure 2). As per Sys et al. (1993), the highest production of wheat and barley is expected when the rainfall is 650–1100 mm (Table 4). Hence, the amount of rainfall in the area is highly suitable to allow the growth and development of the crops (Figure 3(a,b)). Wheat and barley have temperature preference ranging from 15°C to 20°C C and 8–12°C, respectively, for maximum production and productivity (Table A1). The long-term average temperature data showed 43.77% of the watershed was highly suitable for wheat whereas, 29.50% of the watershed was highly suitable for barley production. The remaining 70.50% of the area was moderately suitable in temperature to allow the growth of barley (Table 4). Barely grows from June to September when the season is cooler and thus, could cover in all cultivated lands of the watershed.

### 3.3. Topographic suitability classes

Slope and elevation were selected among the topographic elements affecting cropland suitability. Slope influences the movement of materials along the land surface where sediments are detached from the upper part of the catchment and deposited in the toes slope and foot slope areas. As a result soil depth, drainage, and nutrient availability, are reduced and the rate of soil formation retarded with increasing steepness (Bozdag et al., 2016).

Slope in the watershed ranges from 0% to 80%. Wheat and barley prefer slopes less than 8% for the highest productivity (Sys et al., 1993). Based on the analysis of slopes derived from digital elevation model, only 14% of the watershed was highly suitable for wheat and barley production. Moderately and marginally suitable slope classes, each constitute 40.33% and 31.30% for wheat while 32.64% and 26.38% for barley production (Table 4 and Figure 4(a,b)).

Considering elevation in the watershed, it varies from 2,967 to 3,902 m a.s.l. 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. Accordingly, 1.96%, 59.01%, and 39.03% of the area were moderately suitable, marginally suitable, and unsuitable, respectively, to produce wheat. In the same way, 1.94%, 59.01%, 36.41%, and 2.64% of the watershed were classified as highly suitable, moderately suitable, marginally

| Criteria                | Weight | Percent |
|-------------------------|--------|---------|
| Rainfall (mm)           | 0.083  | 8.3     |
| Temperature (°C)        | 0.070  | 7.0     |
| Slope (%)               | 0.083  | 8.3     |
| Elevation (m)           | 0.073  | 7.3     |
| Soil Depth (cm)         | 0.070  | 7.0     |
| Texture (% clay)        | 0.139  | 13.9    |
| Bulk Density (g cm⁻³)   | 0.031  | 3.1     |
| AWC (mm m⁻¹)            | 0.059  | 5.9     |
| pH                      | 0.153  | 15.3    |
| OC (%)                  | 0.034  | 3.4     |
| TN (%)                  | 0.069  | 6.9     |
| Av. P (ppm)             | 0.064  | 6.4     |
| CEC (cmol, kg⁻¹)        | 0.037  | 3.7     |
| PBS (%)                 | 0.034  | 3.4     |
### Table 4. Parameter suitability class and area coverage

| Criteria   | Suitability Class Level | Wheat |   | Barely |   |
|------------|------------------------|-------|---|--------|---|
|            |                        | Area (ha) | Percent | Area (ha) | Percent |
| Temperature| S1                     | 1023.25 | 43.77 | 689.62 | 29.50 |
|            | S2                     | 624.87  | 26.73 | 1648.07 | 70.50 |
|            | S3                     | 375.08  | 16.04 | -      | -     |
|            | N1                     | 314.49  | 13.45 | -      | -     |
|            | N2                     | -       | -     | -      | -     |
|            | Total                  | 2337.69 | 100.00 | 2337.69 | 100.00 |
| Rainfall   | S1                     | 2337.69 | 100.00 | 2337.69 | 100.00 |
|            | S2                     | -       | -     | -      | -     |
|            | S3                     | -       | -     | -      | -     |
|            | N1                     | -       | -     | -      | -     |
|            | N2                     | -       | -     | -      | -     |
|            | Total                  | 2337.69 | 100.00 | 2337.69 | 100.00 |
| Slope      | S1                     | 327.33  | 14.00 | 329.23 | 14.08 |
|            | S2                     | 942.88  | 40.33 | 762.92 | 32.64 |
|            | S3                     | 731.68  | 31.30 | 616.65 | 26.38 |
|            | N1                     | 143.12  | 6.12  | 285.38 | 12.21 |
|            | N2                     | 192.68  | 8.24  | 343.52 | 14.69 |
|            | Total                  | 2337.69 | 100.00 | 2337.69 | 100.00 |
| Elevation  | S1                     | -       | -     | 45.27  | 1.94  |
|            | S2                     | 45.77   | 1.96  | 1379.56 | 59.01 |
|            | S3                     | 1379.56 | 59.01 | 851.22 | 36.41 |
|            | N1                     | 912.36  | 39.03 | 61.64  | 2.64  |
|            | N2                     | -       | -     | -      | -     |
|            | Total                  | 2337.69 | 100.00 | 2337.69 | 100.00 |
| Soil depth | S1                     | 2152.33 | 92.07 | 2152.33 | 92.07 |
|            | S2                     | 185.36  | 7.93  | 185.36 | 7.93  |
|            | S3                     | -       | -     | -      | -     |
|            | N1                     | -       | -     | -      | -     |
|            | N2                     | -       | -     | -      | -     |
|            | Total                  | 2337.69 | 100.00 | 2337.69 | 100.00 |
| Texture    | S1                     | 1171.08 | 50.10 | 1171.08 | 50.10 |
|            | S2                     | 786.36  | 33.64 | 786.36 | 33.64 |
|            | S3                     | 186.76  | 7.99  | 186.76 | 7.99  |
|            | N1                     | 193.49  | 8.28  | 193.49 | 8.28  |
|            | N2                     | -       | -     | -      | -     |
|            | Total                  | 2337.69 | 100.00 | 2337.69 | 100.00 |
| Bulk density| S1                   | 861.63  | 36.86 | 861.63 | 36.86 |
|            | S2                     | 1476.06 | 63.15 | 1476.06 | 63.14 |
|            | S3                     | -       | -     | -      | -     |
|            | N1                     | -       | -     | -      | -     |
|            | N2                     | -       | -     | -      | -     |
|            | Total                  | 2337.69 | 100.00 | 2337.69 | 100.00 |

(Continued)
| Criteria                          | Suitability Class Level | Wheat |          |          |          | Barely |          |          |          |
|----------------------------------|-------------------------|-------|----------|----------|----------|--------|----------|----------|----------|
|                                  |                         | Area (ha) | Percent | Area (ha) | Percent |
| AWC                              | S1                      | -       | -        | -        | -        |        | S2       | 1141.16  | 48.82    |
|                                  | S2                      | 1141.16 | 48.82   | 1141.16  | 48.82    |        | S3       | 1196.53  | 51.18    |
|                                  | S3                      | 1196.53 | 51.18   | 1196.53  | 51.18    |        | N1       | -        | -        |
|                                  | N1                      | -       | -        | -        | -        |        | N2       | -        | -        |
|                                  | Total                   | 2337.69 | 100.00  | 2337.69  | 100.00   |        |          |          |          |
| pH                               | S1                      | -       | -        | -        | -        |        | S2       | 736.21   | 31.49    |
|                                  | S2                      | 736.21  | 31.49   | 1074.72  | 45.97    |        | S3       | 1363.07  | 58.31    |
|                                  | S3                      | 1363.07 | 58.31   | 1074.72  | 45.97    |        | N1       | 238.41   | 10.20    |
|                                  | N1                      | 238.41  | 10.20   | 1262.97  | 54.03    |        | N2       | -        | -        |
|                                  | Total                   | 2337.69 | 100.00  | 2337.69  | 100.00   |        |          |          |          |
| OC                               | S1                      | 815.67  | 34.89   | 1207.27  | 51.64    |        | S2       | 761.88   | 32.59    |
|                                  | S2                      | 761.88  | 32.59   | 695.35   | 29.75    |        | S3       | 648.48   | 27.74    |
|                                  | S3                      | 648.48  | 27.74   | 407.68   | 17.64    |        | N1       | 111.66   | 4.78     |
|                                  | N1                      | 111.66  | 4.78    | 27.39    | 1.17     |        | N2       | -        | -        |
|                                  | Total                   | 2337.69 | 100.00  | 2337.69  | 100.00   |        |          |          |          |
| TN                               | S1                      | 391.69  | 16.76   | 391.69   | 16.76    |        | S2       | 587.03   | 25.11    |
|                                  | S2                      | 587.03  | 25.11   | 587.03   | 25.11    |        | S3       | 909.63   | 38.91    |
|                                  | S3                      | 909.63  | 38.91   | 909.63   | 38.91    |        | N1       | 449.34   | 19.22    |
|                                  | N1                      | 449.34  | 19.22   | 449.34   | 19.22    |        | N2       | -        | -        |
|                                  | Total                   | 2337.69 | 100.00  | 2337.69  | 100.00   |        |          |          |          |
| Available phosphorous            | S1                      | 16.03   | 0.69    | 16.03    | 0.69     |        | S2       | 160.66   | 6.87     |
|                                  | S2                      | 160.66  | 6.87    | 160.66   | 6.87     |        | S3       | 214.50   | 9.18     |
|                                  | S3                      | 214.50  | 9.18    | 214.50   | 9.18     |        | N1       | 1946.50  | 83.27    |
|                                  | N1                      | 1946.50 | 83.27   | 1946.50  | 83.27    |        | N2       | -        | -        |
|                                  | Total                   | 2337.69 | 100.00  | 2337.69  | 100.00   |        |          |          |          |
| CEC                              | S1                      | 2337.69 | 100.00  | 2337.69  | 100.00   |        | S2       | -        | -        |
|                                  | S2                      | -       | -        | -        | -        |        | S3       | -        | -        |
|                                  | S3                      | -       | -        | -        | -        |        | N1       | -        | -        |
|                                  | N1                      | -       | -        | -        | -        |        | N2       | -        | -        |
|                                  | Total                   | 2337.69 | 100.00  | 2337.69  | 100.00   |        |          |          |          |
| PBS                              | S1                      | 490.34  | 20.98   | 861.63   | 36.86    |        | S2       | 1499.49  | 64.14    |
|                                  | S2                      | 1499.49 | 64.14   | 1476.06  | 63.14    |        | S3       | 347.86   | 14.88    |
|                                  | S3                      | 347.86  | 14.88   | -        | -        |        | N1       | -        | -        |
|                                  | N1                      | -       | -        | -        | -        |        | N2       | -        | -        |
|                                  | Total                   | 2337.69 | 100.00  | 2337.69  | 100.00   |        |          |          |          |
suitable, and unsuitable, respectively, to produce barley (Table 4 and Figure 5(a,b)). As indicated in the result, topographic variables were found to be the major limiting factors for the production of cereals such as wheat and barley.

3.4. Soil suitability classes
Soil properties are fundamental factors to determine the suitability of land for a given crop growth. Based on soil characterization data (Endalkachew et al., 2018), the watershed was found to have Hyperdystric Cambisols (Humic), Haplic Alisols (Humic), Cambic Umbrisols (Colluvic), Haplic Luvisols (Epidystric), and Pellic Vertisols (Mesotrophic) soil types. Soil depth was varied from moderately deep to very deep. The depth of the soil in all profiles was not limiting to the growth of cereals. Silt loam, clay loam, and clay were the identified soil textural classes. The soils differed in reaction from very strongly acid to slightly acid. The soils had medium to high total N, very low to high OC, low to high available P, high to very high CEC, medium to very high exchangeable Ca, low to very high exchangeable Mg, very low to low exchangeable K.

In matching the requirements of wheat and barley to soil characteristics of the watershed, 92% of the area was highly suitable in soil depth (Table 4 and Figure 5(a,b)). As indicated in the result, topographic variables were found to be the major limiting factors for the production of cereals such as wheat and barley.

Figure 3. (a) Temperature suitability class for wheat. (b) Temperature suitability class for barely.

Figure 4. (a) Slope suitability class map for wheat (b) Slope suitability class map for barley.
Since the agricultural activity has been practiced with low external input addition, continues crop removal, and leaching due to high rainfall, most of the essential nutrients are depleted.

3.5. Overall land suitability for wheat and barley

The suitability maps for wheat and barley production for each parameter were prepared by using ArcGIS 10.4 software after the parameters are weighted using AHP. The maps for each parameters
Figure 8. Available P suitability class for wheat and barely.

Figure 9. Total nitrogen suitability class for wheat and barely.

Figure 10. PBS suitability class for wheat and barely.
Figure 11. CEC suitability class for wheat and barely.

Figure 12. Bulk density suitability class for wheat and barely.

Figure 13. AWC suitability class for wheat and barely.
were developed by using Ordinary Kriging interpolation method with 30 m pixel size/spatial resolution which then were reclassified based on FAO standard land suitability classification into S1 for highly suitable, S2 for moderately suitable, S3 for marginally suitable, N1 for currently not
suitable, and N2 for permanently not suitable classes. The reclassified raster maps were processed through a weighted overlay technique (multiplying each raster cells suitability value by its layer weight and totaling the values) to produce final suitability maps. The final land suitability map, resulting from a finally weighted overlay of elements of climate, topography, and soil properties, is shown in Figure 16(a,b).

According to the final map, the watershed was classified into two suitability classes, namely: moderately suitable, and marginally suitable for wheat and barley production. The classified map showed that 83.21% (1945.17 ha) of the study region is moderately suitable, and 16.79% (392.52 ha) was marginally suitable for wheat cultivation (Table 5 and Figure 16). Likewise, it was observed that 86.14% (2013.61 ha) and 13.86% (324.08 ha) of the watershed was moderately and marginally suitable, respectively, for barley production (Table 5 and Figure 16).

The moderately and marginally suitability classes indicated that the watershed has severe limitations in terms of different factors evaluated such as elevation, soil pH, AWC, TN, and available P. Since the watershed is part and parcel of one of the bigger mountains in Ethiopia, the elevation was higher and beyond the requirements of the crops. Moreover, the acidity of the soils made the area less suitable for growing these crops. Soil acidity affects root development due to aluminum toxicity. Acid soils decrease nutrient availability such as nitrogen, phosphorus, and potassium (Kisinyo et al., 2014). The availability of water was also identified as a limiting factor to increase wheat and barley production in the area.

Soil acidity could be managed through the integrated application of lime, organic materials (Fekadu et al., 2019) and selections of tolerant crop varieties (Matsumoto et al., 2017). Physical soil and water conservation structures such as half-moons and stone bunds, combined with an application of organic/inorganic sources of nutrients, are promising practices that could be widely used by smallholder farmers to maintain food production and secure farmers’ livelihoods, while contributing to ecosystem services (Zougmoré et al., 2014).

Related to this study, Yohannes and Soromessa (2018), reported that highly suitable (0.70%), moderately suitable (91.07%), marginally suitable (7.47%), and not suitable rock (0.76%) classes for barley crop production from 473.26 ha in Andit-Tid watershed. Similarly, Dula (2010) analyzed land suitability for crops in Mojo watershed, upper awash sub-basin, Ethiopia and found that wheat production was very limited at highly suitable class in different soils. He reported 78.4%, 76.9%, and 91.0% were moderately suitable on Luvisols, Lithosols, and Vertisols. Only a very small parcel of the land (1.3%) was allocated for barely production with a highly suitability class in Kilte

| Overall Suitability | Class level       | Wheat Area (ha) | Wheat Percent | Barely Area (ha) | Barely Percent |
|---------------------|------------------|-----------------|---------------|------------------|---------------|
|                     | S1- Highly suitable | -               | -             | -                | -             |
|                     | S2- Moderately suitable | 1945.17         | 83.21         | 2013.61          | 86.14         |
|                     | S3- Marginally suitable | 392.52         | 16.79         | 324.08           | 13.86         |
|                     | N1- Currently not suitable | -               | -             | -                | -             |
|                     | N2- Permanently not suitable | -               | -             | -                | -             |
|                     | Total            | 2337.69         | 100           | 2337.69          | 100           |
Awulaelo district, Ethiopia (Robia, 2012). Other studies (Gizachew, 2015; Nahusenay & KibebeW, 2015) indicated different class percentages of suitability for barley and wheat. Factors such as slope, temperature, soil texture, OC, and soil pH were mentioned for variation in the suitability of these crops in different areas (Girmay et al., 2018; Muhaimeed & Jaf, 2016).

4. Conclusion
Under the prevailing farming practice, the productivity of cereals is limited to provide sufficient food to satisfy the ever-increasing population in the country. Thus, urgent land use planning and suitability analysis may help to use the land according to its potential. The present study considered climatic, topographic and soil characteristics in Yikalo sub-watershed at Lay-Gayint district to analyze the suitability of the land for wheat and barley production. The result showed the land was not entirely highly suitable for producing these crops. Most of the lands in the watershed were classified as moderately suitable for the production of barley and wheat. Several limiting factors such as soil availability of water, soil pH, OC, TN, and available P were identified. The implication is that these farmlands need appropriate management measures before they are getting out of production. Application of OM, fertilizers, lime, and soil and water conservation practices should be given due attention. On top of that research on developing varieties that could adapt the cooler temperature of the highlands should also be considered.

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Competing Interest
The authors declare no competing interests.

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Ethical Approval
This article does not contain any studies with human participants or animals performed by any of the authors.

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### Table A1. Land suitability classification for wheat and barley—criteria rating

| Criterion     | S1     | S2      | S3       | N1       | N2       | S1     | S2       | S3       | N1       | N2       |
|---------------|--------|---------|----------|----------|----------|--------|---------|----------|----------|----------|
| Temp.         | 15-20  | 12-15   | 10-12    | 8-10     | < 8, > 20| 8-12   | 12-18    | 18-24    | 28-28    | < 8, > 28|
| Rainfall      | 700-1000 | 1000-1250 | 1250-1500 | 1500-1750 | < 700, > 1750 | 650-1100 | 1100-1300 | 1300-1500 | -         | < 150, > 1500 |
| Elevation     | 2000-2600 | 1500-2000, 2600-3000 | 3000-3300 | < 1500, > 3300 | - | 2000-3000 | 1500-2000, 3000-3300 | 3300-3800 | < 1500, > 3800 | - |
| Slope         | < 8    | 8-18    | 18-30    | 30-35    | > 35     | 2000-3000 | 1500-2000, 3000-3300 | 3300-3800 | < 1500, > 3800 | - |
| Soil Depth    | > 100  | 75-100  | 50-75    | 25-50    | < 25     | > 100   | 75-100   | 50-75    | 25-50    | < 25     |
| Bulk Density. | < 1.2  | 1.2-1.4 | 1.4-1.6  | 1.6-1.8  | > 1.8    | < 1.2   | 1.2-1.4  | 1.4-1.6  | 1.6-1.8  | > 1.8    |
| Text. (clay)  | > 55   | 35-45   | 20-35    | 10-20    | < 10     | > 55    | 35-45    | 20-35    | 10-20    | < 10     |
| AWC           | > 200  | 100-200 | 50-100   | < 50     | -        | > 200   | 100-200  | 50-100   | < 50     | -        |
| pH            | 6.5-7.0, 7.0-7.5 | 5.6-6.5, 7.5-8.2 | 5.2-5.6, 8.3-8.5 | < 5.2, > 8.5 | - | 6.2-7.0, 6.2-8.2, 5.5-5.8, 8.2-8.5 | < 5.5, > 8.5 | - |
| TN            | > 0.2  | 0.15-0.2 | 0.1-0.15 | < 0.1    | -        | > 0.2   | 0.15-0.2 | 0.1-0.15 | < 0.1    | -        |
| OC            | 1.5-2.5 | 1.0-1.5 | 0.5-1.0  | < 0.5    | -        | 1.2-2.0 | 0.8-1.2  | 0.4-0.8  | < 0.4    | -        |
| Av.P          | > 10   | 5-10    | 3-5      | < 3      | -        | > 10    | 5-10     | 3-5      | < 3      | -        |
| CEC           | > 24   | 16-24   | 8-16     | < 8      | -        | > 24    | 16-24    | 8-16     | < 8      | -        |
| PBS           | > 50   | 35-50   | < 35     | -        | -        | > 50    | 35-50    | < 35     | -        | -        |

Appendix

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