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Research Article

Characterization and Classification of Soils and Land Suitability Evaluation for the Production of Major Crops at Anzecha Watershed, Gurage Zone, Ethiopia

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The study was conducted at Anzecha watershed in Gurage Zone, Ethiopia, to characterize and classify the soils and to evaluate the physical land suitability of the area for the production of major crops (maize, teff, and wheat). The soils were classified based on World Reference Base for soil resource. The physical land suitability was made following FAO guideline using maximum limitation method. Four profiles were opened along toposequence and designate as upper, middle, lower, and toe slope positions (pedons 1, 2, 3, and 4), respectively. Soils of the watershed had low level of available phosphorous, low electrical conductivity, no coarse fragments, low acidity, and great depth. The soils were classified as Acrisols, Nitisols, and Vertisols. The land suitability evaluation for production of major crops showed that upper slope position (20.8%) was currently not suitable (N1) for maize, teff, and wheat. Middle slope position (27.3%) was marginally suitable (S3) for maize, teff, and wheat. Lower slope position (32.5%) was moderately suitable (S2) for maize and marginally suitable (S3) for teff and wheat. Toe slope position (19.4%) was moderately suitable (S2) for maize and teff and marginally suitable (S3) for wheat. There is no topographic position that was classified as highly suitable (S1). Hence, farmers of the area should implement major land improvement practice to create optimum condition for production of major crops or should change a land utilization type. Moreover, the soils of the study area were acidic and, therefore, there has to be acid soils management strategy in the area.

1. Introduction

Agriculture is the main economic activity in Ethiopia, accounting for about 45% of gross domestic product (GDP) and 85% total employment, so agriculture is dominant sector in total economy of Ethiopia [1]. However, this sector is beset by several anthropogenic and natural factors that negatively affect its productivity [2, 3].

The condition resulted in low agricultural productivity in Ethiopia related to various factors including the dependency of agriculture on rainfall, lack of modern technology, inappropriate land use practices, and most importantly low soil fertility due to nutrient removal through continuous cultivation without sufficient external inputs addition. Moreover, absence of valuable information on soil characteristics and properties for their crucial management practice [4]. The population increase from time to time results in the expansion of farming area from gently sloping area to steeper slopes and marginal lands [5], which caused disturbance to the ecosystem specially soils that are the determinant factor of product and productivity of agriculture.

The agricultural production plays a vital role in generating enough capital to speed up total socioeconomic conditions of farmers. However, Ethiopia is unable to feed its population due to several biophysical and socioeconomic problems and policy disinclinations [6].

To achieve the increasing demand for food, farmers have to produce more. Furthermore, land is limited and a

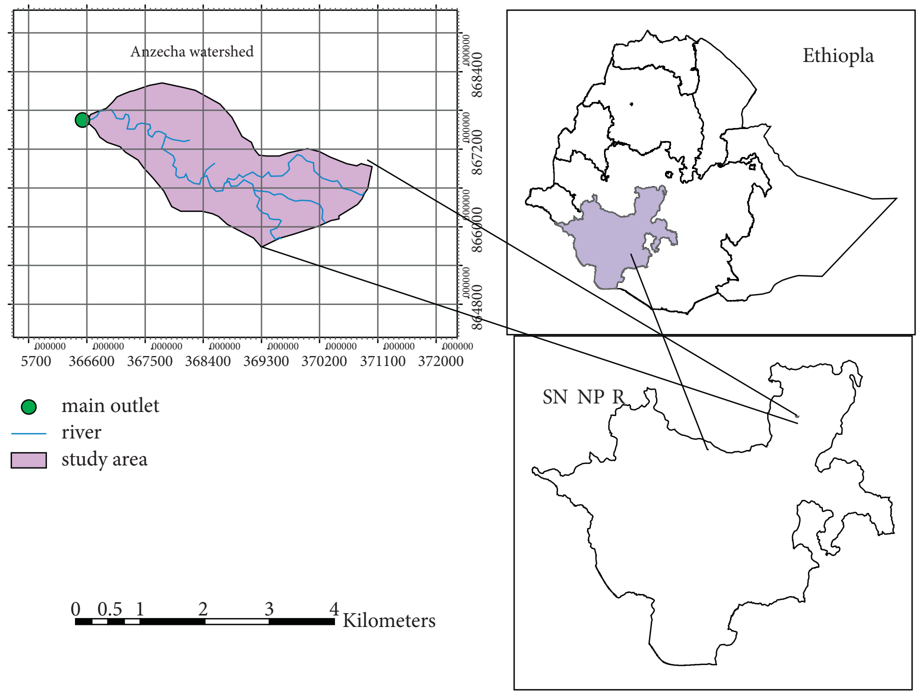


Figure 1: Location map of Anzecha watershed.

potential agriculture requires the sustainable use of soils that largely determine the agricultural potential of an area. At the recent situation, where land is a limiting factor, it is impractical to bring more area under cultivation to satisfy the food demand. Therefore, it is important to understand the nature and properties of soil and management based on their potential and constraints for optimization of crop production [6].

Ethiopia has diverse soil resource because of diverse topography, climatic condition, and geology [7]. However, sustainable soil management practices that are based on understanding of soil system are not available for the most part of the country [8]. Hence, there is a need to establish detailed soil characterization and land evaluation work. The soil characteristics help scientists to interpret how the ecosystem functions and make recommendation for soil use that has an impact on the ecosystem. It can also help to determine the type of vegetation to be planted and land use best suited to the specific location [9]. The study and understanding of soil properties and their distribution over an area provides useful information for the development of soil management plan for efficient utilization of limited land resource and mostly important for agrotechnology transfer [10].

The study of the suitability of land is important for selection of crops and crop rotation for a specific piece of land. The agricultural land suitability is a function of the requirements of crop and soil or land characteristics. Matching the crop requirements with land characteristics results in the suitability. So, suitability is a measure of how well the quality of a land unit matches with a specific form of land use. It is the ability of a part of land to tolerate production of crops in a sustainable means [11]. Land evaluation is a method for matching the characteristics of land resource for specific purpose using scientifically standardized method. The result is guided by land users and planners to select alternative land uses [12].

Characterization of soil is crucial to all soil studies. It is an important tool for soil classification, land evaluation, and successful transfer of research results from one study area to another [10]. The proper understanding of the nature and properties of soil of the country and their management based on their potential and problems is important for increasing crop production to the optimum level [13].

The purpose of this study was to characterize and classify the soils of the study area and to evaluate the land for production of major crops (maize, teff, and wheat) of the study area. The study would have great contribution in managing the soils for sustainable agricultural production and for an appropriate land use decision.

2. Materials and Methods

2.1. Description of the Study Area. The study was conducted in Anzecha watershed which is located in Endegagn woreda, Gurage Zone of Southern Nations Nationalities and Peoples Regional State (SNNPRS) (Figure 1). The study area is found about 230 km away from Addis Ababa and 72 km from Wolkite town, capital of Gurage Zone towards the southwest direction. The geographical location of Anzecha watershed extends from $36^0\,66''\,00''$ to $37^0\,09''\,40''$ E longitudes and from $08^0\,65''\,48''$ to $08^0\,68''\,22''$ N latitudes and altitude ranges from 2100 to 2400 meter above sea level (m. a. s. l.). The total area of the watershed is 540 ha and a slope of 1–12% gradient (Figure 2).

Based on the ten years (2011–2021) meteorological data obtained from the Ethiopian National Meteorology Agency,

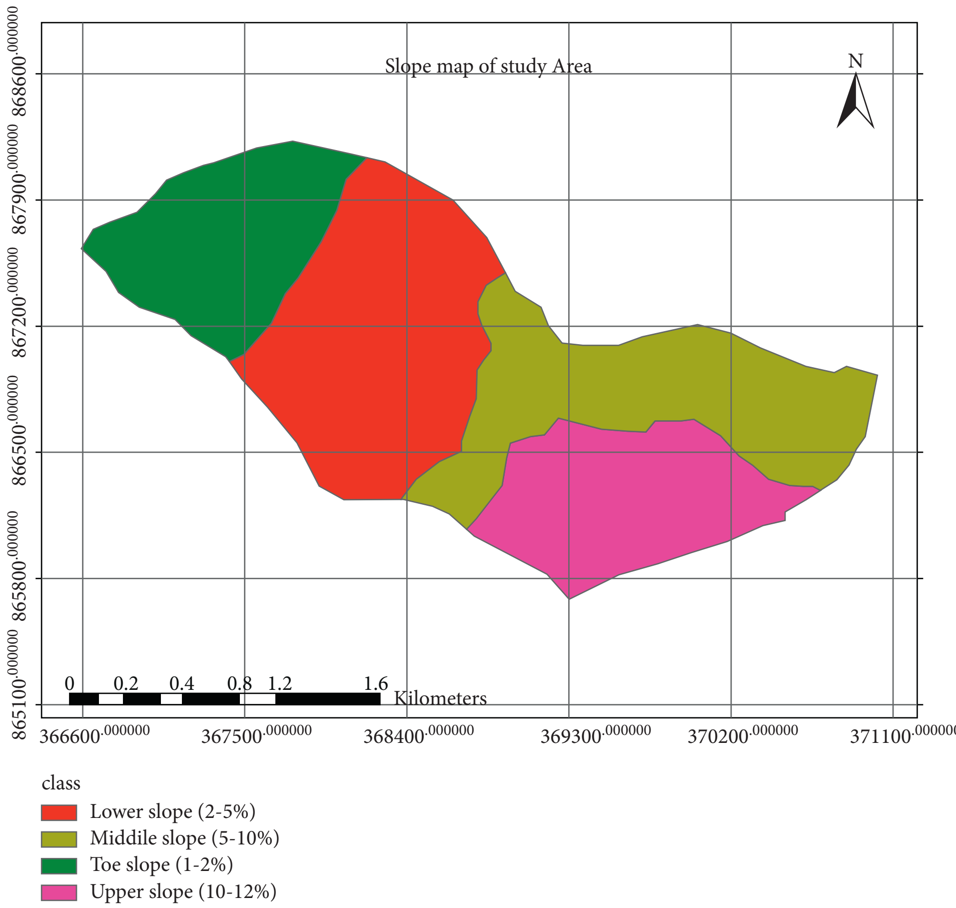
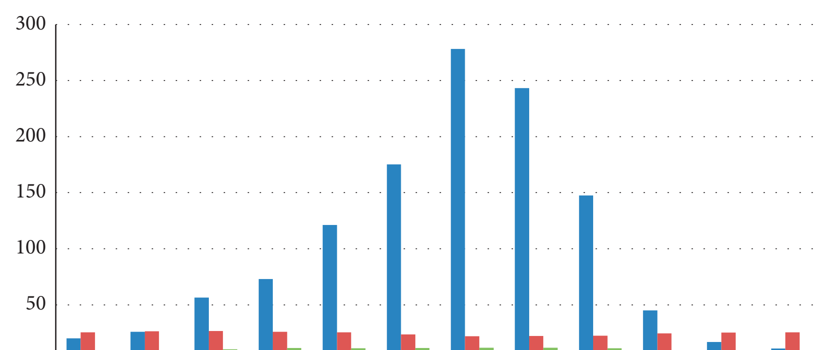


Figure 2: Slope map of study area.



	Jan	Feb	Mar	Apr	MAY	Jun	July	Aug	Sep	Oct	Nov	Dec
RF (mm)	20.1	25.9	56.5	72.9	121.2	175.3	278.3	243.2	147.6	45.1	16.8	11
T.Max	25.5	26.3	26.6	26	25.4	23.5	21.9	22.2	22.5	24.5	25.2	25.4
T.Min	9	9.5	10.2	11.4	11.2	11.4	11.7	11.7	11.3	9.5	7.8	7.3

Figure 3: Mean monthly rainfall (mm) and mean monthly maximum and minimum temperature (°C).

the study area receives adequate rainfall in the main rainy season, from May to September, in the rest of the months, there is a small amount of rainfall, and there are entirely dry months. Dry months are months with precipitation less than 100 mm and are applicable for annual crops [14]. The rainfall during growing period is 965.6 mm. The average maximum and minimum temperatures of study area are 24.6°C and 10.2°C, respectively, and the mean temperature of growing cycle is 17.3°C (Figure 3).

The geological formations that cover the study area are western escarpment of the rift and within Gibe River basin. Tertiary Volcanic of Trap Series and Quaternary sediments mainly characterize the geology of study area (Figure 4). The regional and local geology of study area is generally

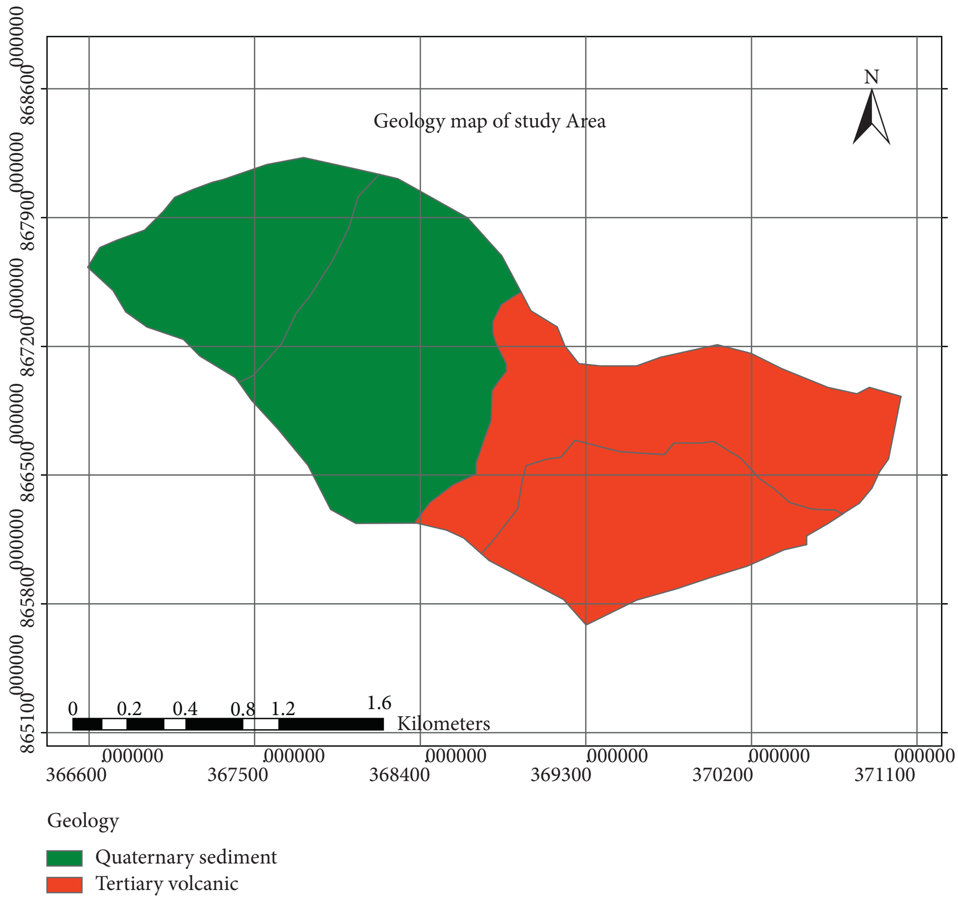


Figure 4: Geology map of the study area.

characterized by geological formation of Quaternary (resent sediments) and Tertiary basaltic flows consisting of ignimbrite (found interbedded with the plateau basalt), trachyte (constituted of the tertiary volcanic of area), and basalt (occupied the lower elevation) of study area [15].

According to the 2018 Annual Report of Office of Farming and Natural Resource Sector of Endegagn District, the land utilization type of the study area was cultivated land (maize, teff, wheat, barley, enset, potato, pea, and bean) occupying about 47% and grazing land occupying about 35%, and the remaining area is occupied by manmade and natural forest. Farmers apply chemical fertilizers mainly Diammonium phosphate and urea for crop production. In addition, homestead plots receive manure. Crop residues were used as livestock feed and fuel and animals were allowed to graze free on the cultivated land after crops are harvested.

2.2. Field Survey and Sampling. The preliminary interpretation of topographic map (1 : 50,000) obtained from the Ethiopian mapping authority (EMA) before starting the main survey was made in the office to identify watershed boundary and slope classes and to fix tentative pedon points. Based on slope gradient of the area, 4 (four) slope classes were encountered along toposequence of the watershed. The mapping units were delineated on the bases of slope classes (upper, middle, lower, and toe) and slope positions and the tentative map of the area was prepared with the help of Arc GIS 10.3 from the topographic map.

Physiographic approaches were followed such that the soil was studied along toposequence of a hill slope consisting of the upper, middle, lower, and toe slopes (Figure 5). After that, field visual observation and surveying were done by a transect walk with the help of a tentative map of the area to determine representative sampling sites; about 54 auger observation pits were opened to a depth of at least 120 cm and were described in the field based on guideline for soil description [14] for selection of representative pedon sites. Based on homogeneity/heterogeneity of soils and slope gradient, about 4 pedon sites were identified. Points of the auger hole and profiles were georeferenced using GPS (Figure 6). Accordingly, pedons were described along toposequence with a depth of 1.5 m × 2 m using guide line for soil description [14].

The soil morphological characteristics were described in the field using procedures outlined in the FAO guidelines for soil description [14] and 15 disturbed and 15 core soil samples were collected from all genetic horizons. The core (undisturbed) soil samples were collected using core sampler and colors were determined using the Munsell color chart [16] in moist and dry conditions.

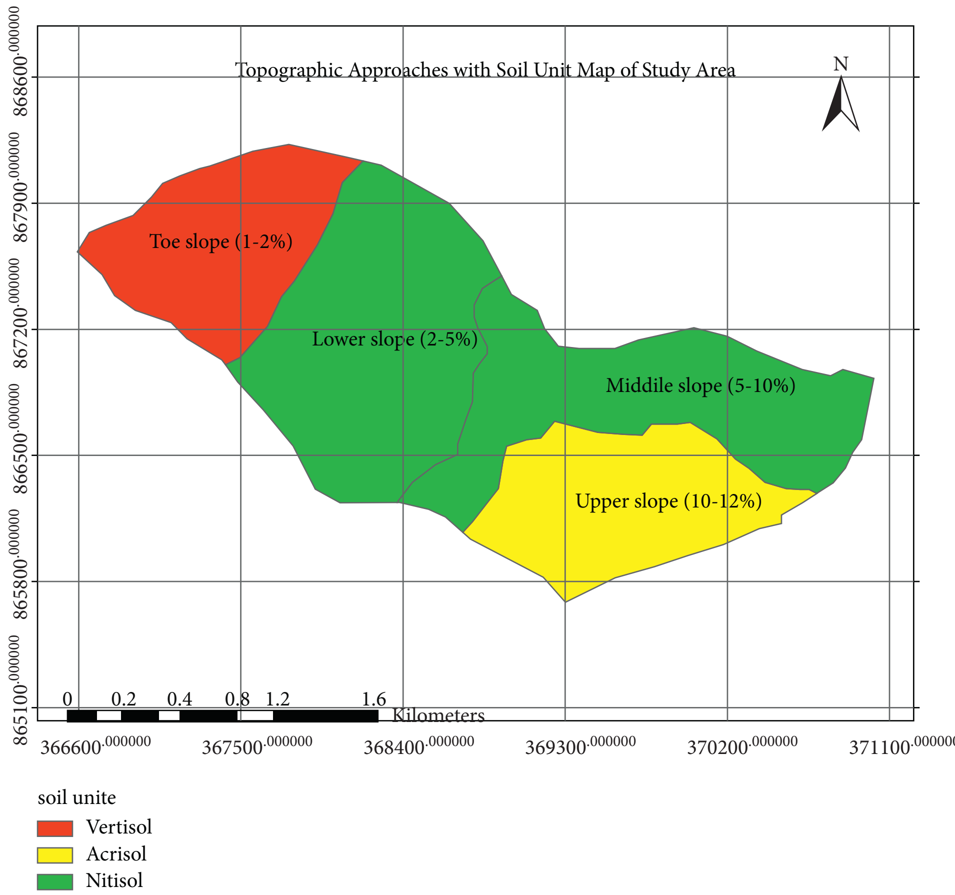


Figure 5: Topography with soil unit map of the study area.

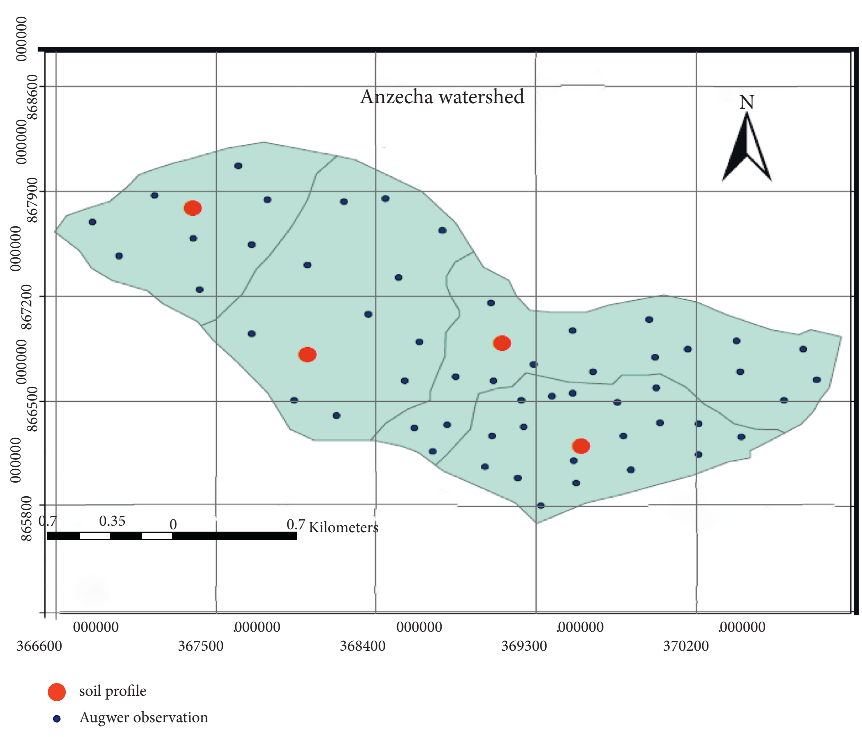


Figure 6: Distribution of profiles and auger observation points of Anzecha watershed.

2.3. Soil Sample Preparation and Analysis. The soil samples were carefully labeled, bagged, and transported for laboratory analysis. The samples were air dried, crushed using mortar and pestle, sieved using 2 mm diameter sieve, and stored using plastic box. All analyses were made on soils that pass through a 2 mm sieve except bulk density, total nitrogen, and organic carbon. For determination of organic carbon and total nitrogen, the samples were passed through 0.5 mm diameter sieve and the bulk density was measured from undisturbed soil sample using core sampler.

The soil analysis was done in Wolkite and Hawassa regional soil laboratories. Texture (particle size distribution) of the soil was analyzed by Bouyoucos hydrometer method [17]. The bulk density of soil was estimated from core soil sample collected by core sampler and weighed at field moisture and determined using the procedures outlined by Blake [18]. Total porosity was estimated by the formula set by [19]

$$\mathrm{TP}\,(\%) = 1 - \left(\frac{\mathrm{Bd}}{\mathrm{Pd}}\right) * 100, \quad (1)$$

where BD = bulk density, PD = particle density (use 2.65 g/cm^3 for mineral soil), and TP = total porosity. Soil pH was determined in 1 : 2.5 soil-water suspensions using a glass electrode [20]. Organic carbon content was determined using [21] method.

The SOM was determined by the formula (%) SOM = 1.724X (%) SOC, assuming that SOM contains 58% carbon [22]. Total nitrogen was analyzed using the Kjeldahl method described by [18]. Available phosphorus was analyzed using [23] method. Cation exchange capacity and exchangeable bases were determined by ammonium acetate method as it was described by Rowell [24]. Calcium and Mg were read by AAS and K and Na were read by flame photometer. Percent base saturation (PBS) was calculated by the 100 product of sum of exchangeable base divided by CEC. Soil exchangeable acidities (H^+ and Al^{3+}) were determined by Sims method [25]. The electrical conductivity of a saturated soil paste extracted (ECe) at 25°C was determined using electrical conductivity meter as described by [20].

2.4. Soil Classification and Land Suitability Evaluation. Based on morphological and physicochemical properties, the soils of the study area were classified according to World Reference Base for soil resource system of soil classification [26]. The maps (soil map and map of current overall land suitability for each major crop) were prepared based on the data on the field and laboratories with the help of GPS and study area topographic map interpretation using Arc GIS 10.3 software.

The physical land suitability evaluation method applied in this study was following the procedures laid down in the FAO framework for land evaluation [27]. Firstly, the land utilization types (LUTs) were described through discussion with farmers and development agents with the bases of potentially produced crops and importance of these crops in the livelihood of concerned community. Evaluation criteria were selected. Important land quality (LQ)/land characteristics (LC) data such as LGP (days), rainfall during growing period, mean temperature of growing cycle, rooting condition (effective soil depth and texture), flooding and drainage, natural fertility (EC, CEC, SOM, SOC pH, and PBS), erosion hazard (slope gradient), and land preparation (rock outcrops and coarse fragments) of the land unit were collected and used for suitability evaluation.

Length of growing period (LGP) was determined by comparing decadal rainfall with reference evapotranspiration (ETo). The beginning of growing period, end of rains, and start and end of humid period were determined using graphic method as described by [28]. Coarse fragments and texture were calculated for the depth of rooting zone and surface horizons were used for the evaluation of EC, SOM, OC, pH, PBS, and CEC. The principle of the maximum limitation factor approaches was used in combining land suitability ratings. To obtain information about the potential and limitation of land in the study area for rain-fed production of principal crops: maize (*Zea mays L.*), teff (*Eragrostis tef*), and bread wheat (*Triticum aestivum*), land use requirement of each crop was established using [28–32] procedures.

2.5. Statistical Analysis. To find out the relationship between and among selected physicochemical properties of soil, the data obtained from laboratories were subjected to simple linear correlation analysis using SAS software [33].

3. Results and Discussion

3.1. Soil Morphological Properties

3.1.1. Soil Depth. The soil depths in the study area were very deep which is greater than 150 cm in all pedons. As per the rating by [14], it indicates that the soils of Anzecha watershed were well developed. According to [34], the depth of soil influences both the storage of water and plant nutrients in addition to its effect on root development. Therefore, soils in study area were very deep which had capacity to hold nutrient and moisture for long period and were favorable for root development.

3.1.2. Soil Color. The study area showed variation in color of soils both in dry and moist condition. The colors of soil in the upper slope position (pedon 1) varied from reddish brown (5YR5/4) to dark red (2.5YR3/6) when dry and reddish grey (5YR5/2) to dusky red (2.5YR3/2) when moist. The color of soil in middle slope position (pedon 2) varied from red (2.5YR4/6) to dark red (2.5YR3/6) when dry and dusky red (2.5YR4/4) to dark reddish brown (2.5YR 3/3) when moist. The color of soil in the lower slope position (pedon 3) varied from red (2.5YR4/6) to dark red (2.5YR3/6) when dry and dusky red (2.5YR3/2) to dark reddish brown (2.5YR3/3) when moist. The color of soil in toe slop position (pedon 4) varied from dark brown (7.5YR3/2) to strong brown (7.5YR5/6) when dry and black (7.5YR2.5/1) to very dark brown (10YR2/2) when moist (Table 1).

Table 1: Soil morphological properties of Anzecha watershed.

LSP	Depth (cm)	Horizon	Color		Structure			Consistency			HB	RO	CF
			Dry	Moist	Grade	Size	Type	Dry	Moist	Wet			
Pedon 1	0–25	A	5YR5/4	5YR5/2	WE	FI	GR	SO	LO	SST/SPL	CS	V	N
	25–65	B1	5YR5/2	5YR 5/3	WE	FI	BL	SO	LO	SST/PL	CS	V	N
	65–125	B2	2.5YR 3/6	2.5YR 3/2	MO	ME	SB	HA	VFR	ST/PL	CS	V	N
	125–200+	Bt	5YR 5/2	5YR 5/2	MS	ME	PR	VHA	FR	ST/VPL	—	V	N
Pedon 2	0–30	A	2.5YR 4/6	2.5YR 3/2	MO	ME	AS	SHA	VFR	SST/SPL	DI	N	N
	30–85	B1	2.5YR 4/8	2.5YR 3/4	MO	ME	SA	HA	FR	ST/PL	DI	N	N
	85–120	Bt	2.5YR 3/6	2.5YR 3/3	ST	ME	SB	VHA	FR	ST/PL	GI	N	N
	120–200+	B	2.5YR 3/6	2.5YR 3/2	ST	CO	SB	VHA	VFI	VST/VPL	—	N	N
Pedon 3	0–35	A	2.5YR 4/6	2.5YR 3/2	MO	ME	AS	SHA	FR	ST/PL	DI	N	N
	35–95	Bt1	2.5YR4/6	2.5YR 3/2	MS	ME	SB	VHA	FI	ST/VPL	DI	N	N
	95–200+	Bt2	2.5YR 3/2	2.5YR 3/3	ST	CO	SB	VHA	VFI	VST/VPL	—	N	N
Pedon 4	0–30	A	7.5YR 3/2	7.5YR2.5/1	ST	CO	GR	HA	FI	ST/PL	AS	N	N
	30–80	B	7.5YR3/3	10YR 2/2	ST	CO	GR	VHA	VFI	VST/VPL	AS	N	N
	80–120	Bt1	7.5YR 5/6	7.5YR 4/3	ST	VCO	WE	EHA	EFI	VST/VPL	AS	N	N
	120–200+	Bt2	7.5YR5/4	7.5YR 4/3	ST	VCO	WE	EHA	EFI	VST/VPL	—	N	N

LSP = landscape position, WE = weak, MO = moderate, MS = moderate to strong, ST = strong, FI = fine/thin, ME = medium, CO = coarse/thick, VCO = very coarse/tick, GR = granular, BL = blocky, SB = subangular blocky, AS = angular and subangular blocky, SA = subangular and angular blocky, PR = prismatic, WE = wedge-shaped, SO = soft, EHA = extremely hard, VHA = very hard, HA = hard, SHA = slightly hard, LO = loose, FR = friable, FI = firm, VFI = very firm, EFI = extremely firm, VFR = very friable, SST = slightly sticky, SPL = slightly plastic, VST = very sticky, VPL = very plastic, ST = sticky, PL = plastic, HB = horizon boundary, CS = clear smooth, DI = diffuse irregular, GI = gradual irregular, AS = abrupt smooth, RC = rock outcrop, CF = coarse fragments V = very few, N = none.

The variation of soil colors was related to organic matter content and parent material. The color of soil at pedon 1 indicates that the soil was dominated by iron oxide (red color). The color of soil at pedon 2 and 3 indicates that there was a considerable amount of iron oxide (red color) and humified organic matter (dark color). The color of soil at pedon 4 indicates the amount of iron oxide (brown color), humified organic matter (dark color) and manganese oxide (black color), which was abundant. The observations of soil color at the watershed agreed with [35], which reported that variations in soil color are due to the difference in organic matter or the difference in parent material.

3.1.3. Soil Structure and Consistency. The surface layer of pedon 1 had weak, fine, and granular structure. Pedons 2 and 3 had moderate, medium and angular and subangular blocky structure. Pedon 4 had strong, coarse, and granular structure. The subsurface layers of pedon 1 had weak to moderately strong, fine to medium, and blocky to prismatic structure. Pedon 2 had moderate to strong, medium to coarse and subangular and angular blocky to subangular blocky structure. Pedon 3 had moderately strong to strong, medium to coarse, and subangular blocky structure. Pedon 4 had strong, coarse to very coarse and granular to wedge-shaped structure (Table 1).

According to [19], the structure of soil is highly influenced by the amount of clay. Soil structures at the study watershed showed variation. The subsurface layers' structure varies from granular to wedge-shaped, whereas in surface layers it varies from granular to angular and subangular blocky. With increasing the depth of soil, the structure becomes stronger and coarser due to the increment in clay content.

The consistency of soil in study area showed that variation between pedons and described horizons. Surface layers showed variation from soft to hard when dry, loose to firm when moist, and slightly sticky/slightly plastic to sticky/plastic when wet. Whereas subsurface layers showed variation from soft to extremely hard when dry, loose to extremely firm when moist, and slightly sticky/plastic to very sticky/very plastic when wet (Table 1).

According to the findings of [36], the consistency of soil changes with the depth of soil due to variation in amount of clay and organic matter. Very hard, very firm, and very plastic characteristics of consistency are common in subsurface horizon because of high clay content and low soil organic matter. This supports the result of soil consistency in the study area.

3.1.4. Soil Horizon Boundary. The soil profiles in study area showed variation in horizon boundaries. There were clear smooth horizon boundaries at upper slope position, diffuse irregular and gradual irregular at the middle slope position, diffuse at lower slope position and abrupt smooth in toe slope position (Table 1). According to [14], the presence of difference in horizon boundaries showed that there were different processes and anthropogenic impacts that were involved in soil formation of study area. These may be due to intensive weathering and cultivation practices.

3.1.5. Rock Outcrops and Coarse Fragments. The observations of study area showed that there were only very few (0–2%) rock outcrops in upper slope position and the other (middle slope, lower slope, and toe slope) positions did not have the rock outcrops. There was no coarse fragment at surface layer of the watershed (Table 1).

The presence of coarse fragments was correlated with the presence of rock outcrops. The rock outcrops are hindering the utilization of modern mechanized agricultural farm machineries and the development of roots of crops [14]. This result generally indicates that the studied watershed was favorable for root growth and mechanized agriculture.

3.2. Soil Physical Properties

3.2.1. Soil Texture. The textural classes of the profiles in surface horizons were sandy loam in upper slope position; sandy clay in middle and lower slope positions; and clayey in toe slope position. The textural classes of subsurface horizons were varied from sandy loam to heavy clay. The silt to clay ratios were inconsistently varied with the depth of all profiles. Generally, the particle size distribution of Anzecha watershed varied along the toposequence. Pedon 1 had relatively higher sand content (45–62%) followed by soils located at pedon 2 (34–53%), pedon 3 (11–51%), and pedon 4 (13–21%). Pedon 1 had relatively higher silt content (25–34%) followed by pedon 4 (22–30%), pedon 3 (13–24%), and pedon 2 (11–18%). The amount of clay content was relatively higher at pedon 4 (49–62%), followed by pedon 3 (36–65%), pedon 2 (34–53%), and pedon 1 (13–21%) of the soil profiles (Table 2).

The highest silt to clay ratio was recorded in the upper slope position of the study area (Table 2). According to [10], the highest silt to clay ratio could be recorded on areas where there is removal of finer particles; these indicate that there was a relatively higher erosion problem at the upper slope position (pedon 1) of Anzecha watershed.

A previous study found that the amount of clay content increases with the increasing depth of soil [37], which is due to clay eluviations in the soil. This is in agreement with the amount of clay content in the study watershed which had an increasing pattern with the depth of soil throughout all profiles. The textures of surface horizons in the watershed were relatively coarser and the textures of subsurface horizons were also relatively finer (Table 2).

3.2.2. Bulk Density and Total Porosity. The mean values of bulk density were relatively lower in surface horizons than the underlying horizons of all pedons. The soil at the upper slope position had relatively high bulk density (1.37–1.40 g/cm^3) followed by middle slope position (1.36–1.40 g/cm^3), lower slope position (1.33–1.40 g/cm^3), and toe slope position (0.91–1.23 g/cm^3) (Table 2). The coarser texture soils have the greater bulk density than the finer textured soils because finer texture soils have a greater number of pores than coarser ones [38], which supports the results of bulk density at the watershed. As the slope gradient becomes lower, the soil particle becomes relatively finer in the watershed; for example, the particle size distribution of soils studied at the upper slope position (sandy loam to loam) was coarser than soils studied at toe slope position (clayey to heavy clay soil) due to deposition of finer particle at low laying area.

The results of bulk density at the watershed were in agreement with the finding of scholars of [39] who reported that the values of bulk density of soils were increased with increasing the depth of soil profile due to compaction of the overlaying horizon and decreasing trend of SOM down a profile.

The mean values of total porosity of the soils were relatively the highest at toe slope position (53.58–65.66%) followed by lower slope position (47.16–49.81%), middle slope position (47.16–48.67%), and upper slope position (47.16–48.30%) (Table 2). The results were in agreement with [19]; they reported that the finer textured soils were more porous than coarser textured soils because of the number of micro pores. Relatively, the highest values of total porosity were recorded in surface horizon more than subsurface horizons in all pedons of the study watershed. Comparatively, the highest SOM at surface horizon improves the structure of soil, supporting microbial biomass and having a high effect on soil disturbance. This result was similar with [40], which reported a decrease in total porosity with increasing profile depth because of decreasing organic matter content and increasing compaction.

3.2.3. Soil Drainage and Flooding. The drainage classes of soils at Anzecha watershed range from moderately well drained to well drained and there was no problem of flooding (Table 2). According to [41], the textural class, porosity, and the amount of organic matter influence the drainage class of soils; thus, such parameters may be favorable for drainage condition. According to [12], well drained to moderately well drained soils are ideal for the production of crops and thus the study area was ideal for crop production according to its drainage class and absence of flooding at any time of the year.

3.3. Soil Chemical Properties

3.3.1. Soil pH. The pH value of surface horizons of soils ranged from 4.80 in pedon 1 to 5.54 in pedon 4. In subsurface horizons, it ranged from 4.91 in pedon 1 to 6.00 in pedon 4. The mean pH value in Pedon 1 had relatively lower pH followed by pedons 2, 3, and 4, respectively. The variations of soil reaction in study area were highly related to variations in topographic situation. According to [19], lack of excessive leaching left basic cations in surface horizon; thus, soil reaction in upper slope position was influenced by leaching of basic cations due to relatively higher slope gradient. The leached cations were deposited at relatively lower slope gradients because this higher slope positions were more acidic than the following sloppy positions.

The pH value of the watershed showed slightly increasing pattern with increasing profile depth (Table 3). The result is in agreement with the finding of paper [42] which reported that the soil acidity decreased with the increasing of soil depth due to less hydrogen ions that were released from low amount of organic matter to be decomposed in a depth of soil and acidic soil also promoted accumulation of aluminum ions. Through the process of decomposition, the

Table 2: Soil physical properties of Anzecha watershed.

LSP	Depth (cm)	Horizon	Particle size distribution (%)			Silt/clay	Textural class	BD (g/cm^3)	TP (%)	DR	FL
			Sand	Silt	Clay						
Pedon 1	0–25	A	62	25	13	1.6	SL	1.37	48.30	WD	N
	25–65	B1	50	33	17	1.9	L	1.38	47.92	WD	N
	65–125	B2	57	27	16	1.7	SL	1.40	47.16	WD	N
	125–200+	Bt	45	34	21	1.6	L	1.40	47.16	WD	N
Pedon 2	0–30	A	53	13	34	0.38	SC	1.36	48.67	MW	N
	30–85	B1	42	16	42	0.38	C	1.38	47.92	MW	N
	85–120	Bt	36	11	53	0.20	C	1.40	47.16	MW	N
	120–200+	B	34	18	48	0.37	C	1.40	47.16	MW	N
Pedon 3	0–35	A	51	13	36	0.36	SC	1.33	49.81	MW	N
	35–95	Bt1	17	21	62	0.33	HC	1.39	47.54	MW	N
	95–200+	Bt2	11	24	65	0.36	HC	1.40	47.16	MW	N
Pedon 4	0–30	A	21	30	49	0.61	C	1.00	62.26	MW	N
	30–80	B	15	29	56	0.51	C	0.91	65.66	MW	N
	80–120	Bt1	16	22	62	0.35	HC	1.19	55.09	MW	N
	120–200+	Bt2	13	25	62	0.40	HC	1.23	53.58	MW	N

LSP = landscape position; SL = sandy loam; L = loam; SC = sandy clay; C = clay; HC = heavy clay; BD = bulk density; TP = total porosity; DR = drainage; FL = flooding; WD = well drained; MW = moderately well drained; N = none.

Table 3: Soil reaction, soil organic matter, organic carbon, total nitrogen, and available phosphorous.

LSP	Depth (cm)	Horizon	pH (H_2O)-1 : 2.5	OC (%)	SOM (%)	TN (%)	AP (mg/kg)
Pedon 1	0–25	A	4.80	1.21	2.08	0.11	5.90
	25–65	B1	4.91	1.01	1.74	0.10	5.30
	65–125	B2	5.30	0.80	1.38	0.08	2.00
	125–200+	Bt	5.50	0.60	1.03	0.05	2.10
Pedon 2	0–30	A	5.44	3.14	5.41	0.27	6.20
	30–85	B1	5.50	3.05	5.25	0.26	4.00
	85–120	Bt	5.60	2.62	4.51	0.23	4.20
	120–200+	B	5.61	2.40	4.13	0.21	1.23
Pedon 3	0–35	A	5.50	3.50	6.03	0.31	6.25
	35–95	Bt1	5.53	3.47	5.98	0.30	2.35
	95–200+	Bt2	5.66	2.43	4.18	0.22	0.83
Pedon 4	0–30	A	5.54	3.45	5.94	0.30	5.20
	30–80	B	6.00	3.57	6.15	0.30	4.40
	80–120	Bt1	5.57	2.86	4.93	0.25	0.60
	120–200+	Bt2	5.82	2.50	4.31	0.23	0.11

LSP = landscape position, pH = soil reaction, OC = organic carbon, SOM = soil organic matter, TN = total nitrogen, AP = available phosphorous.

reaction of carbon dioxide and water forms both organic and inorganic acids and soil pH was positively and significantly correlated with SOM ($r = 0.637^*$) (Table4).

As per ratings of [43, 44], the surface soil pH value at pedon 1 (4.8) was very strongly acidic and in all other pedons, it ranged from 5.44 to 5.54 being strongly acidic; pH range from 6 to 7.5 is preferable for most plant and soil microorganisms.

3.3.2. Soil Organic Carbon and Total Nitrogen. The organic matter contents in surface horizons of soils in the study area ranged from 2.08% pedon 1 to 6.03% in pedon 3. In subsurface horizon, it ranged from 1.03% in pedon 1 to 6.15% in pedon 4. The mean value of SOM showed the relatively decreasing trend with the increasing soil depth (Table 3), and also in similar manner reported by [45], surface layers have shown higher organic matter content than subsurface layers due to continuous addition of plant and animal residues.

The level of organic carbon was relatively low on upper slope positions of the study area (Table 3). This indicated the existence of high organic matter removal rates by erosion on upper slope position and the deposition process made in middle, lower, and toe slope positions to have relatively higher organic matter status. This might have been caused by slope gradient and human influence on soil and water conservation practices at the study watershed.

According to the rating of [43, 44], the amount of soil organic carbon (1.21%) in surface soil at upper slope position was rated as low level, which requires management practice to improve the amount of organic carbon due to its influence on nutrient recycling, water availability, and soil structure.

Table 4: Pearson's correlation coefficient (r) among selected soil physicochemical properties.

	Ca	Mg	K	Na	EAl	EH	EA	CEC	EC	PBS	pH	SOM	OC	TN	C : N	AP	Sand	Silt	Clay	Silt : clay	TP
Ca	1	0.834**	0.834**	0.751**	0.052	−0.118	−515*	−0.661**	0.786**	−0.941***	0.216	0.834**	0.834**	0.751**	0.052	−0.118	−0.515	−0.661*	0.786**	0.941***	0.216
Mg		1	0.775**	0.900***	−0.659*	0.105	−0.573*	0.772**	0.125	0.778**	0.720**	0.932***	0.932***	0.838**	0.086	−0.084	−0.628*	−0.632*	0.843**	−0.969***	0.339
K			1	0.708**	−0.673*	−0.176	−0.660*	0.593*	0.200	0.711**	0.751**	0.684**	0.685*	0.612*	0.081	−0.117	−0.517	−0.402	0.706**	−0.766**	0.361
Na				1	−0.710**	−0.159	−0.658*	0.589*	0.332	0.833**	0.770**	0.806**	0.805**	0.711**	0.125	−0.341	−0.730**	−0.551*	0.905***	−0.930***	0.291
EAl					1	0.527	0.978***	−0.354	−0.332	−0.737**	−0.864**	−0.498	−0.498	−0.463	0.235	0.546*	0.599*	0.331	−0.719**	0.734**	−0.197
EH						1	0.599*	0.428	−0.302	−0.356	−0.392	0.276	0.276	0.226	0.238	0.608*	0.144	−0.090	−0.155	0.042	0.136
EA							1	−0.276	−0.353	−0.700**	−0.839**	−0.408	−0.408	−0.392	0.238	0.573*	0.544	0.297	−0.655*	0.665*	−0.199
CEC								1	0.100	0.261	0.530	0.915***	0.915***	0.909***	−0.142	0.292	−0.405	−0.424	0.534*	−0.690*	0.540
EC									1	0.057	0.482	0.046	0.045	.090	−0.151	−0.639*	−0.649*	0.353	0.454	−0.100	0.309
PBS										1	0.651*	0.575*	0.575*	.458	0.194	−0.412	−0.575*	−0.565*	0.813**	−0.866**	0.030
pH											1	0.637*	0.637*	0.692*	−0.401	−0.348	−0.706**	−0.177	0.768**	−0.729**	0.504
SOM												1	1.00***	0.950***	−0.005	0.158	−0.545	−0.565*	0.737**	−0.888***	0.501
OC													1	0.950***	−0.005	0.158	−0.544	−0.565*	0.737**	−0.889**	0.500
TN														1	−0.278	0.226	−0.514	−0.413	0.655*	−0.789**	0.622*
C : N															1	−0.100	0.021	−0.326	0.091	−0.085	−0.296
AP																1	0.574*	−0.140	−0.472	0.181	0.102
Sand																	1	−0.098	−0.912***	0.628*	−0.519
Silt																		1	−0.286	0.670*	0.285
Clay																			1	−871**	0.372
Silt: clay																				1	−0.261
TP																					1

*significant at $p < 0.05$ level, **significant at $p \leq 0.01$ level, and ***significant at $p \leq 0.001$ level.

The level of soil organic carbon in surface layers of the following other slope positions (3.14–3.5%) was rated as high level.

The amount of total nitrogen in the watershed showed a relatively decreasing pattern with the depth of soil. The value ranges from the lowest (0.05%) in subsurface layer of upper slope position to the highest (0.31%) in surface layer of lower slope position of the study area (Table 3). The linear correlation analysis indicated that total nitrogen and soil organic matter were positively and significantly correlated ($r = 0.95^{***}$) (Table 4).

3.3.3. Available Phosphorus. The level of available phosphorus in study area showed a decreasing trend with an increasing of soil depth. The highest value (6.25 mg/kg of soil) was recorded at surface horizons of lower slope position and the lowest value (0.11 mg/kg of soil) was recorded at subsurface horizon of toe slope position and the relative proportion of available phosphorous was high in surface horizons and low in subsurface horizons (Table 3).

Similar to [44] findings, the level of available phosphorous decreased with the increasing depth of soil due to phosphorous fixation by clay. This is in agreement with the values of available phosphorous in the watershed. In addition to that, the values of available phosphorous at the watershed were in agreement with reference [39], which reported higher available phosphorous in surface soil due to application of animal manure, compost, and Di-ammonium phosphate (DAP) fertilizer to improve the fertility status of farmland.

Generally, according to the ratings of [43, 44], the amount of available phosphorous is low (<7 mg/kg) in study watershed. The result was in agreement with [46]; they reported that available phosphorous is deficient in most Ethiopian soil especially in high lands even under improved drainage conditions. The result showed that the need of management practice like application of animal manure, compost, and inorganic fertilizers to improve the level of available phosphorous in study area.

3.3.4. Exchangeable Cations, Cation Exchange Capacity, and Percent Base Saturation. The level of exchangeable basic cations showed an irregular variation with the depth of soil. Exchangeable calcium varied from the highest 13.5 cmolc/kg of soil in surface horizon of middle slope position to the lowest 2.7 cmolc/kg of soil in subsurface horizon of upper slope position. Exchangeable magnesium varied from the highest 10.1 cmolc/kg of soil to the lowest 1.03 cmolc/kg of soil in subsurface horizons of lower and upper slope positions respectively. Exchangeable potassium varied from the highest 3.63 cmolc/kg of soil to 0.45 cmolc/kg of soil in subsurface horizons of middle and upper slope positions respectively. Exchangeable sodium varied from the highest 1.55 cmolc/kg of soil in subsurface of toe slope position to 0.2 cmolc/kg of soil in surface horizon of upper slope position (Table 5).

According to [19], lack of excessive leaching leaves basic cations in surface horizons. The mean values of cation distribution were high in some of surface horizons; these might be successful soil and water conservation practices as well as the nature of cover crops that inhibits leaching of basic cations. Whereas the distributions of basic cations were relatively low in surface horizons and high in subsurface horizon, these might be leaching of basic cations. This is in agreement with [47], which reported exchangeable cation content of the soil increased with the soil depth due to leaching of the basic cations.

The level of exchangeable acidity in surface horizons of study watershed ranges from 2.9 cmolc/kg of soil in upper slope position to 1.17 cmolc/kg of soil in middle slope position, and in subsurface horizon, it ranged from 3.1 cmolc/kg of soil in upper slope position to 0.33 cmolc/kg soil in toe slope position (Table 5). There were generally the decrements on the value of exchangeable acidity with the increment of the depth of soils in study area.

Cation exchange capacity of soil in study area generally showed a decreasing trend with the depth of soil. It ranged from 41.2 cmolc/kg of soil in toe slope position to 23.33 cmolc/kg of soil in upper slope position of surface horizons and 43.2 cmolc/kg of soil in lower slope position to 19.5 cmolc/kg of soil in upper slope position of subsurface horizons (Table 5). The CEC of soil is high in surface horizon than subsurface horizon as there is a strong relationship with the amount of organic matter [46]. These findings support the result of cation exchange capacity in the current study watershed because there was a decreasing pattern with the soil depth due to the decrement of the amount of organic matter with soil depth.

The percent base saturations of soil in study area recorded the lowest (27.76%) in upper slope position to the highest (71.31%) in middle slope position of surface horizons and from the lowest (23.57%) in upper slope position to the highest (95.69%) in middle slope position of subsurface horizon (Table 5). Generally, PBS increased with the depth of soil in study watershed due to its inverse relation with CEC of soil as CEC of soil had strong relation with soil organic matter.

3.3.5. Electrical Conductivity. Soil electrical conductivity generally showed an increasing trend with the depth of soils in the study watershed. It ranged from the lowest (0.61 dS/m) in the upper and lower slope positions to the highest (0.77 dS/m) in middle slope position of surface horizons and the lowest (0.53 dS/m) in the middle slope position to the highest (1.35 dS/m) in toe slope position of subsurface horizons (Table 5). As per ratings of [43, 44], the electrical conductivity of soils in study watershed was less than 1.5 dS/m, rated as no yield reduction.

3.4. Soil Classification. Based on soil description result, the profiles generally showed increment in clay contents with increasing depth of soil. The texture of the soil changes from sandy loam to heavy clay with the depth, and the bedrock was absent through the profiles of soil in watershed (Table 2).

The soils had a property of argic subsoil horizon: due to the relatively high clay content in subsurface horizon

Table 5: Exchangeable cations, exchangeable aluminum, exchangeable hydrogen, exchangeable acidity, cation exchange capacity, electrical conductivity, and percent base saturation.

LSP	Depth (cm)	Horizon	Ca	Mg	K	Na	Sum	EAl	EH	EA	CEC	EC (dS/m)	PBS (%)
			CmolcKg^{-1} soil										
Pedon 1	0–25	A	3.1	1.81	1.36	0.2	6.47	2.33	0.58	2.9	23.3	0.61	27.76
	25–65	B1	2.7	1.03	0.45	0.24	4.42	2.6	0.5	3.1	18.8	0.8	23.57
	65–125	B2	2.7	1.9	1.51	0.27	6.38	0.88	0.22	1.1	19.5	1.0	32.71
	125–200+	Bt	3.6	1.23	1.63	0.29	6.75	0.41	0.12	0.53	20	1.1	33.75
Pedon 2	0–30	A	13.5	9.3	3.33	0.97	27.1	0.79	0.38	1.17	38	0.77	71.31
	30–85	B1	13.5	9.63	3.63	1.3	28.1	0.57	0.37	0.94	36.4	0.61	77.08
	85–120	Bt	12.6	7.6	3.48	1.2	24.88	0.26	0.18	0.44	26	0.53	95.69
	120–200+	B	11.8	7.26	1.34	1.24	21.64	0.32	0.19	0.51	24.3	0.6	89.05
Pedon 3	0–35	A	9.24	9.9	2.03	1.33	22.5	0.64	0.57	1.21	37.8	0.61	59.52
	35–95	Bt1	11.6	9.24	2.4	1.4	24.64	0.56	0.52	1.08	43.2	1.31	57.03
	95–200+	Bt2	8.8	10.1	2.83	1.39	23.12	0.31	0.31	0.62	25.1	1.21	92.11
Pedon 4	0–30	A	9.6	8.9	2.74	0.73	21.97	0.69	0.65	1.34	41.2	0.68	53.32
	30–80	B	10.4	8.81	3.1	1.5	23.81	0.32	0.25	0.57	40.2	1.32	59.22
	80–120	Bt1	11.1	8.77	3.2	1.46	24.53	0.22	0.2	0.42	31.3	1.31	78.37
	120–200+	Bt2	12.3	8.63	3.26	1.55	25.74	0.21	0.12	0.33	29.1	1.35	88.4

LSP = landscape position; EAl = exchangeable aluminum; EH = exchangeable hydrogen; EA = exchangeable acidity; CEC = cation exchange capacity; EC = electrical conductivity; PBS = percent base saturation.

Table 6: Diagnostic horizons, properties, materials, and soil units.

LSP	Pedon	Diagnostic horizons		Diagnostic properties	Diagnostic materials	Soil unit
		Surface	Subsurface			
Upper slope	1	—	Argic	—	—	Nudiargic Acrisol (Aric)
Middle slope	2	—	Nitic	—	—-	Eutric Nitisols (Aric)
Lower slope	3	—	Nitic	—	—	Eutric Nitisol (Aric)
Toe slope	4	—	Vertic	—	—	Pellic Vertisol (Aric)

LSP = landscape position.

(Table 2), low base saturation 50–100 cm depth (Table 5), low organic matter, and organic carbon (Table 3). The presence of argic horizon was less than or equal to 100 cm and the base saturation calculated from the sum of exchangeable base and exchangeable aluminum was less than 50% between 50 and 100 cm or less indicating the presence of Acrisol (Table 5). Acrisols with argic horizon started at the surface Nudiargic principal qualifier and were ploughed to a depth of greater than or equal to 20 cm from the soil surface Aric supplementary qualifier.

The soil at middle and lower slope positions had greater than 30% clay in all horizons, and the silt/clay was less than 0.4 (Table 2), moderate to strong and subangular blocky structure with shiny soil aggregate faces. All horizons had thickness of greater than or equal to 30 cm and had color of hue 2.5YR (Table 1) indicating the presence of nitic horizon. The presence of nitic horizon with diffuse horizon boundary, moderate to strong, angular and subangular blocky structure (Table 1), and subsurface horizons had greater than 30% clay (Table 2), high amount of CEC, and high amount of organic matter at surface layer (Tables 5 and 3) indicating the presence of Nitisol. Nitisols with base saturation were calculated from the sum of exchangeable base plus exchangeable aluminum greater than 50% in the major part between 20 and 100 cm from the mineral soil surface Eutric principal qualifier and were ploughed to a depth of greater than or equal to 20 cm from soil surface Aric supplementary qualifier.

The soil at toe slope position was characterized by the presence of wedge-shaped soil structure, hard to extremely hard consistency, and deep wide cracks from the surface downward when dry; individual horizon with thickness greater than 25 cm (Table 1) and greater than 30% clay throughout the profile (Table 2) indicates the presence of vertic horizons. The surface layer had strong granular structure with cracks indicating the presence of Vertisol. The upper 30 cm of soil has a color value of less than or equal to 3 and chroma of less than or equal to 2 both in moist and dry (Table 1) using Pellic principal qualifier and it was ploughed to a depth of greater than or equal to 20 cm using Aric supplementary qualifier (Table 6).

The upper, middle, lower, and toe slopes of the study area were classified as Nudiargic Acrisol (Aric), Eutric Nitisol (Aric), Eutric Nitisol (Aric), and Pellic Vertisol (Aric), respectively (Figure 7).

3.5. Land Suitability Evaluation

3.5.1. Determination of LGP and Characterization of the Slope Positions. The length of growing period (LGP) was determined based on normal growing type. According to

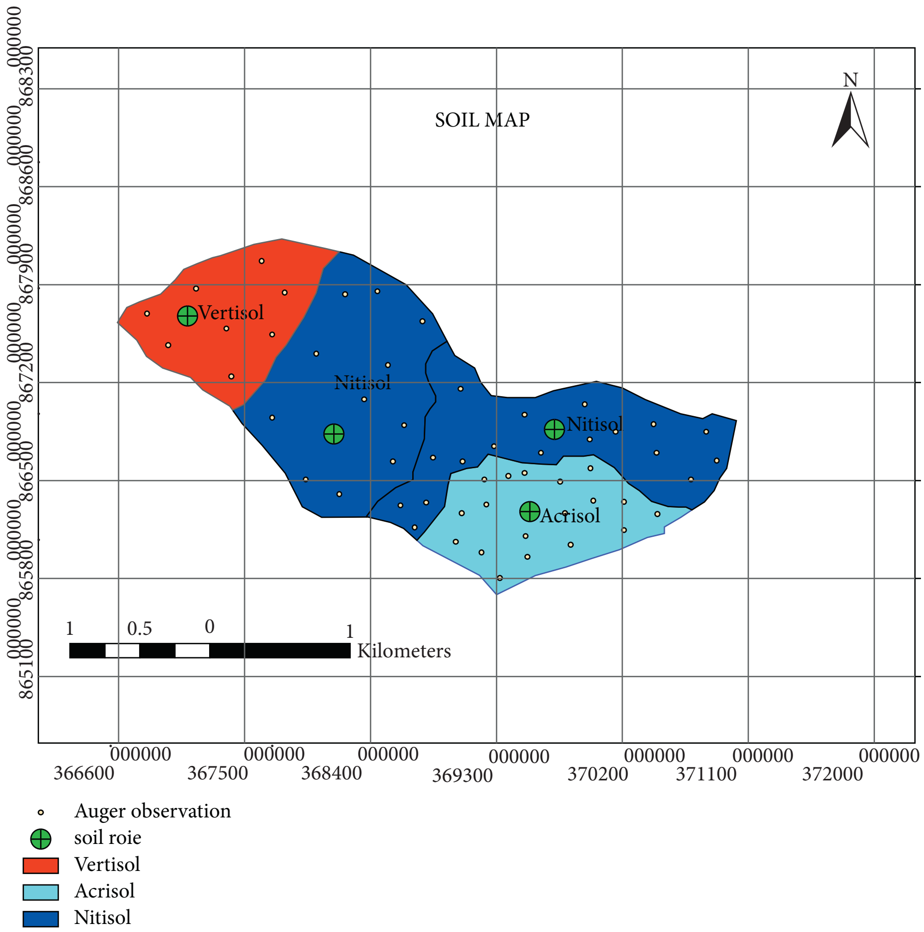


Figure 7: Soil map of Anzecha watershed.

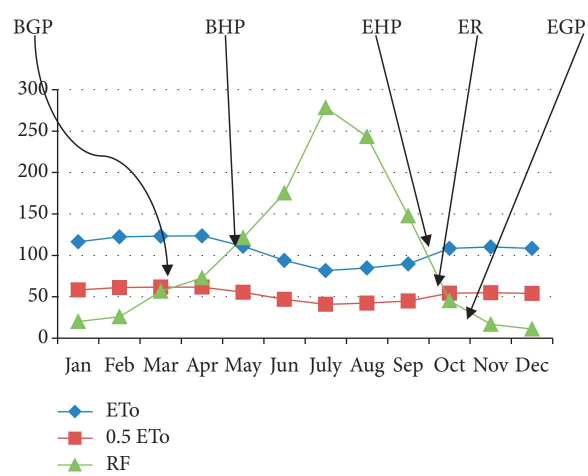


Figure 8: Determination of LGP in the watershed. BGP = beginning of growing period, BHB = beginning of humid period, EHP = end of humid period, ER = end of rainy season, and EGP = end of growing period.

FAO working definition which exhibits a humid period (precipitation > potential evapotranspiration), the start of the growing period was apparently based on the start of the rainy season in which the rainfall was greater than or equal to half of reference evapotranspiration (ETo) (Figure 8). The average ETo during the rainy season of the area was estimated to be 92.22 mm/month (3.07 mm/day).

The period that agreed with FAO procedure humid period and the beginning of growing period was derived from the start of the rainy season ($RF \geq 0.5ETo$). The beginning of the rainy season (start of growing period) in the study area was on April 2 and the end was ($RF \leq 0.5ETo$) on October 10. The mean calculated value of LGP in study area is about 188 days (Figure 5). However, the assumed 100 mm

Table 7: Climatic, surface soil, and landscape characteristics at Anzecha watershed.

Land requirements		Landscape position			
Land quality	Diagnostic factor and unit	Upper slope	Middle slope	Lower slope	Toe slope
Moisture availability (c)	LGP (days)	215	215	215	215
	RF during growing cycle (mm)	965.6	965.6	965.6	965.6
Temperature (c)	Mean temperature of growing cycle (°C)	17.3	17.3	17.3	17.3
Rooting condition (s)	Texture (class)	SL	SC	SC	C
	Effective soil depth (cm)	200+	200+	200+	200+
Wetness (w)	Drainage	WD	MW	MW	MW
	Flooding	N	N	N	N
Natural fertility (f)	CEC (Cmolc/kg) soil	23.3	38	37.8	41.2
	pH (H_2O)	4.8	5.44	5.5	5.54
	EC (dS/m)	0.61	0.77	0.61	0.68
	SOM (%)	2.08	5.41	6.03	5.94
	SOC (%)	1.21	3.14	3.5	3.45
	PBS (%)	27.76	71.31	59.52	53.32
Erosion hazard (t)	Slope (%)	10–12	5–10	2–5	1-2
Land preparation (ip)	Coarse fragments (%)	N	N	N	N
	Rock outcrops	Very few	N	N	N

SC = sandy clay; WD = well drained; MW = moderately well drained; C = clay; N = none; LGP = length of growing period; RF = rainfall; CEC = cation exchange capacity; pH = soil reaction; EC = electrical conductivity; SOM = soil organic matter; SOC = soil organic carbon; PBS = percent base saturation.

of water expected to be stored within the soil at the end of rain requires some additional number of days to be evaporated. The daily evapotranspiration in October was 3.61 mm/day, and removing 100 mm water in the soil reserve requires 27 days, which expands the end of growing period up to November 7. Accordingly, the LGP extended up to November 7, which was a total of 215 days required for the end of the growing period (Figure 8).

The important climatic, surface soil, and landscape characteristics were used to evaluate the suitability of land for rain-fed production of maize, teff, and wheat in study watershed depicted in Table 7. Varieties considered for the production of major crops in the watershed were BH661 for maize, Quncho for teff, and Hidasie for wheat.

3.5.2. Climatic, Soil and Landscape Suitability Evaluation. The overall climatic evaluation of the study area was moderately suitable for maize, marginally suitable for teff, and highly suitable for wheat (Table 8–11). The limiting factor for maize production was excessive rainfall and low temperature during the growing cycle (Table 12); maize can grow well at a rainfall range of 500–750 mm and the temperature range of 24–19.5 or 24–32°C. The limiting factor for teff production was excessive rainfall during growing cycle (Table 13); teff can grow well at the rainfall range of 450–500 mm and the area was highly suitable for wheat production (Table 14).

The overall soil and landscape suitability evaluation for upper slope position was currently not suitable for maize, teff, and wheat production (Table 9) (Figures 9–11). The limiting factors for production of maize were coarse texture (sandy loam); low levels of CEC (23.3 Cmolc/kg soil), pH (4.8), SOM (2.08%), SOC (1.21%), and PBS (27.76); and high erosion hazard (slope 10–12%).

The overall soil and landscape suitability evaluation for middle slope position was marginally suitable for maize, teff, and wheat production (Table 10). The limiting factors for maize production were low level of pH (5.44) and PBS (71.31%) and high erosion hazard (slope 5–10%). The limiting factor for teff production was coarse texture (sandy clay) and low pH (5.44). The limiting factor for wheat production was low level of pH and high erosion hazard.

The overall soil and landscape suitability evaluation for lower slope position was moderately suitable for maize production and marginally suitable for teff and wheat (Table 11). The limiting factors for maize production were low levels of pH (5.5) and PBS (59.52%). The limiting factor for teff production was coarse texture (sandy clay). The limiting factor for wheat production was low pH.

The overall soil and landscape suitability evaluation for toe slope position was moderately suitable for maize production, marginally suitable for wheat production, and highly suitable for tef production (Table 8). The limiting factor for maize production was low level of pH (5.54) and PBS (53.32%). The limiting factor for wheat production was low level of pH.

The combination of climatic, soil, and landscape parameters were used to evaluate the overall suitability of major crops at study area. For maize production, upper slope position was currently not suitable. The constraints were excessive rainfall; low temperature; coarse soil texture; low values of CEC, pH, SOM, OC, and PBS; and high erosion hazard. Middle slope position was marginally suitable. The constraints are excessive rainfall, low levels of temperature, soil reaction, PBS, and high erosion hazard. Lower and toe slope positions were moderately suitable. The constraints were excessive rainfall, low levels of temperature, PBS, and soil reaction (Table 15).

For teff production, upper slope position was currently not suitable. The constraints were excessive rainfall, coarse

Table 8: Climatic, soil, and landscape suitability evaluation for maize, teff, and wheat at Anzech watershed for upper slope position.

Upper slope position					
Land requirements			Land utilization type		
Land quality	Diagnostic factor and unit	Factor value	Maize	Teff	Wheat
Moisture availability (c)	LGP (days)	215	S1	S1	S1
	RF during growing cycle (mm)	965.6	S2	S3	S1
Temperature (c)	Mean temperature of growing cycle (°C)	17.3	S2	S1	S1
	Overall climatic suitability		S2	S3	S1
Rooting condition (s)	Texture (class)	SL	S2	N1	S3
	Effective soil depth (cm)	200+	S1	S1	S1
Wetness (w)	Drainage	WD	S1	S1	S1
	Flooding	N	S1	S1	S1
Natural fertility (f)	CEC (cmolc/kg soil)	23.3	S3	S3	S1
	pH (H_2O)	4.8	N1	N1	N1
	EC (ds/m)	0.61	S1	S1	S1
	SOM (%)	2.08	S3	S3	S3
	SOC (%)	1.21	S2	S3	S2
	PBS (%)	27.76	S3	S2	S3
Erosion hazard (t)	Slope (%)	10–12	S2	S1	S2
Land preparation (ip)	Coarse fragments (%)	N	S1	S1	S1
	Rock outcrops (%)	0-2	S1	S1	S1
Overall soil and landscape suitability			N1	N1	N1

SL = sandy loam; WD = well drained; N = none; LGP = length of growing period; RF = rainfall; CEC = cation exchange capacity; pH = soil reaction; EC = electrical conductivity; SOM = soil organic matter; SOC = soil organic carbon; PBS = percent base saturation; S1 = highly suitable; S2 = moderately suitable; S3 = marginally suitable; N1 = currently not suitable.

Table 9: Climatic, soil, and landscape suitability evaluation for maize, teff, and wheat at Anzech watershed for middle slope position.

Middle slope position					
Land requirements			Land utilization type		
Land quality	Diagnostic factor and unit	Factor value	Maize	Teff	Wheat
Moisture availability(c)	LGP (days)	215	S1	S1	S1
	RF during growing cycle (mm)	965.6	S2	S3	S1
Temperature (c)	Mean n temperature of growing cycle (°C)	17.3	S2	S1	S1
	Overall climatic suitability		S2	S3	S1
Rooting condition (s)	Texture (class)	SC	S1	S3	S1
	Effective soil depth (cm)	200+	S1	S1	S1
Wetness (w)	Drainage	MW	S1	S1	S1
	Flooding	N	S1	S1	S1
Natural fertility (f)	CEC (cmolc/kg soil)	38	S1	S1	S1
	pH (H_2O)	5.44	S3	S2	S3
	EC (dS/m)	0.77	S1	S1	S1
	SOM (%)	5.41	S1	S1	S1
	SOC (%)	3.14	S1	S1	S1
	PBS (%)	71.31	S2	S1	S1
Erosion hazard (t)	Slope (%)	5–10	S2	S1	S2
Land preparation (ip)	Coarse fragments (%)	N	S1	S1	S1
	Rock outcrops (%)	N	S1	S1	S1
Overall soil and landscape suitability			S3	S3	S3

SC = sandy clay; WD = moderately well drained; N = none; LGP = length of growing period; RF = rainfall; CEC = cation exchange capacity; pH = soil reaction; EC = electrical conductivity; SOM = soil organic matter; SOC = soil organic carbon; PBS = percent base saturation; S1 = highly suitable; S2 = moderately suitable; S3 = marginally suitable.

texture, low levels of pH, CEC, SOM, SOC, and PBS. All of the other land mapping units were marginally suitable. The constraints for middle slope position were excessive rainfall, coarse texture, and low soil acidity. The constraints for lower slope position were excessive rainfall and coarse texture. The constraint for toe slope position was excessive rainfall (Table 15).

For wheat production, upper slope position was currently not suitable. The constraints were coarse texture; low levels of pH, SOM, OC, and PBS; and high erosion hazard.

Table 10: Suitability evaluation for teff and wheat at Anzech watershed for lower slope position.

Lower slope position					
Land requirements			Land utilization type		
Land quality	Diagnostic factor and unit	Factor value	Maize	Teff	Wheat
Moisture availability(c)	LGP (days)	215	S1	S1	S1
	RF during growing cycle (mm)	965.6	S2	S3	S1
Temperature (c)	Mean n temperature of growing cycle (°C)	17.3	S2	S1	S1
	Overall climatic suitability		S2	S3	S1
Rooting condition (s)	Texture (class)	SC	S1	S3	S1
	Effective soil depth (cm)	200+	S1	S1	S1
Wetness (w)	Drainage	MW	S1	S1	S1
	Flooding	N	S1	S1	S1
Natural fertility (f)	CEC (cmolc/kg soil)	37.8	S1	S1	S1
	pH (H_2O)	5.5	S2	S1	S3
	EC (dS/m)	0.61	S1	S1	S1
	SOM (%)	6.03	S1	S1	S1
	SOC (%)	3.5	S1	S1	S1
	PBS (%)	59.52	S2	S1	S1
Erosion hazard (t)	Slope (%)	2–5	S1	S1	S1
Land preparation (ip)	Coarse fragments (%)	None	S1	S1	S1
	Rock outcrops (%)	None	S1	S1	S1
Overall soil and landscape suitability			S2	S3	S3

SL = sandy clay; WD = moderately well drained; N = none; LGP = length of growing period; RF = rainfall; CEC = cation exchange capacity; pH = soil reaction; EC = electrical conductivity; SOM = soil organic matter; SOC = soil organic carbon; PBS = percent base saturation; S1 = highly suitable; S2 = moderately suitable; S3 = marginally suitable.

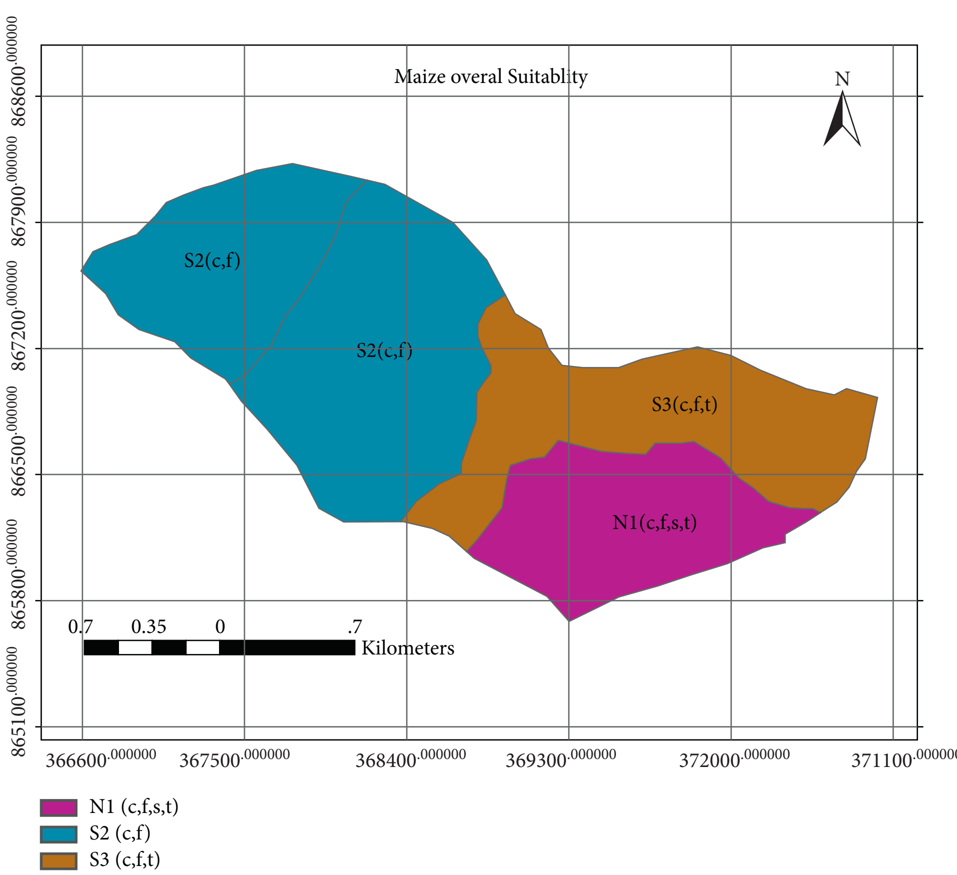


Figure 9: Overall current suitability map of Anzecha watershed for maize production.

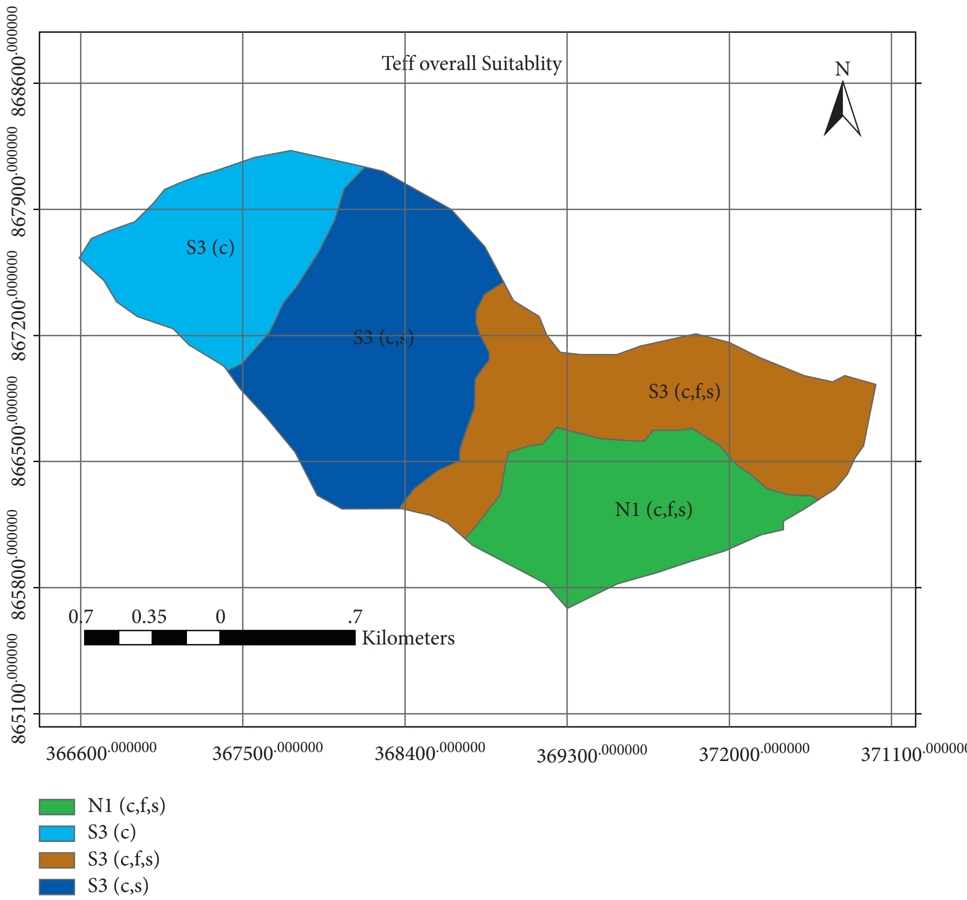


Figure 10: Overall current suitability map of Anzecha watershed for teff production.

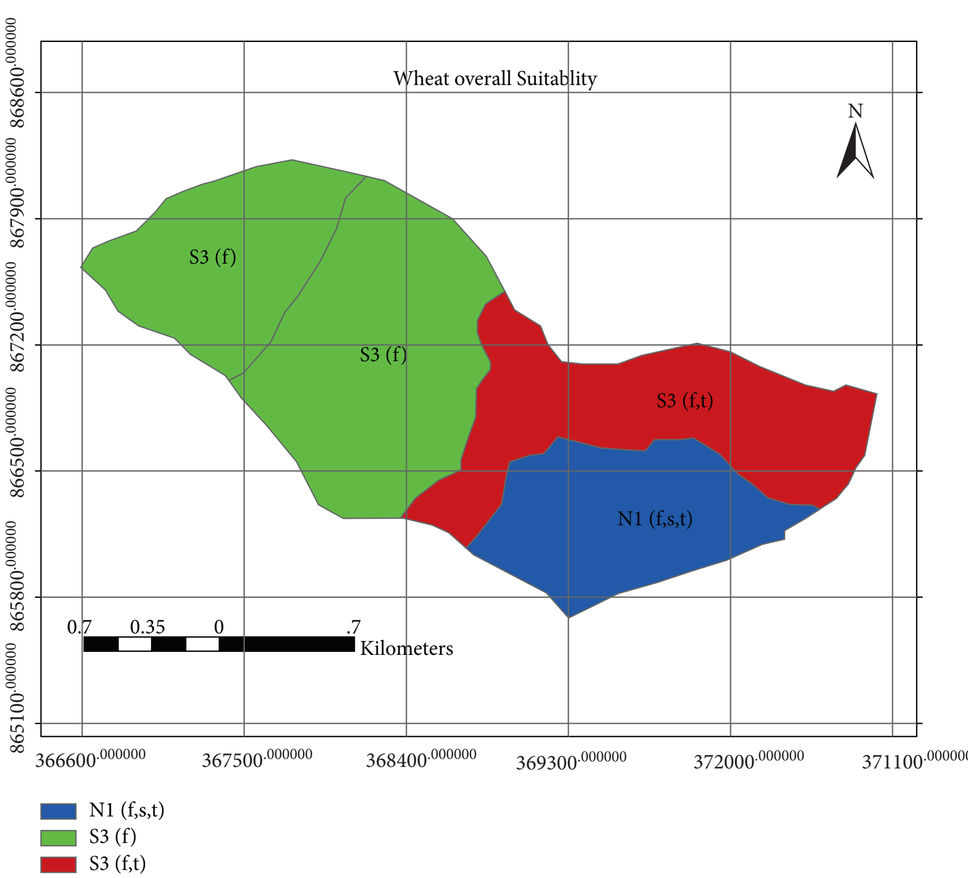


Figure 11: Overall current suitability map of Anzecha watershed for wheat production.

Table 11: Climatic, soil, and landscape suitability evaluation for maize, teff, and wheat at Anzech watershed for toe slope position.

Toe slope position					
Land requirements			Land utilization type		
Land quality	Diagnostic factor and unit	Factor value	Maize	Teff	Wheat
Moisture availability (c)	LGP (days)	215	S1	S1	S1
	RF during growing cycle (mm)	965.6	S2	S3	S1
Temperature (c)	Mean temperature of growing cycle (°C)	17.3	S2	S1	S1
	Overall climatic suitability		S2	S3	S1
Rooting condition (s)	Texture (class)	C	S1	S1	S1
	Effective soil depth (cm)	200+	S1	S1	S1
Wetness (w)	Drainage	MW	S1	S1	S1
	Flooding	N	S1	S1	S1
Natural fertility (f)	CEC (Cmolc/kg soil)	41.2	S1	S1	S1
	pH (H_2O)	5.54	S2	S1	S3
	EC (dS/m)	0.68	S1	S1	S1
	SOM (%)	5.94	S1	S1	S1
	SOC (%)	3.47	S1	S1	S1
	PBS (%)	53.32	S2	S1	S1
Erosion hazard (t)	Slope (%)	1-2	S1	S1	S1
Land preparation (ip)	Coarse fragments (%)	None	S1	S1	S1
	Rock outcrops (%)	None	S1	S1	S1
Overall soil and landscape suitability			S2	S1	S3

C = clay; WD = well drained; N = none; LGP = length of growing period; RF = rainfall; CEC = cation exchange capacity; pH = soil reaction; EC = electrical conductivity; SOM = soil organic matter; SOC = soil organic carbon; PBS = percent base saturation; S1 = highly suitable; S2 = moderately suitable; S3 = marginally suitable; N1 = currently not suitable.

Table 12: Land use requirements based on land characteristics data for rain fed maize.

Land use requirements		Class, degree of limitation, and rating scale				
Land quality	Diagnostic factor and unit	100–85%	85–60%	60–40%	<40%	
		S1	S2	S3	N1	N2
Moisture availability (m)	LGP (days)	140–220	120–140; 220–270	90–120; 270–300	<90; >300	—
	Rainfall growing cycle (mm)	500–750	400–500; 750–1200	300–400; 1200–1600	—	<300; >1600
Temperature regime (T)	Mean temperature of growing cycle (°C)	24–19.5, 24–32	19.5–16, 32–35	16–14, 35–40	—	<14, >40
Rooting condition (r)	Texture (class)	SiC, SiCL, Si, SiL, CL, SC, L, C	SL, LS	SCL	—	cS, LcS, Cm
	Effective soil depth (cm)	>80, 80–50	40–80	20–40	—	<20
Wetness (w)	Flood risk (f)	Fo	—	F1	—	F2+
	Drainage (class)	Good, moderate	Imperfect	Poor	Poor but	VP
Natural soil fertility (n)	CEC (cmolc/kg soil)	>31	31–27	27–16	<16	—
	pH (H_2O)	7.0–6.0	6.0–5.5, 7.0–7.8	5.5–5.2, 8.2–8.5	<5.2, >8.5	—
	EC (dS/m)	<2.5	2.5–3.8	3.8–5.9	5.9–12	>12
	SOM (%) (0–50 cm)	>3	3.0–2.5	2.5–1.0	<1	—
	SOC (%)	>2	1-2	0.5–1	<0.5	—
	PBS (%)	>80	40–80	20–40	<20	—
Erosion hazard (e)	Slope (%)	0–8	8–16	16–30	30–50	>50
Land preparation (ip)	Coarse fragment (%) (0–50 cm)	<3	5–35	35–55	—	>55
	Rock outcrop (%)	<5	5–15	15–25	>25	—

Source: (FAO [28, 29]; Sys et al. [32]; Lupia [31]; Djaenudin et al. [30]). LGP = length of growing period; S1 = highly suitable; S2 = moderately suitable; S3 = marginally suitable; N1 = currently not suitable but potentially suitable; N2 = potentially not suitable; CEC = cation exchange capacity; EC = electrical conductivity; PBS = percent base saturation; SOM = soil organic matter; SOC = soil organic carbon; pH = soil reaction; SL = sandy loam; L = loam; C = clay; CL = clay loam; Si = silt; SiC = silty clay; SiL = silty loam; SiCL = silty clay loam; SC = sandy clay; SCL = sandy clay loam; Cm = massive clay; cS = heavy sand; SiCm = silty massive clay; FO = no risk; F1 = slight; F2 = common; VP = very poorly drained.

Table 13: Land use requirements based on land characteristics data for rain fed teff.

Land use requirements		Class, degree of limitation, and rating scale				
Land quality	Diagnostic factor and unit	100–85% S1	85–60% S2	60–40% S3	<40% N1	N2
Moisture availability (m)	LGP (days)	100–150	95–110	75–90, 150–180	<75, >180	—
	Rain fall growing cycle (mm)	450–550	300–450, 550–800	800–1200	<200, >1200	—
Temperature regime (T)	Mean temperature of growing cycle (°C)	15–21	14–15, 21–22	11–14, 22–25	11–12, 23–25	<11, >25
Rooting condition (r)	Texture (class)	Si, SiC, C	SiCL	SiL, CL, L, SC	SCL, SL	S, LS
	Effective soil depth (cm)	>50	30–50	20–30	10–20	<10
Wetness (w)	Flooding (f)	F0	F1	F2	—	F3+
	Drainage (class)	Good	Imperfect	Poor	Poor but	VP
Natural fertility (n)	CEC (cmolc/kg soil)	>30	30–28	28–16	<16	
	pH (H_2O)	5.5–7.5	5.2–5.5, 7.5–7.8	5.0–5.2, 7.8–8.5	4.5–5	<4.5, >8.5
	EC (dS/m)	<2.5	2.5–3.8	3.8–5.9	5.9–10	>10
	SOM (%)	>3.0	2.5–3.0	2.0–2.5	1.0–2.0	—
	SOC (%)	>1.74	1.45–1.74	1.16–1.45	0.58–1.16	—
	PBS (%)	>50, 50–35	35–15	<15	—	—
Erosion hazard (e)	Slope (%)	<13	13–25	25–50	50–55	>55
Land preparation (ip)	Coarse fragment (%)	<3	3–10	10–15	—	—
	Rock outcrops (%)	<5	5–15	15–25	>25	—

Source: (FAO [28, 29]; Sys et al. [32]; Lupia [31]; Djaenudin et al. [30]). LGP = length of growing period; S1 = highly suitable; S2 = moderately suitable; S3 = marginally suitable; N1 = currently not suitable but potentially suitable; N2 = potentially not suitable; CEC = cation exchange capacity; EC = electrical conductivity; PBS = percent base saturation; SOM = soil organic matter; SOC = soil organic carbon; pH = soil reaction; SL = sandy loam; L = loam; C = clay; CL = clay loam; Si = silt; SiC = silty clay; SiL = silty loam; SiCL = silty clay loam; SC = sandy clay; SCL = sandy clay loam; FO = no risk; F1 = slight; F2 = common; VP = very poorly drained.

Table 14: Land use requirements based on land characteristics data for rain fed wheat.

Land use requirements		Class, degree of limitation, and rating scale				
Land quality	Diagnostic factor and unit	100–95% S1	95–85% S2	85–60% S3	<40% N1	N2
Moisture availability (mm)	LGP (days)	130–140, 120–155	100–120, 155–180	80–100, 180–230	<80, >230	—
	Rainfall growing cycle (mm)	700–1000, 350–1250	250–350, 1250–1500	250–200, 1500–1750	—	<200, >1750
Temperature regime (t)	Mean temperature of growing cycle (°C)	18–20, 15–20	12–15, 20–25	10–12, 25–27	8–10, 27–30	<8, >30
Rooting condition (r)	Texture (class)	SiC, C, Si, SiL, CL, SC, L	SCL	SL	—	S, SiCm
	Effective soil depth (cm)	>90	50–90	20–50	10–20	<10
Wetness (w)	Flooding (f)	F0	F1	F2	—	F3+
	Drainage (class)	Good, moderate	Imperfect	Poor	Poor but	VP
Natural soil fertility (n)	CEC (cmolc/kg soil)	>24, 24–16	<16 (−)	<16 (+)	—	—
	pH (H_2O)	6.5–7.5, 6–8.2	6–5.6, 8.2–8.3	5.6–5.2, 8.3–8.5	<5.2, >8.5	—
	EC (dS/m)	0–1, 1–3	3–5	5–6	6–10	>10
	SOM (%)	>3.0	2.5–3.0	2.0–2.5	1.0–2.0	—
	SOC (%)	>2.5, 1.5–2.5	1.0–1.5	0.5–1.0	<0.5	—
	PBS (%)	>80, 80–50	50–35	<35	—	—
Erosion hazard (e)	Slope (%)	<2, 2–8	8–16	16–30	—	>30
Land preparation	Coarse fragment (%)	<3, 3–15	15–35	35–55	—	—
	Rock outcrop (%)	<5	5–15	15–25	>25	—

Source: (FAO [28, 29]; Sys et al. [32]; Lupia [31]; Djaenudin et al. [30]). LGP = length of growing period; S1 = highly suitable; S2 = moderately suitable; S3 = marginally suitable; N1 = currently not suitable but potentially suitable; N2 = potentially not suitable; CEC = cation exchange capacity; EC = electrical conductivity; PBS = percent base saturation; SOM = soil organic matter; SOC = soil organic carbon; pH = soil reaction; SL = sandy loam; L = loam; C = clay; CL = clay loam; Si = silt; SiC = silty clay; SiL = silty loam; SC = sandy clay; SCL = sandy clay loam; S = sand; SiCm = massive silty clay; FO = no risk; F1 = slight; F2 = common; F3 = frequent; VP = very poorly drained.

Table 15: Overall suitability evaluation for maize, teff, and wheat production at Anzecha watershed.

Landscape position	The climatic suitability	The soil and landscape suitability	The current overall suitability	The potential overall suitability	Area/ ha	(%)
Maize						
Upper slope	S2 (c)	N1 (f, s, t)	N1 (c, f, s, t)	S2 (c, s, t)	112.7	20.8
Meddle slope	S2 (c)	S3 (f, t)	S3 (c, f, t)	S2 (c, t)	147.4	27.3
Lower slope	S2 (c)	S2 (f)	S2 (c, f)	S2 (c)	175.4	32.5
Toe slope	S2 (c)	S2 (f)	S2 (c, f)	S2 (c)	104.5	19.4
Teff						
Upper slope	S3 (c)	N1 (f, s)	N1 (c, f, s)	N1 (c, s)	112.7	20.8
Middle slope	S3 (c)	S3 (f, s)	S3 (c, f, s)	S3 (c, s)	147.4	27.3
Lower slope	S3(c)	S3 (s)	S3 (c, s)	S3 (c, s)	175.4	32.5
Toe slope	S3 (c)	S1	S3 (c)	S3 (c)	104.5	19.4
Wheat						
Upper slope	S1	N1 (f, s, t)	N1 (f, s, t)	S3 (s, t)	112.7	20.8
Middle slope	S1	S3 (f, t)	S3 (f, t)	S2 (t)	147.4	27.3
Lower slope	S1	S3 (f)	S3 (f)	S1	175.4	32.5
Toe slope	S1	S3 (f)	S3 (f)	S1	104.5	19.4

c = climatic limitation (moisture and temperature); f = natural fertility limitations (CEC, OC, PBS, EC, and pH); t = topographic limitations (erosion hazard).

All the remaining land mapping units were marginally suitable. The constraints for middle slope position were soil acidity and high erosion hazard. The constraints for both lower and toe slope positions were high soil acidity (Table 15).

Soil acidity was the major limiting factor for all crop production in the study watershed except in lower and toe slope positions for teff production in addition to that of PBS which was also a major constraint for maize production in all land-mapping units. The climatic condition was highly suitable for wheat production, excessive rainfall and low temperature were a constraint for maize production, and excessive rainfall was also a constraint for teff production; the coarse texture was a constraint at upper slope position for maize and wheat production and major constraint for teff production except in toe slope position. The slope gradient of the area was the limiting factor for maize and wheat production in upper and middle slope positions in study watershed (Table 15).

4. Conclusions

The climatic conditions of the area are moderately suitable (S2) for maize due to excessive rainfall and low temperature, marginally suitable (S3) for teff due to excessive rainfall and highly suitable (S1) for wheat production. The soil acidity is the major limiting factor for maize, teff, and wheat except in the lower and toe slope positions for teff production. The coarser texture of soil is the limiting factor at upper slope position for all selected major crop productions. The slope gradient is the limiting factor for maize and wheat production at upper and middle slope positions of the watershed. Based on overall current suitability, upper slope position is unsuitable (N1) for maize, teff, and wheat production and middle slope position is marginally suitable (S3) for maize, teff, and wheat production. Lower and toe slope positions are moderately suitable for maize and marginally suitable for teff and wheat production. Generally, the acidity and low status of available phosphorus of the soils of the study area were the very limiting factors for optimum and sustainable production of the considered crops. Acid soil amelioration-related research should be one of the research priority topics in the study area, as soil acidity is the major limiting factor for the production of maize, teff, and wheat (see Tables 13–15).

The conventional way of crop production activities of the study area does not consider optimization and sustainability. An appropriate land use decision is very important for optimum and sustainable crop production. An appropriate land use decision is only possible after conducting soil survey and land suitability evaluation of the area. Therefore, the study could have great contribution for making an appropriate land use decision and soil management for optimum and sustainable crop production of the study area.

Data Availability

All data can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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