GIS and Remote Sensing Based Physical Land Suitability Analysis for Major Cereal Crops Using Multi-Criteria Evaluation Approach: The Case of Gimbi District, West Wollega Zone, Western Ethiopia.

FULL TITLE

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ARTICLE TYPE

Research Article

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Alemayehu Gemeda *

Abstract:

Land suitability analysis is crucial for manageable agricultural production. This was aimed at evaluating the current physical land suitability for major cereal crops: teff, wheat, barley and maize in the Gimbi district, West Wollega Zone, West Ethiopia.A GIS and RS technique with a multi-criteria evaluation approach was applied for evaluating the physical land suitability for the major crops. Various physical land attributes, namely temperature, rainfall, altitude, slope, soil (soil depth, pH, texture, and drainage), land use land cover, accessibility to market and proximity to road have been used as input parameters. Physical land suitability maps were generated for the major cereal crops. This study demonstrates that 0.85%, 0.35%, 0.2 %, 1.63% and 2.44 % of the study area are classified as highly suitable for Teff, Wheat, Barley, Maize and Sorghum production, respectively. This indicates that most of the study area is best suitable for maize and sorghum as the dominant cereal crop produced in this study are in relation to other crops. On the other hand, 4.87%, 3.37%, 2.5 %, 9.83% and 10.44% were found to be moderately suitable while 19.89%, 12.2%, 8.9%, 42.66 and 44.09% were marginally suitable land for teff, wheat, barley, maize and sorghum respectively. However 38.72%, 49.53%, 53.6%, 14.45% and 14.22% of the study area were classified as currently not suitable for teff, wheat, barley, maize and sorghum respectively. This study report urges the concerned stakeholders to properly use and adopt precisely the optimum physical land suitability planning to expend the present land resources for more cereal crop productivity in a sustainable manner for better socio-economic development of the region.

Keywords: Cereal crops; district; GIS; remote sensing, land suitability

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Public interest

Most of the Ethiopian highland croplands and grass lands are affected by water induced soil erosion. Because of erosion, vast amount of soil is lost from these lands, leading to environmental degradation, poor agricultural productivity, and food insecurity that has became a major development challenge of the nation. This study paper provides information on the *Land Suitability Analysis for Major Cereal Crops Using Multi-Criteria Evaluation Approach* in *Gimbi District*, which is one of the *Districts* in Ethiopia.

The findings of this study help decision makers and other stakeholders in planning appropriate crops to increase the productivity of the land and reduce the problems of food security and improve social and environmental wellbeing of the people within the watershed areas.

1. INTRODUCTION

Globally, agriculture has recognized the potential to increase food supplies faster than the growth of the population, a pattern to be expected in the foreseeable future [10]. The available resources and technologies to answer the demands of the growing population for food and other agricultural commodities remains uncertain [21].

There is growing concern and worsening in food security in Sub Saharan Africa [21]. World population is growing rapidly and an increase of food supply is urgently needed to meet those demands. According to [24] on the three decades of agriculture in the Sub Saharan region, besides losing export market failed to increase the production of food calories per capital above 2100/day Regionally. Land resource is becoming scarce and limited as population growth may exert a pressure on the available land. To increase food production and provide food security, crops need to be grown in areas where they are best suited and carrying out land suitability analysis can help identify such areas [58].

According to [54] report, agricultural land suitability analysis is very important since agriculture accounts on average for about 42.9% of Growth Domestic Product compared to 46.5 percent in 2009/10 Nationally. On the other hand 83.9% of the exports were from agriculture and 80% of the labor force in Ethiopia is engaged in this sector. The same source indicated that Ethiopia has great agricultural potential because of its vast areas of fertile land, diverse agro-ecological environment, generally adequate rainfall, and large labor pool is magnificently available which can progress the agricultural productivity.

Cereal crop production constitutes to agricultural production and significantly to the national domestic product. Only two percent are produced by commercial farms, primarily for seed purposes. Ethiopian agriculture has remained underdeveloped because of drought, a poor economic base, and low level of technologies on agricultural applications [28].

The most important and urgent problems in Ethiopia is to improve agricultural land management to increase the agricultural production with effective and efficient, use of land resources for better socioeconomic development of the country [35].

According to [11], analysis of land suitability contribute to the world's food production and improves food security by providing requisite information for matching crop production with land suitability . The process of land suitability analysis is the categorization and grouping of specific areas of land in terms of their suitability for defined usage [15]. Land needs careful and appropriate use with effective and operative management of land information because land is one of the non-renewable natural resource. Land evaluation is concerned with the assessment and valuation of land when used for specified purposes.

Gimbi district is one of the district in which agriculture is the dominant activity in Ethiopia.But this agricultural activity is not based on land suitability analysis. Therefore, there is an urgent need to develop land suitability analysis of the land and for crop production. *[29]*

This study integrates multi-criteria evaluation with GIS to identify the suitable areas for the selected cereal crops *teff (Eragrostis tef Zucc),wheat (aestivum L), sorghum (sorghum vulgare L. , barley (Hordeum Vulgare L. and maize (Zea mays L)* using the relevant variables of soil, climate, land use land cover, market, road and topographic factors to improve crop production and livelihood status of particularly small holder farmers.

The problem of selecting the correct land for cultivation of a certain agricultural product according to its potential suitability is still a serious problem particularly in developing countries as it is a long standing and mainly empirical issue [61]. According to [32], Western Ethiopia in general and West Wollega in particular currently face various problems resulting from unwise use of land resource due partly to the fact that the level of the problem has not been studied.
Some authors like [73, 34, 11, 37] carried out land suitability analysis by using factors such as climate, soil, land use, and topography. All of them recommend that these factors are not the only end to say one land is suitable for any type of crops. But there are also other factors that can influence land suitability. For instance, other socioeconomic and infrastructure factors are important that has to be considered like market and roads proximity. It is advisable and recommendable to carry out a research study of physical land suitability analysis in Gimbi district due to many reasons such as; the agricultural system in the area is commonly rain fed practice and most of the communities' livelihood is highly dependent on agriculture. Currently associated with large population growth, limited livelihood opportunity and global climate variability, agricultural productivity per hectare of land suitability is declining and food security becoming a chronic problem in the study area. So, crop-land suitability analysis is a very crucial to achieve optimum land utilization for sustainable agricultural productivity.

Therefore, the results of this study may help land policy makers for land use planning and management in the district for better land resources utilization, sustainable agriculture in cereal production and bio-diversity conservation. This study interested to do so by including these factors so as to determine weather the land of the study area is suitable for the identified cereal crops. Hence, it is very important and advisable to study land suitability analysis for cereal crop productivity for better socioeconomic development.The aim of this study was to analyze physical land suitability, identify the major land suitability factors, evaluate and optimize land suitability and generate land suitability maps.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

2.1.1. Location of Gimbi District

The study was conducted at Gimbi District, located between 35°42'10" to 36°8'40"E and 8°58'11" to 9°21'7"N. Gimbi is one of the 20 West Wollega Zone districts and is about 441 km from the capital Addis Ababa to the south west direction. The head quarters of the district is Gimbi town. It has 32 village administrations with a total area of 102,970 hectares. The altitude of the district ranges from 1048 to 2218 meters. *(ETHIOGIS, ETHIODEM)*

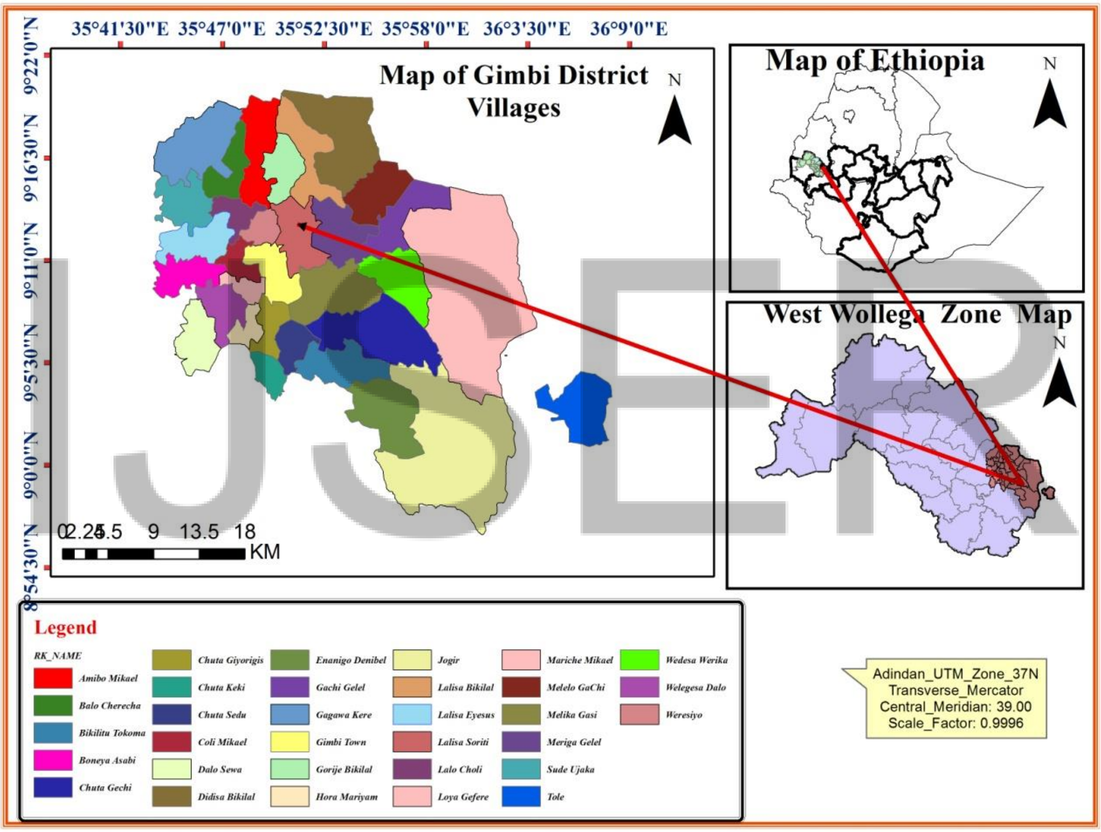

Figure 1: Location Map of the Study Area

2.1.2. Demographic Characteristics

According to Central Statistical Agency population data projected for 2018, the total population of Gimbi district was estimated to be 88,788 of which 43,560 and 45,228 were male and females respectively. [9].

2.1.3. Agro-ecology

According to [53] traditional classification, agro-ecology of Ethiopia is classified as Kur, Wurch, Dega, Woina-dega, Kolla and Bereha. The altitude of the area ranges from 1190 to 2323m a.m.s.l. Based on the agro ecological classification, the agro-ecology of the Gimbi district, falls in Weina Dega and Kolla. The area receives an average annual rain fall ranging from 800 to 2,000 mm. Mean monthly rainfall not exceeding 2,000 mm. The annual average, mean minimum and mean maximum temperatures are 20, 14 and 26^0 C, respectively. [29]

2.1.4. Soil

Types of soils in the area are nitosols and gleysols as the most dominant. Accordingly, nine major soil types exist of which nitosols and gleysols covers the largest area followed by luvisols, fluvisols. Orthic solonchaks, in contrast, Orthic acrisols covers least part of the study area.

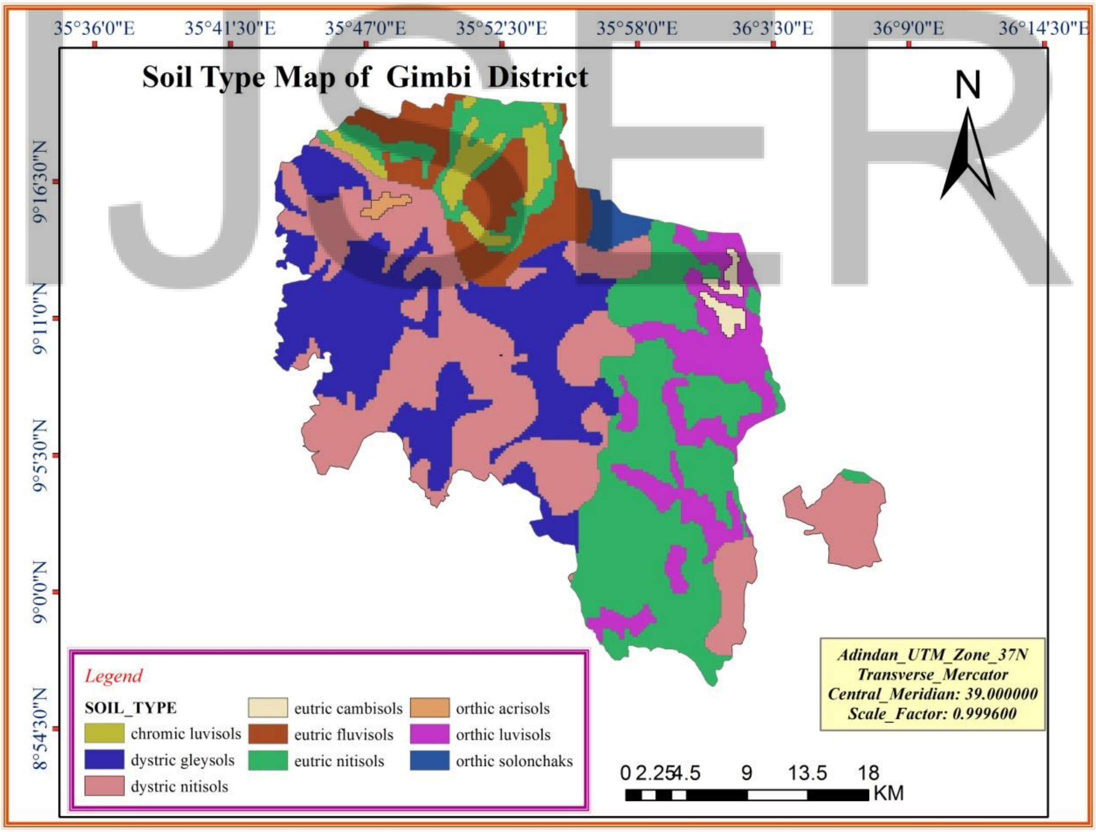

Figure 2: Soil Type Map of Gimbi District

2.1.5. Crop Production

The area is covered with teff, wheat, barley, maize, sorghum, and millet, pulses (chickpea, lentil, faba bean, vetch and pea), oil seeds (linseed) and vegetables (garlic, onion, green pepper, potato). Cereals are produced for consumption and market while the Pulses (mainly chick pea and lentil) are produced largely for market and they are considered as valuable cash crop for the study area. Teff, wheat, chick pea and lentil are the most important crops in terms of area coverage, production per hectare and market demand [29]

Table 1: Cereal Crop Production of 4 Years Yield/Quintal

No	*Type of Cereal Crops*	*Cropping Year*							
		2014/2015(2007)		*2015/2016(2008)*		*2016/2017(2009)*		*2017/2018(2010)*	
		Land (Ha.)	*Yield (Q/Ha)*	*Land (Ha.)*	*Yield (Q/Ha)*	*Land (Ha.)*	*Yield (Q/Ha)*	*Land (Ha.)*	*Yield (Q/Ha)*
1	*Teff*	*1,500*	*18,037*	*1,540*	*18,480*	*1,600*	*19,000*	*1,600*	*21,300*
2	*Maize*	*4,460*	*191,908*	*4,500*	*198,000*	*4,500*	*200,300*	*4,500*	*258,550*
3	*Sorghum*	*2,850*	*94,860*	*2,900*	*94,900*	*2,950*	*92,960*	*2,837*	*119,196*
4	*Wheat*	*394*	*6,648*	*410*	*6,770*	*397*	*6,352*	*400*	*6,370*
5	*Barley*	*250*	*3,980*	*260*	*4,160*	*300*	*4,100*	*254*	*5,570*
Total		***9,454***	***315,433***	***9,610***	***322,310***	***9,747***	***322,712***	***9,591***	***410,986***

Source: Gimbi District Agricultural and Natural Resource Office (2019). NB: this was the data sources of the District.

2.2. Research Design

This research was based on partially mixed sequential dominant status-quantitative/ technical research design. As indicated in [62], quantitative/technical and qualitative phases occur one after the other, with the quantitative/technical phase being given higher priority and mixing occurring at the data interpretation stage. The two methods were embedded during the interpretation stage and priority was given to the quantitative data of the study.

2.2.1. Data Types and Source

The success of any GIS application depends on the quality of the geographic data used [47]. Collecting high quality geographic data input for GIS, marks a critical stage. Both data types were used. Primary data are first hand socioeconomic data that were obtained through field survey and key informant interview; Ground control points were collected by using GPS. Secondary data types like Satellite image, Soil Data, DEM, Climate data were obtained from USGS, HWSD/ISRIC/, USGS, Worldclim, as well as from Agriculture and Rural Development Office and Land Administration and Land Use Planning Offices.

2.2.2. Sampling Techniques and Sample Size

In order to collect the socioeconomic data of the study area non-probability sampling technique was used to get rich information from the experts and the farmers. Based on these principle 2 agricultural experts, 2 Development Agent from villages and purposively selected 4 community leaders as well as 6 model farmers of different villages (Jogir, Bikiltu Tokumma , Didisa Bikilal) were interviewed for triangulation of the results.

Table 2: Types and Sources of the Data

No	Data Type	Source	Resolution	Resample to	Software's used	Date of Acquisition
1	Sentinel-2 (2019)	USGS	10*10m	Original	ERDAS 2015, ArcGIS 10.5	18/03/2019
2	DEM	USGS	30*30m	10*10m	ArcGIS 10.5, ERDAS 2015	18/03/2019
3	Soil	FAO	30arc-second (~1 km)	10*10m	ArcGIS 10.5	18/03/2019
4	Climate	Worldclim-2	1km	10*10m	ArcGIS 10.5	18/03/2019
5	Market and Road	Field survey by GPS	-	-	ArcGIS 10.5, ERDAS 2015	10/04/2019
6	KII	Field survey	-	-	-	10/04/2019
7	Digital Photo	Field survey	-	-	-	

2.2.3. Data Collection Instruments

The instruments used to collect primary data were GPS, KII and Digital Camera. By GPS ground control points used for accuracy assessment of supervised image was collected. As well as market places and roads which are recently constructed was tracked. Cereal agricultural production profile of the district was collected by key informant interview of agricultural experts and farmers.

2.2.4. Methods of Data Processing

Data Re-sampling

Data types were accessed from different source possess with different spatial resolutions. All data sets were calibrated into similar raster data resolution of 10 by 10m re-sample extensions of raster data management tool. Masking of the data to maintain the extent of the study area was performed by using ERDAS 2015 for Sentinel-2 satellite image and ArcGIS 10.5 for the remaining data like rain fall, temperature, altitude, soil by using study area boundary shape file. Bilinear re-sample technique was used a bilinear interpolation and a weighted distance average of the four nearest input cell centers. It is useful for rainfall, temperature and soil data using ArcGIS 10.5

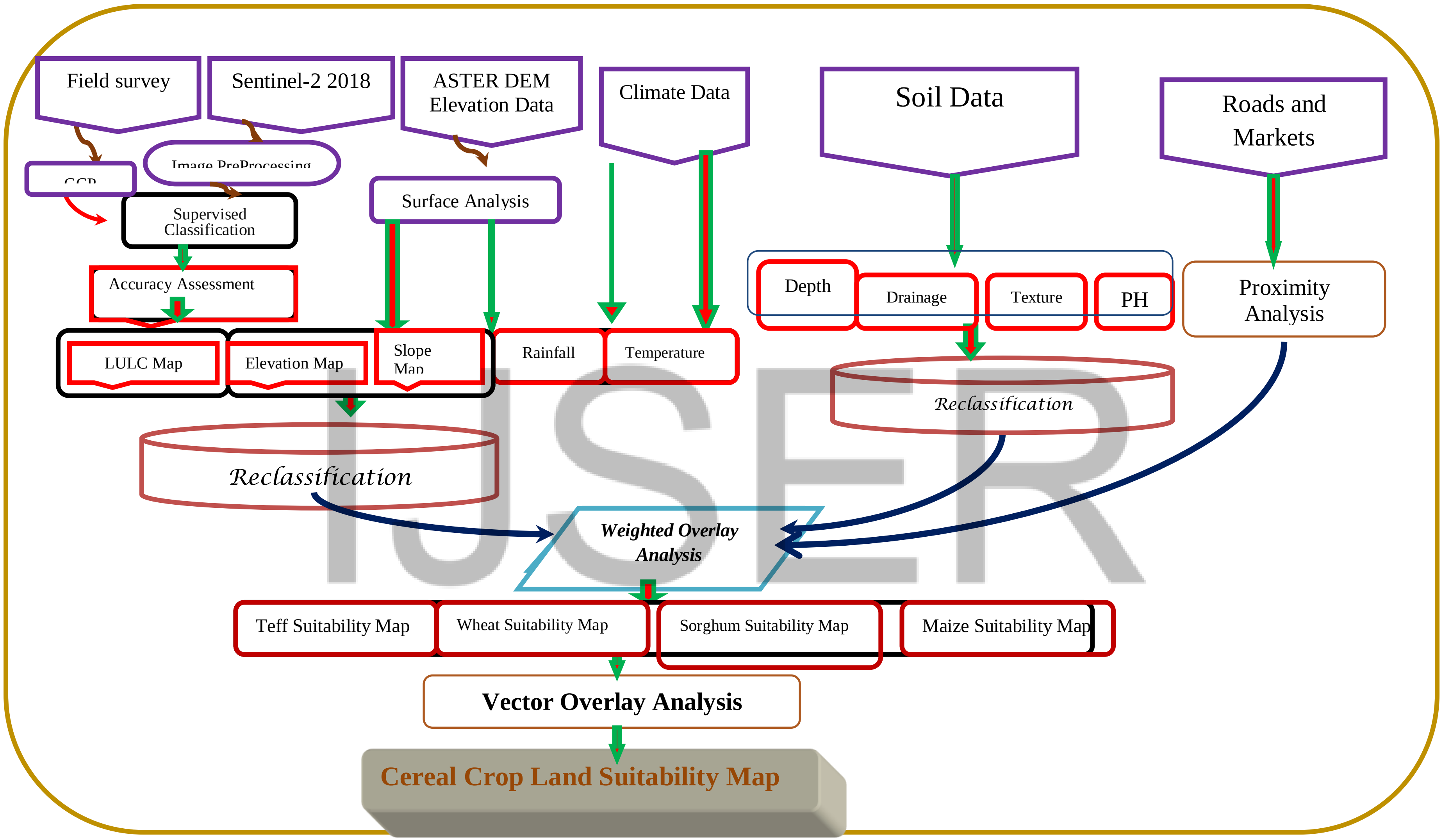

Figure 3Methodological Flow Chart of the Study

2.3. Methods of Data Analysis

2.3.1. Satellite Image Analysis

The satellite image of Sentinel-2 of February 26, 2019 was used to prepare land use/ land cover map of the study area through ERDAS 2015 image processing software. Before doing LULC the following tasks were performed.

1. ***Pre-Processing of satellite image***; atmospheric correction (haze removal), band composite were performed. Since the district is found on three swath mosaic of the layers were done by downloading these three images of February 26, 2019 with tile number L1C_T36PZR_A010314, L1C_T36PZQ_A010314 and L1C_T36PYR_A010314 from USGS. The mosaic-ed image was masked to the study area.

2. ***Classification of satellite image;*** to classify pixels in the image to the same information, class identification of training points/signature editor was used. Depending on the training points signature editor value; all the pixels value were classified to the belonging class with the parametric rule of maximum likelihood classification algorithm. The area was classified into five major different categories of land use types practiced based on field survey and the data from the office as well as by cross checking the image with Google-earth. The land use categories are Farmland, Forest, Bush land, Wetland and Settlement area. These land uses was classified with high level of accuracy.

Figure 4 and Table 4 shows that the land use land cover of the area is dominated by Shrubs (39.94%),farmland (26.54%) and forest (25.32%). The remaining area of builtup and wetland constitutes 3.49% and 4.71%, respectively. Thus, land use land cover classified shows that the area has high potential for agriculture.

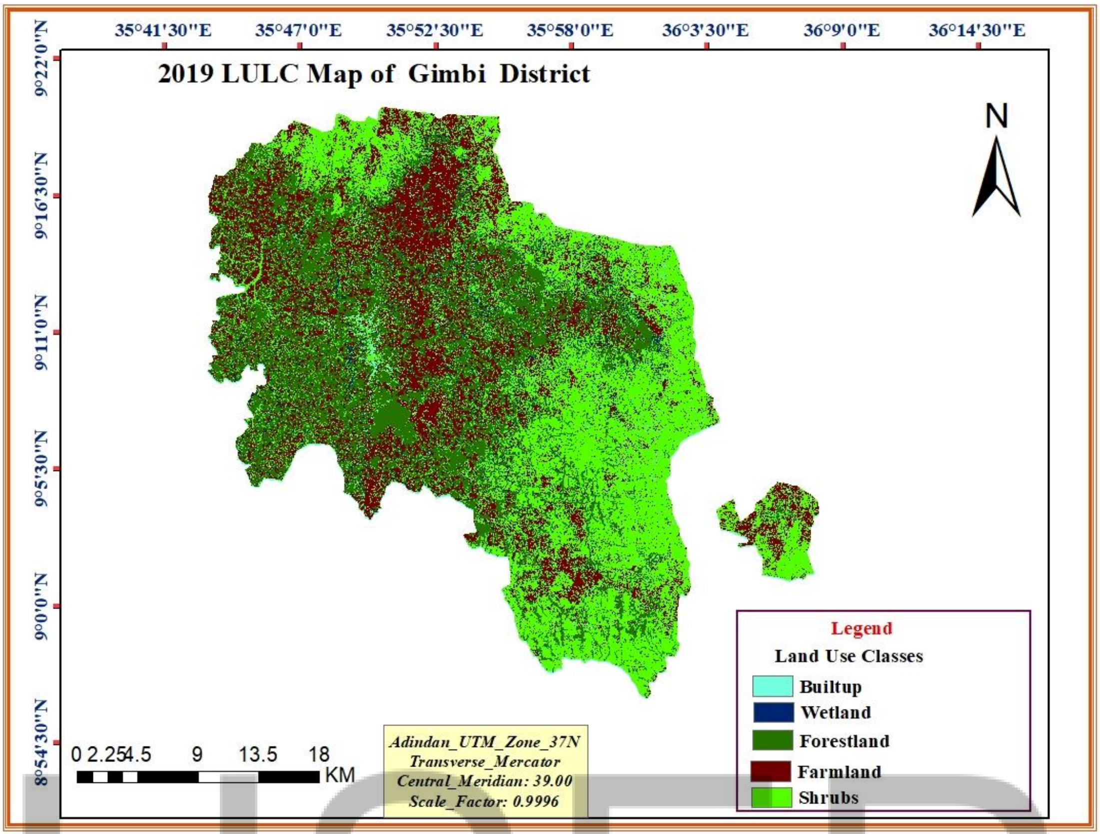

Figure 4 ***Land Use Land Cover Map of Gimbi District in 2019***

Table 3: Land Use Land Cover Classes of the Study Area

No	LU	Area (Ha)	Percentage
1	Builtup	3598	3.49
2	Wetland	4851	4.71
3	Forestland	26073.2	25.32
4	Farmland	27326	26.54
5	Shrubs	41122	39.94
Total		**102,970.2**	**100**

3. ***Accuracy Assessment:*** Errors in any digitally generated land cover maps are obtained from remote sensing imagery and occur from the source itself because of errors during data acquisition or from classification techniques during image processing. As a result, a robust and through assessment of the classification accuracy is required in order to guarantee the reliability of the results. [8, 46].

After the preparation of land use land cover; its accuracy assessment was done from 78 ground truth points of GPS coordinate. These points were identified from each class of the land cover classification for the 2019 land use land cover maps. Each classified point was computed with these field data to ascertain the classification accuracy. This accuracy measure indicates the probability of a reference pixel being correctly classified. On the other hand, if the total number of correct pixels in a category is divided by the total number of pixels that are classified in that category, it is said to be user's accuracy is reliability. Kappa coefficient measures the agreement between the classifications on map and the reference or GCP data.

Accordingly the overall classification accuracy in this study was 86.6% and its Kappa index agreement was 0.834. This implies that the classification process is avoiding 83% of the errors that a completely random classification generates. On the other hand, the accuracy of individual class varies from 80.95% to 93.75% for producer's accuracy and from 85.71% to 90.91% for user's accuracy. With regard to producer's accuracy, all classes are accurate by more than 80%. The result of the overall land classification reveals a good result which is feasible for further applications as shown below Table 5:

Table 4: Accuracy Assessment of Land Use Land Cover

		Reference data					Row Total	Number Correct	Producers Accuracy	Users Accuracy
	Classified data	Built up	Farm land	Forest Land	Wetland	Shrubs				
Classified data	Built up	10	1	0	0	0	11	10	90.91	90.91%
	Farmland	1	17	0	1	1	20	17	80.95	89.47%
	Forestland	0	1	15	0	1	17	15	93.75	88.24%
	Wetland	0	0	0	12	1	14	12	85.71	85.71%
	Shrubs	0	1	0	1	14	16	14	82.35	87.50%
	CT	11	20	15	14	17	78	68	86.6	

Finally each land use assigned a suitability class based on their suitability for cereal crop production. Accordingly the farmland was mapped as highly suitable, shrubs and wetland as marginally suitable, while built up and forest were classified as restricted area.

2.3.2. Temperature Data Analysis

Climate plays vital role on the suitability of lands for Cereal crops cultivation particularly amounts of rain fall and temperature measure. According to [39] there was three agro-ecological zones namely Dega, Weina Dega and Kolla. Temperature is one of the limiting factors for crop production and it's classified into four suitability classes for the selected crops.

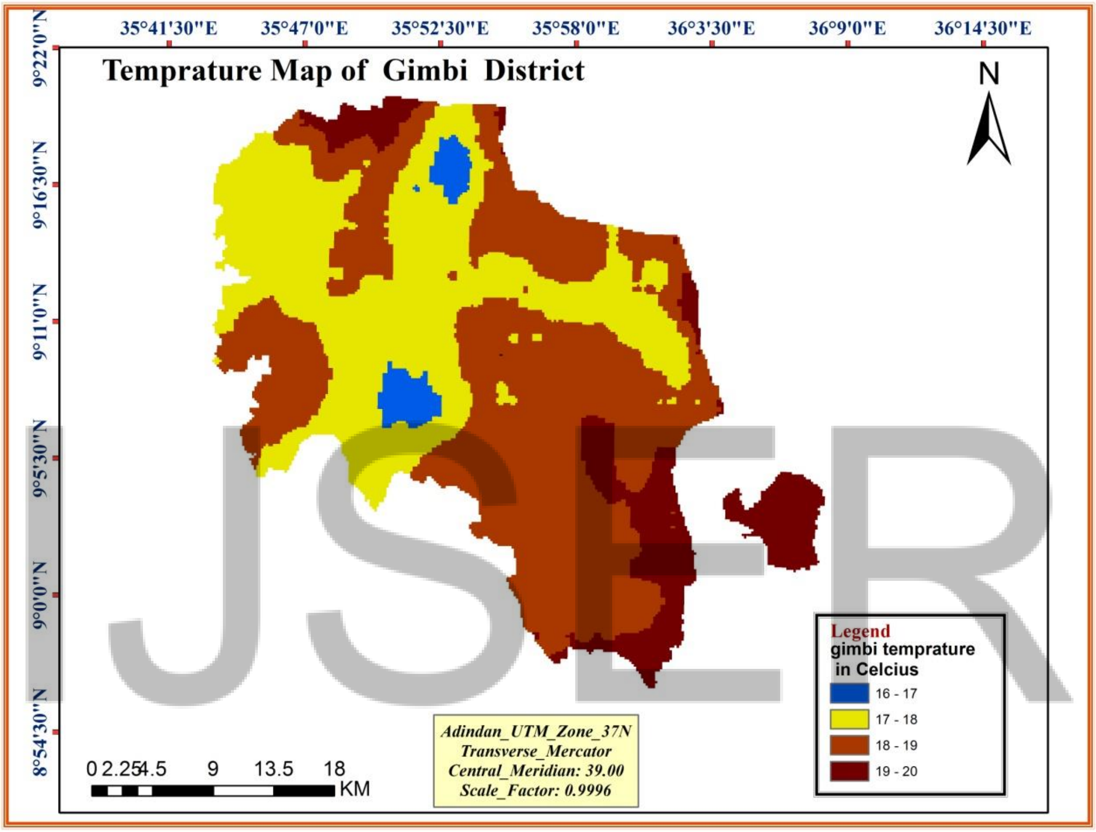

Figure 5 Temperature Suitability

Based on the reclassified temperature shown on Figure 5 the temperature ranges between 16-17°c (2.6%), 17-18°c (36%), 18-19°c (48.8%), and 19-20°c (12.6%) was classified as highly suitable, moderately suitable, marginally suitable and not suitable for **teff, and wheat, respectively.** For maize and sorghum the temperature classification was 19-20°c (12.6%), 18-19°c (48.8%), 17-18°c (36%) and 116-17°c (2.6%) was classified as highly suitable, moderately suitable, marginally suitable and not suitable for maize production respectively.

2.3.3. Rainfall Data Analysis

Water for rain-fed agriculture is rainfall, and its distribution and dependability plays a significant role in optimizing agricultural production. The average rainfall distribution with variation in both frequency and extent entail its agronomic significance.

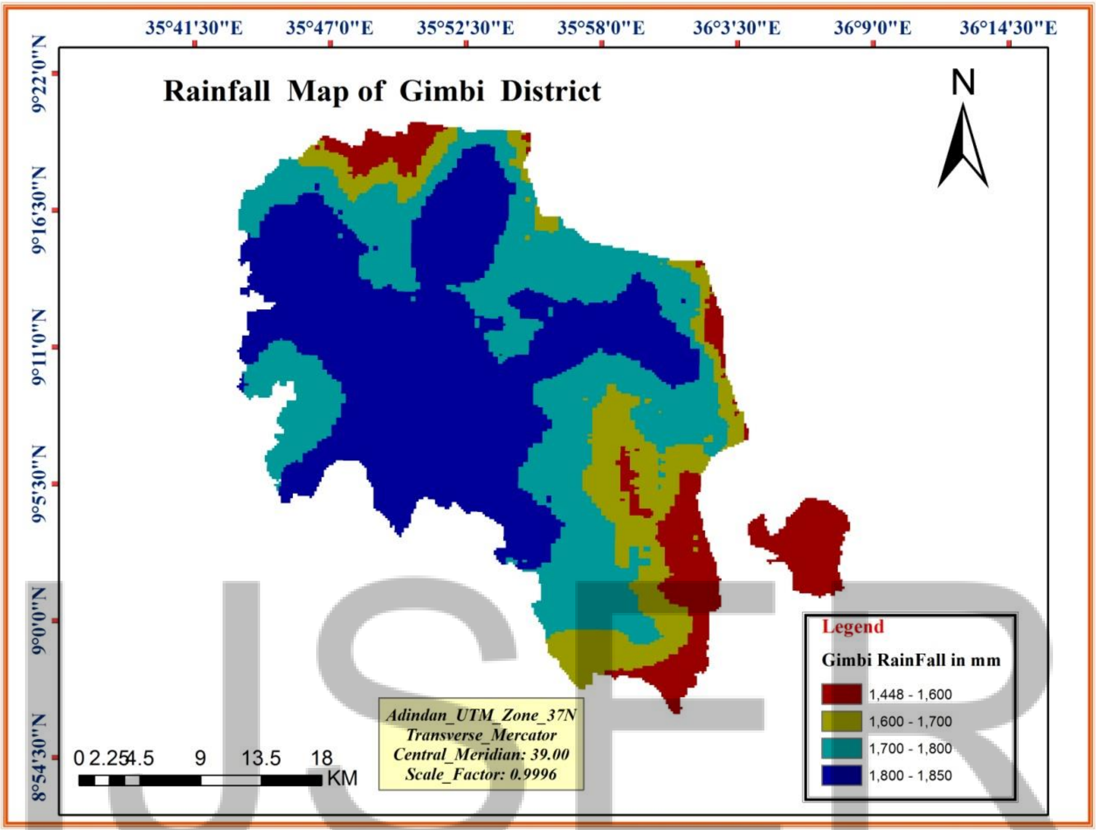

Figure 6 Rainfall Suitability

Figure 6 reveals that the rainfall ranges between 1851-1931mm (14.4%), 1751-1850mm (47.3%), 1651-1750mm (26.3%) and 1441-1650mm (12%) and was classified as highly suitable, moderately suitable, marginally suitable and not suitable for teff, and wheat respectively. For maize and sorghum 1441-1650mm (12%), 1651-1750mm (26.3%), 1751-1850mm (47.3%), and 1851-1931mm (14.4%) was classified as highly suitable, moderately suitable, marginally suitable and not suitable respectively.

2.3.4. Altitude Data Analysis

The elevation and slope of the study area was derived from ASTER DEM of 30m resampled to 10m spatial resolution. Altitude and slope plays an important role for agricultural activities in general, and specifically for crop production. The altitude of the study area ranged between 1,048m to 2,218m a.s.l and the slope ranges between 0-70%.The altitude and slope of the study area was categorized into four suitability classes' namely highly suitable, moderately suitable, marginally suitable, currently not suitable classes according to [17, 11,57] land suitability analysis.

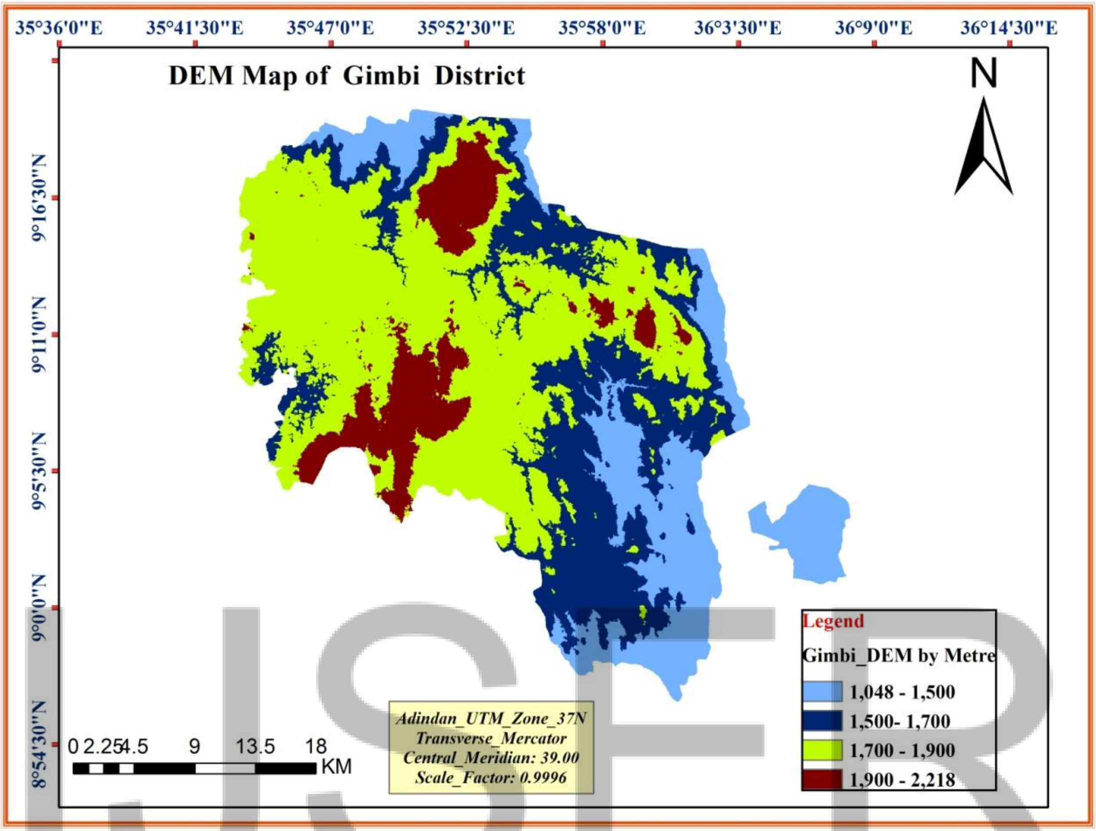

Figure 7: Altitude Suitability

As shown on figure 7 the altitude ranges between 2000-2218m (4%), 1800-2000m (27.96%),1500-1800m (48.78) and 1048-1500m (19.26%) meters are classified as highly suitable, moderately suitable, marginally suitable and not suitable for teff, and wheat respectively. For maize and sorghum 1048-1500m (19.26%), 1500-1800m (48.78), 1800-2000m (27.96%), and 2000-2218m (4%) are highly suitable, moderately suitable, marginally suitable and not suitable respectively.

3.3.5. Slope Analysis

Slope of a given area plays a crucial role for agricultural process in general, and specifically for cereal crop production.

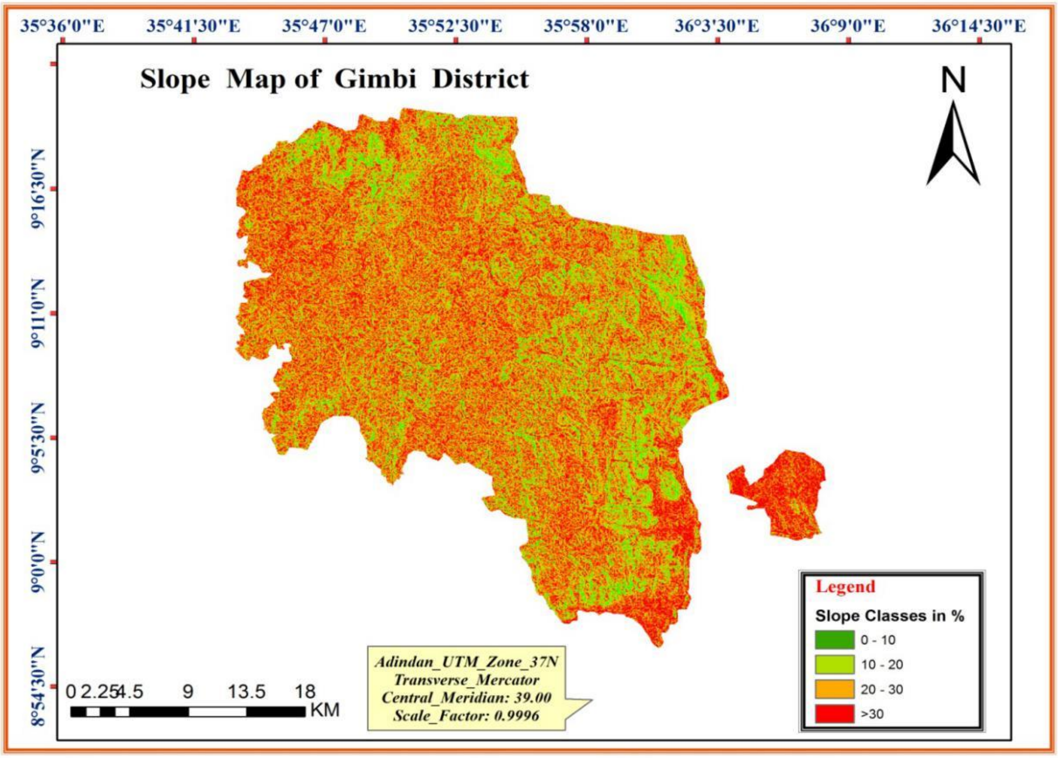

Figure 8: Slope Suitability

As shown on Figure 7 the slope ranges between 0-8 (45.5%), 9-15 (31.5%), 16-24 (17.25%) and >25 (5.7%) are classified as highly suitable, moderately suitable, marginally suitable and not suitable for teff, wheat, sorghum and maize respectively.

2.3.6. Soil Data Analysis

The soil characteristics such as soil depth, texture, drainage and pH were taken as indicators to assess the general soil suitability for agriculture. Categorized according to FAO; (1976),the land suitability classes were structured in to land suitability order, land suitability class, land suitability sub class and land suitability units. Deep and well-drained soil shows a root penetration stopped at shallower depth because of root restricting physical or chemical soil properties [37].The soil parameters considered for this land suitability analysis are soil depth, drainage, pH and texture.

Figure 9: Soil Property Suitability

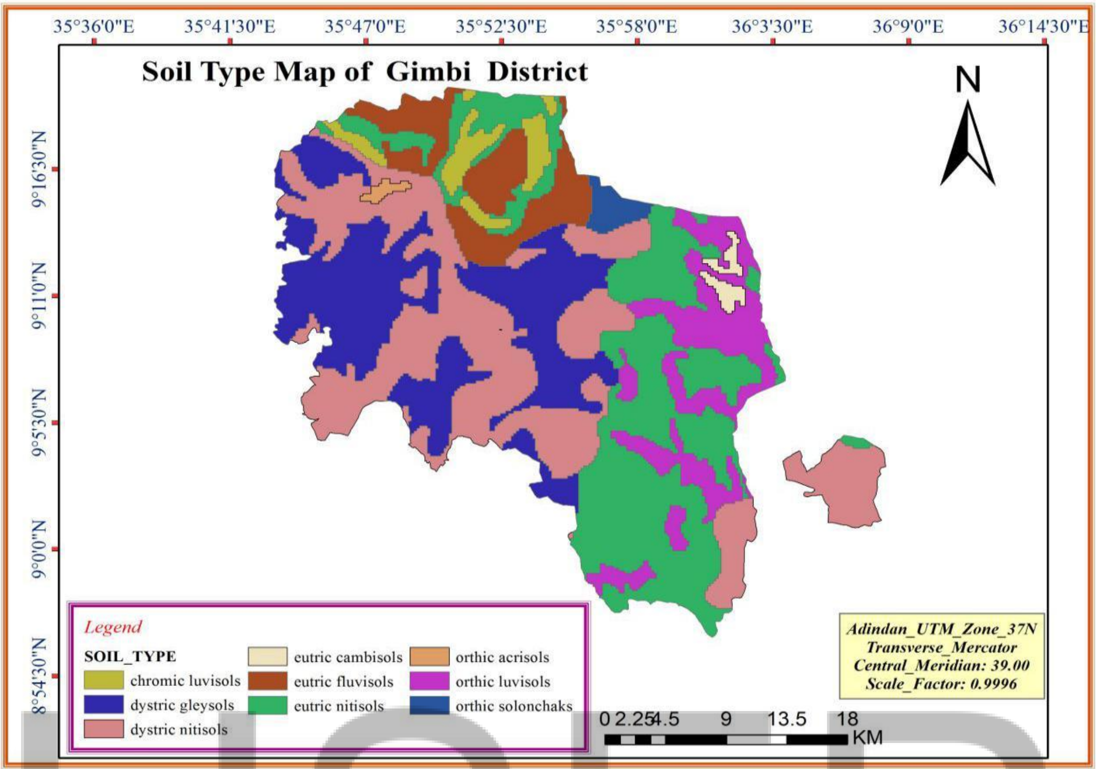

Figure 9: Soil Property Suitability

Table 6: Soil Type Suitability

No	SOIL_TYPE	Area in Ha	Percentage
1	dystric nitisols	55853.90	54.24
2	dystric gleysols	22806.10	22.15
3	chromic luvisols	13604.10	13.21
4	eutric fluvisols	8259.36	8.02
5	orthic solonchaks	1214.60	1.18
6	eutric cambisols	888.00	0.86
7	orthic acrisols	344.00	0.33
	Total	102,970.06	100

According to [17] in the study area soils with very high potential like Nitosols which covers 55,854ha (54.23%), gleysols 22,806ha (22.15%), Luvisols 13604ha (13.21%), fluvisols 8,259.36ha (8.02%), orthic solonchaks 1215ha (1.18), and soils with few limitations for agriculture like Cambisols 888ha (0.86%) and acrisols 344ha (0.33%) are found. Hence dystric nitosols, eutric nitosols are highly suitable for crops production since they are most fertile and moderate resilience and moderate to low sensitivity. Luvisols 13604ha (13.21%) is moderately suitable for their slightly acid to neutral soil reaction and very high natural chemical fertility. On the other hand eutric fluvisols 8,259.36 (8.02%) is marginally suitable due to low water holding capacity, shallow and extremely gravel and highly variable. Lastly orthic acrisol 344 (0.33 %) is classified as not suitable because it is most inherently infertile soil and strongly leached acid soils.

2.3.7. Road Analysis

Accessibility of road to agricultural land is important for raw material transportation as well as to get good market for crops produced. It was observed that most of the district's villages are connected with gravel road.

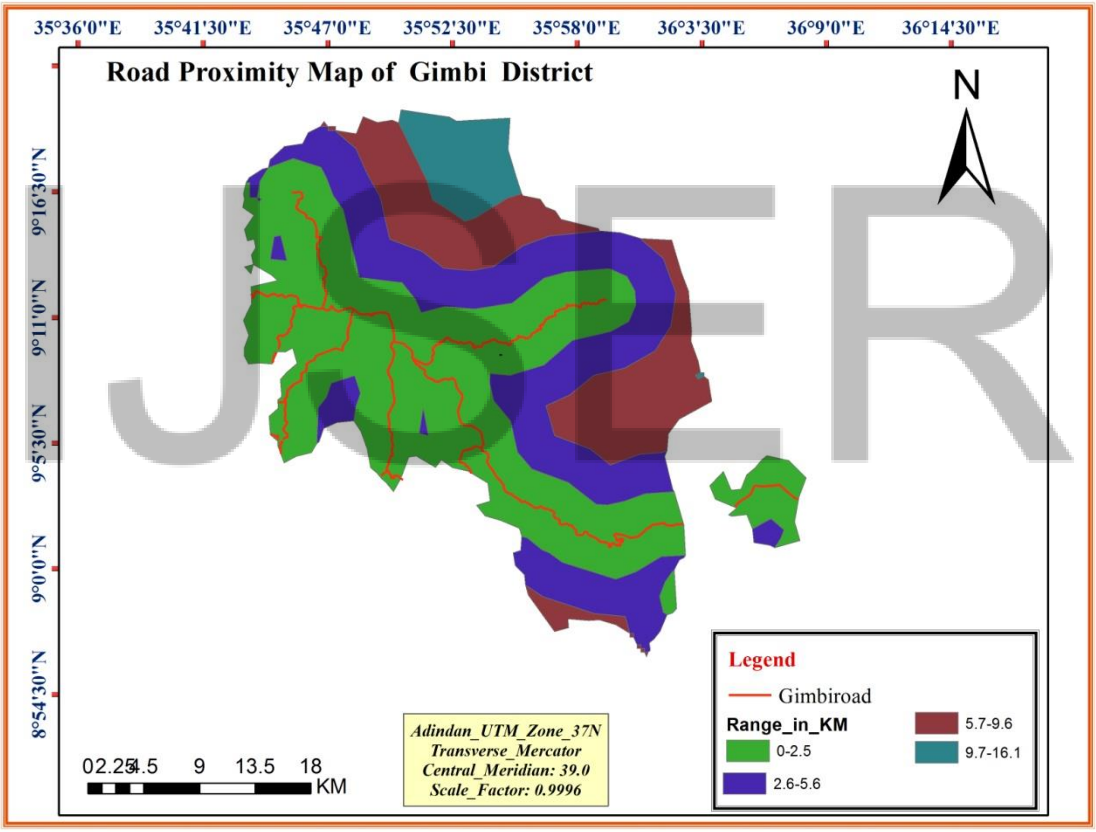

Figure 9: Road Proximity

Figure 12 reveals that using spatial analyst tool Euclidean distance of the road proximity analysis the land far from road by 0-2.5km(48.2%), 2.6-5.6 km (28.1%), 5.7-9.6km (18%) and 9.7-16.1km (5.7%), are classified as highly suitable, moderately suitable, marginally suitable and not suitable due to the distance from the crop land respectively.

2.4. Crop Requirement

Crops have specific requirements for successful growth and production. Knowledge of crop requirements is the basis for a sound suitability assessment. And selection of the crop environmental requirements usually referred as land use requirements of land use type were based on four criteria: 1) importance for the use; (2) existence of critical value in the study area; (3) practicability of obtaining information; (4) availability of knowledge with which to evaluate the corresponding land quality. Accordingly, major crop requirements were selected in the present crop environmental requirements characterization for evaluation:

1) Climate,that include amount of rainfall and temperature;

2) Rooting condition including effective soil depth and texture;

3) Wetness and oxygen availability as expressed by drainage;

4) Natural fertility status based on soil pH and

5) Mechanization potential and risk of erosion referring to slope;

Crop requirementsare established according to approach of [17, 8] and the guidelines of [74]. Adaptation is made as grouping of requirements according to [17] guidelines. Reviews are consolidated through consultations with experienced experts. The selected crops that were evaluated include: teff, wheat, barley, maize and sorghum.

2.5. Factor / Criteria Rating

Land Suitability analysis for agricultural crops needs the consideration of different environmental factors/ criteria. In this land suitability analysis the criteria are topography (altitude and slope), climate (rainfall and temperature), soil (soil depth, soil pH, soil texture and soil drainage), land use/land cover, market and road.The crop requirements that were considered in the evaluation and factor rating for crops are then decided. Factor ratings are sets of values which indicate how well each factor is satisfied and usually made in terms of five classes: highly suitable, moderately suitable, marginally suitable, currently not suitable, and permanently not suitable [18, 21].

2.5.1. Criteria Standardization

The evaluation choices could be expressed according to different scales. The large value of multi-criteria method needs that all criteria are expressed in the same scale. Standardization of criteria allows the re-scaling of evaluation dimensions between 0 and 1 where o indicates not suitable and value 1 indicates suitable. Following the processing and preparation of data, the factors were organized in the class of fit to their weight of importance. In Analytcal Herarcy Process approach, the criteria are standardized, by using pair wise comparison methods. The standardization of factors or criteria brought about in rating was based on literature and agricultural experts.

2.5.2. Assigning Criterion Weights

The purpose of weighting in land suitability analysis for agricultural crops is to express the importance or preference of each factor relative to other factor effects on crop yield and growth rate. In the procedure for Multi-Criteria Evaluation, it is necessary that the weights sum to 1. In developing pair wise comparison matrix, all the factors are compared two at a case in terms of their standing related to the declared objective. In developing weights, an individual or group compares every possible pairing and enters the evaluation into a pair wise comparison matrix [14]. Since the matrix is symmetric, only the lower triangle actually necessarily to be filled in. The remaining cells are then simply the reciprocals of the lower triangle.

Table 5: Saaty (2006) Scale of Rating Influence of Factors.

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective.
3	Moderate Importance	Experience and judgment slightly favor one activity over an other
5	Strong Importance	Experience and judgment strongly favor one activity over another
7	Very Strong or Demonstrated Importance	An activity is favored very strongly over another, its dominance demonstrated in practice.
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
2,4,6,8	Intermediate Values	When compromise is needed

To this end, after consideration and careful analysis of the set of evaluation criteria with literature's and experts, all the pair wise comparisons the set of the considered criteria were made. The module allows repeated adjustments to the pair wise comparisons and reports the new weights and consistency ratio for each iteration. Based on this Analytical Herarcy Process derivation Eigen vectors of weights for all factors considered for all selected cereal crops for analysis are generated.

2.5.3. Aggregating the Criterion Weights and the Standardized Criterion Maps

GIS is unique in its capacity for integration and spatial analysis of multi-source data sets [49]. In the context of GIS, three decision rules i.e. Boolean overlay, weighted overlay and ordered weighted averaging are common for MCE [43, 49]. The type of aggregation used is Boolean intersection or logical and the weighted overlay technique for developing the suitability maps for each land use types and vector overlay analysis for deriving composite suitable land allocation map was adopted.

2.5.4. Weighted Overlay Analysis

Weighted overlay analysis of all factors under investigation are combined by applying a weight results produce the final land suitability map. A land unit must be drawn on the map defined by polygon of specific area. It must ensure the homogeneous characteristics of the land and also have to be supported specifically by the description of attribute data. Land units were determined by simple measures based on features that were observed directly on the field or remote sensing or others [4].

According to [64], land suitability analysis desires a multi criteria decision making process as the analysis is guide of a decision makers regarding problem considers a number of parameters. Land suitability analysis was based on the functions of physical factors. IDRISI software decision wizard software component was used to support multi criteria in which evaluation process multi-layer were aggregated to yield a single out suitability overlay map. The weights were developed by providing a serious of pair wise comparison matrix of the relative importance of the factors to the suitability of pixels for the activity was analyzed.

The pair wise matrix comparisons were then analyzed to produce a set of weights that sum to one .The formula for weight combination is given as follows [69]:

$$S = \sum WiXi \qquad \textbf{1}$$

Where: S is suitability, Wi is weight of factor, and Xi is Criterion score of factor i.

Finally from the reclassified and weighted factors land suitability map for cereal crops were computed by the Weighted Overlay tool of ArcGIS Spatial Analyst Toolbox.

3. RESULTS AND DISCUSSIONS

3.1. Analysis of Land Suitability for Selected Cereal Crops

The land suitability analysis results are highly suitable, moderately suitable, marginally suitable and currently not suitable.

Table 6: Land Suitability Status for Teff, Wheat, Barley, Maize and Sorghum.

Suitability Status									
No	***Crop type***	***Suitability Status***	***Hectare***	***Percent***	***No***	***Crop type***	***Suitability Status***	***Hectare***	***Percent***
1	**Teff**	Highly Suitabe	871	0.85	3	**Barley**	Highly Suitable	249	0.2
		Moderately Suitable	5011	4.87			Moderately Suitable	2594	2.5
		Less Suitable	20479	19.89			Less Suitable	9194	8.9
		Restricted	35768	34.74			Restricted	35768	34.74
		Not Suitable	39869	38.72			Not Suitable	55165	53.6
		Total	**102970**	**100**			**Total**	**102970**	**100**
2	**Wheat**	Highly suitable	359	0.35	4	**Maize**	Highly suitable	1679	1.63
		Moderately Suitable	3470	3.37			Moderately Suitable	10123	9.83
		Less Suitable	12373	12.02			Not Suitable	14879	14.45
		Restricted	35,768	34.74			Restricted	29664.2	28.81
		Not Suitable	51000	49.53			Less Suitable	43925	42.66
		Total	**102970**	**100**			**Total**	**102970**	**100**
					5	**Sorghum**	Highly Suitable	2508	2.44
							Moderately Suitable	10754	10.44
							Not Suitable	14643.8	14.22
							Restricted Area	29664.2	28.81
							Less Suitable	45400	44.09
							Total	**102970**	**100**

Table 8 demonstrates that 0.85%, 0.35%, 0.2 %, 1.63% and 2.44 % of the study area are classified as highly suitable for Teff, Wheat, Barley, Maize and Sorghum production, respectively. The study result shows most of the area is best suitable for maize and sorghum. On the other hand, 4.87%, 3.37%, 2.5 %, 9.83% and 10.44% were found to be moderately suitable while 19.89%, 12.2%, 8.9%, 42.66 and 44.09% were marginally suitable land for teff, wheat, barley, maize and sorghum respectively.The land suitability analysis maps for the selected cereal crops are presented in figure 11, 12, 13 14 and 15.

Teff is grown in the altitude ranging from 1800-2800meters above mean sea level [70, 36]. Also an annual rainfall up to 2500mm and elevation from 1800- 2800m above mean sea level with high tolerance to water logging. [73].

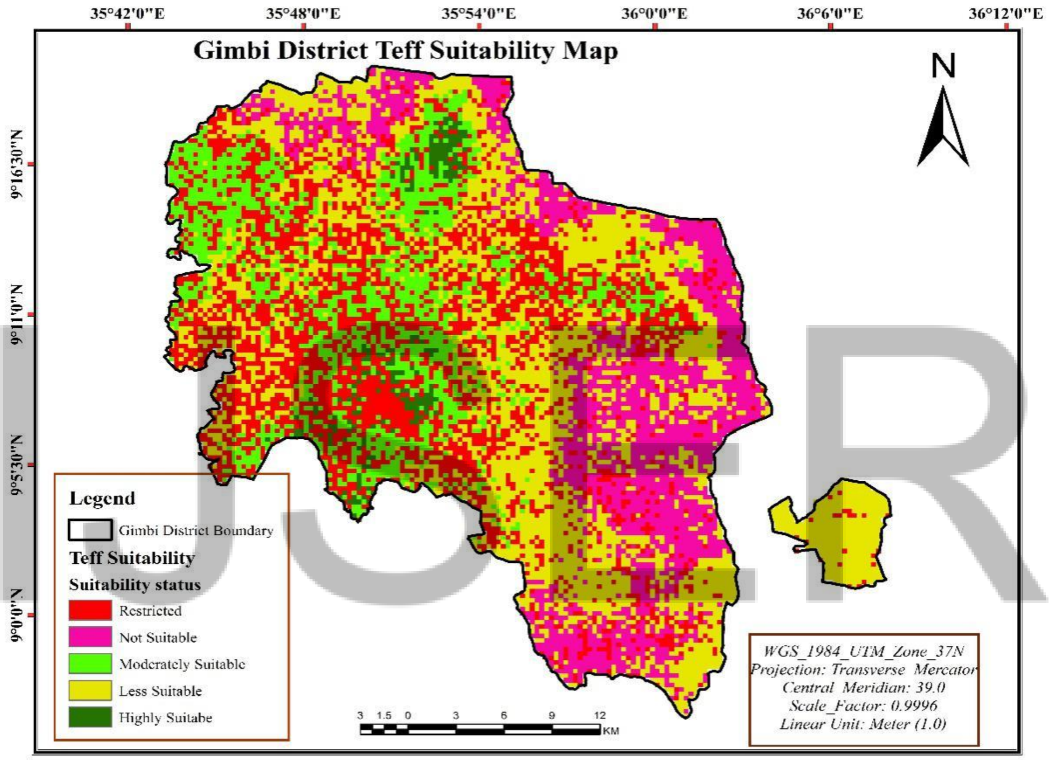

Figure 10: Teff Suitability Map

Figure 11 shows that, 871 hectares (0.85%) of the total area is highly suitable, 5,011 hectares (4.87%) is moderately suitable, 20,479 hectares (19.89%) is marginally/less suitable and 39,869 hectare (38.72%) were not suitable for teff production. In the study analysis, restricted area like forest, wetland and settlement constitutes 35,768 hectare which is 34.74%.

Wheat is highly adapted to medium to high altitude, an annual rainfall of 500-3000 mm and tolerance to high water logging problem.

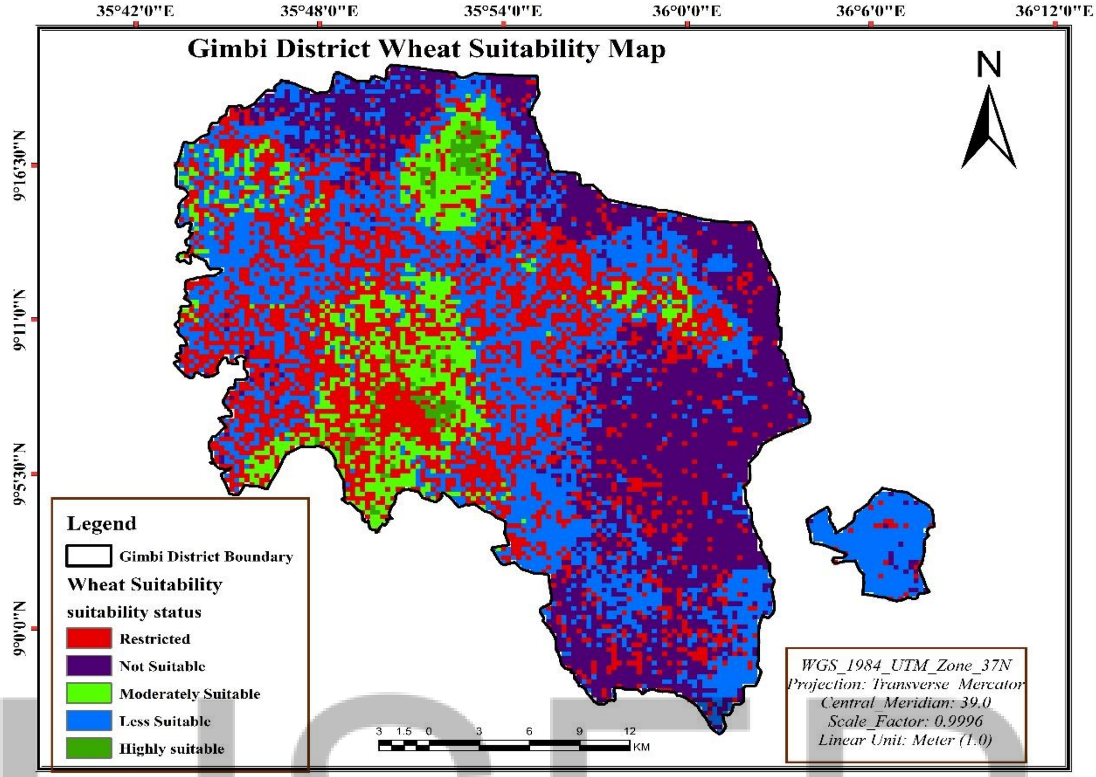

Figure 11: Wheat Suitability Map

As depicted on figure 12 from the total land of the study area 359 hectares (0.35%) is highly suitable, 3470 hectares (3.37%) is moderately suitable, 12,373hectares (12.02%) is marginally/less suitable, and 51,000 hectares (49.53%) is not suitable. Restricted area for wheat production is forest, wetland and settlement) constitutes 35,768 hectares (34.74%).

Barley is an essential grain crop and grown from 1800 to 3400 m altitude in different seasons and production systems in Ethiopia [55].

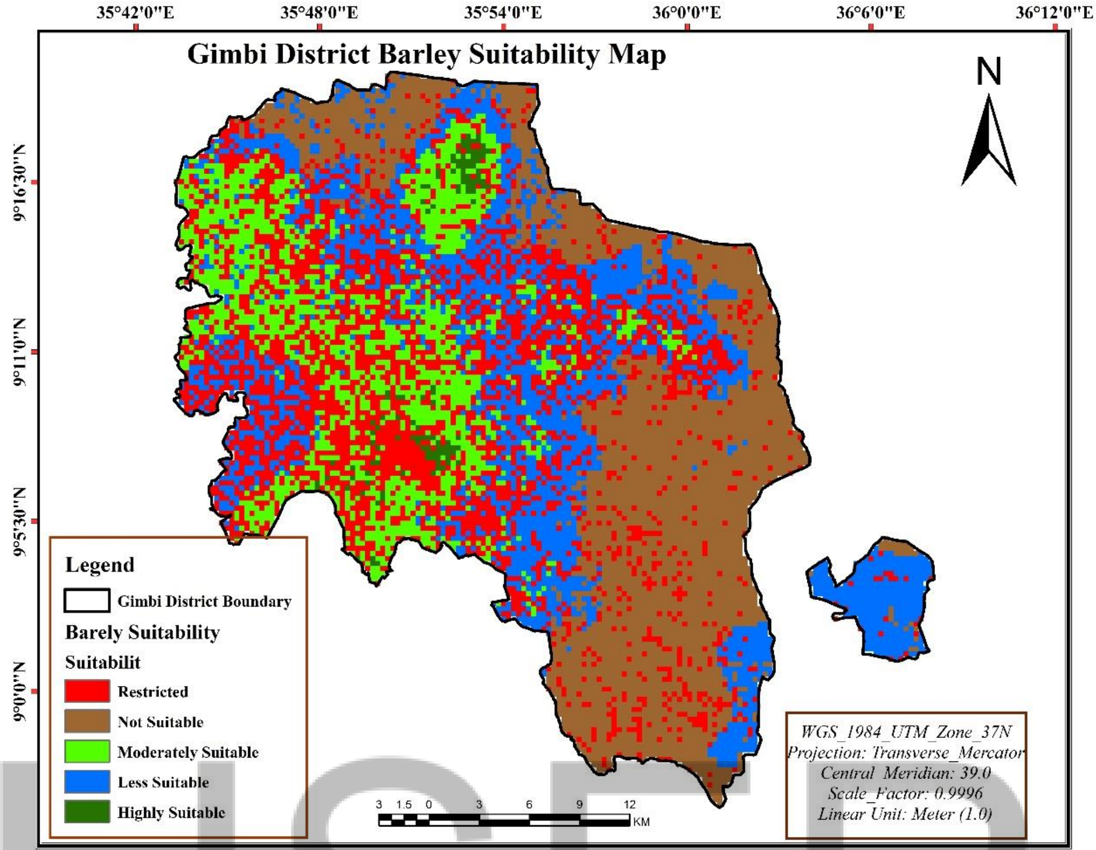

Figure 12: Barley Suitability Map

Figure 13 reveals that from the total area of the study 249 hectares (0.2%) is highly suitable, 2594 hectares (2.5%) is moderately suitable, 9194 hectares (8.9%) is marginally/less suitable and 55165 hectares (53.6%) were classified as not suitable for barley production. From the total area of the study 35768 (34.74%) is classified as restricted area (forest, wetland and settlement). Similarly the study carried out in south Wollo by [55] shows that the study areas 3.8%, 42%, 53.73 is highly, moderately and marginally suitable for barley production respectively. But the percentage difference might be due to the variations in geographical settings and others.

Maize shows tolerance to a wide range of environmental conditions and grows at optimal temperature between 18 – 32^{0}C, annual precipitation between 1000 – 1500 mm, and 500 – 1200 mm in the growing cycle.

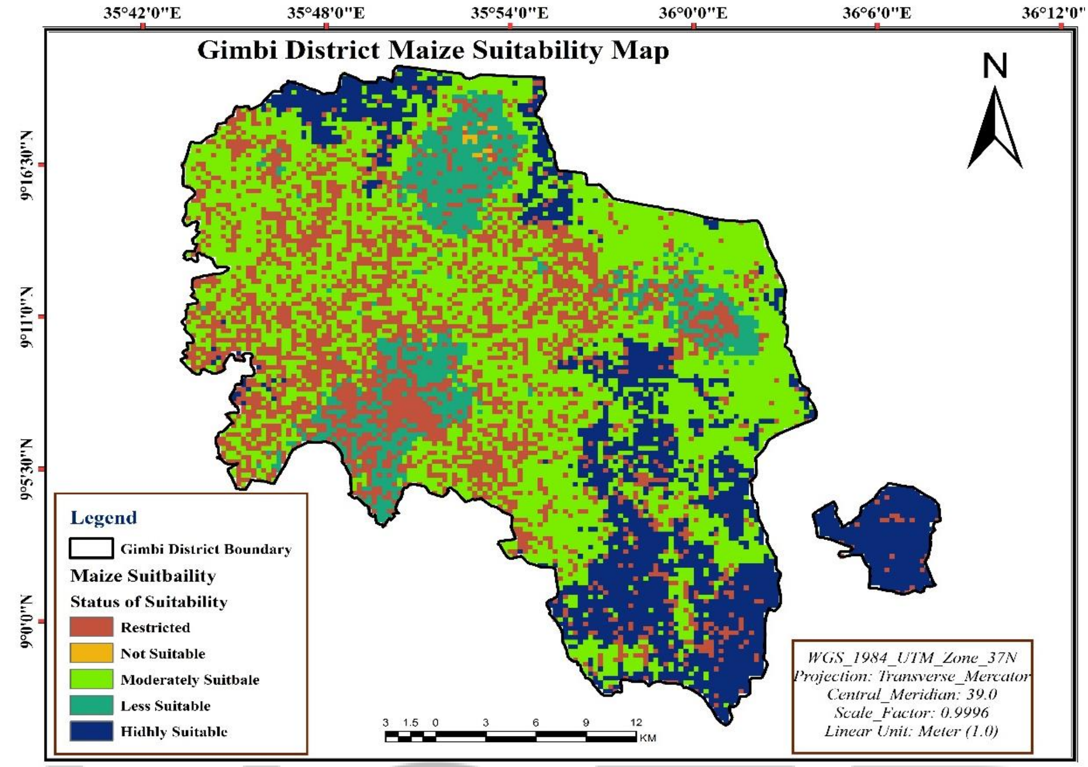

Figure 13: Maize Suitability Map

As presented in figure 14 from the total study area 1679 hectares (1.63%) is highly suitable, 10123 hectares (9.83%) is moderately suitable, 43925 hectares (42.66%) as marginally/less suitable and 14879 hectares (14.45%) is not suitable. On the other hand from the total area of the study 29,664.2 hectares (28.81%) is restricted area which is covered by forest and settlement.

3.2. Optimum Land Suitability Allocation for the Selected Cereal Crops

The land suitability result acquired for overall land suitability analysis is an indicative of appropriate land allocation. Table 10 demonstrates the result of appropriate land allocation for the selected land utilization types along with their best suitability classes. The result demonstrates the condition where a plot of land is suitable for one or more than one land utilization types at the same level of suitability class. This indicates competing nature of land utilization types for the same parcel of land. This means for instance, 223 ha (0.22%) of a single plot of land is highly suitable for barley, teff and wheat. Similarly, 1359 hectares (1.32%) is moderately suitable for barley, teff and wheat. In the same manner, 2792 ha (2.71%) of the study area is marginally/less suitable for barley, teff and wheat on the same geographical area.

The detail of the result is presented on Table 8 and figure 15 which shows map of suitable land allocation for the evaluated crops. The red section in the map reveals places which are restricted and not suitable for all evaluated land utilization types.

Table 7: Overall Suitability Analysis

No	Code	Area In Hectare	Area %		No	Code	Area In Hectare	Area %
1	S1_Tf	113	0.11		17	S2_Tf,Ba	1330	1.29
2	S1_Wh	31	0.03		18	S2_Ba,Wh	223	0.22
3	S1_Ba	19	0.02		19	S2_Tf,Wh	498	0.48
4	S1_Ma	673	0.65		20	S2_Tf,Wh,Ba	1359	1.32
5	S1_Srg	987	0.96		21	S3_Tf	379	0.37
6	S1_Ma,Srg	1542	1.50		22	S3_Wh	398	0.39
7	S1_Tf,Ba	239	0.23		23	S3_Ba	1766	1.72
8	S1_Ba,Wh	113	0.11		24	S3_Ma	4747	4.61
9	S1_Tf,Wh	6	0.01		25	S3_Srg	3805	3.70
10	S1_Tf,Wh,Ba	223	0.22		26	S3_Ma,Srg	2057	2.00
11	S2_Tf	508	0.49		27	S3_Tf,Ba	1812	1.76
12	S2_Wh	398	0.39		28	S3_Ba,Wh	1091	1.06
13	S2_Ba	236	0.23		29	S3_Tf,Wh	1225	1.19
14	S2_Ma	912	0.89		30	S3_Tf,Wh,Ba	2,792	2.71
15	S2_Srg	2,039	1.98		Agricultural Land Potential		**37330**	36.25
16	S2_Ma,Srg	5809	5.64		**Total Area**		**102970**	**100**

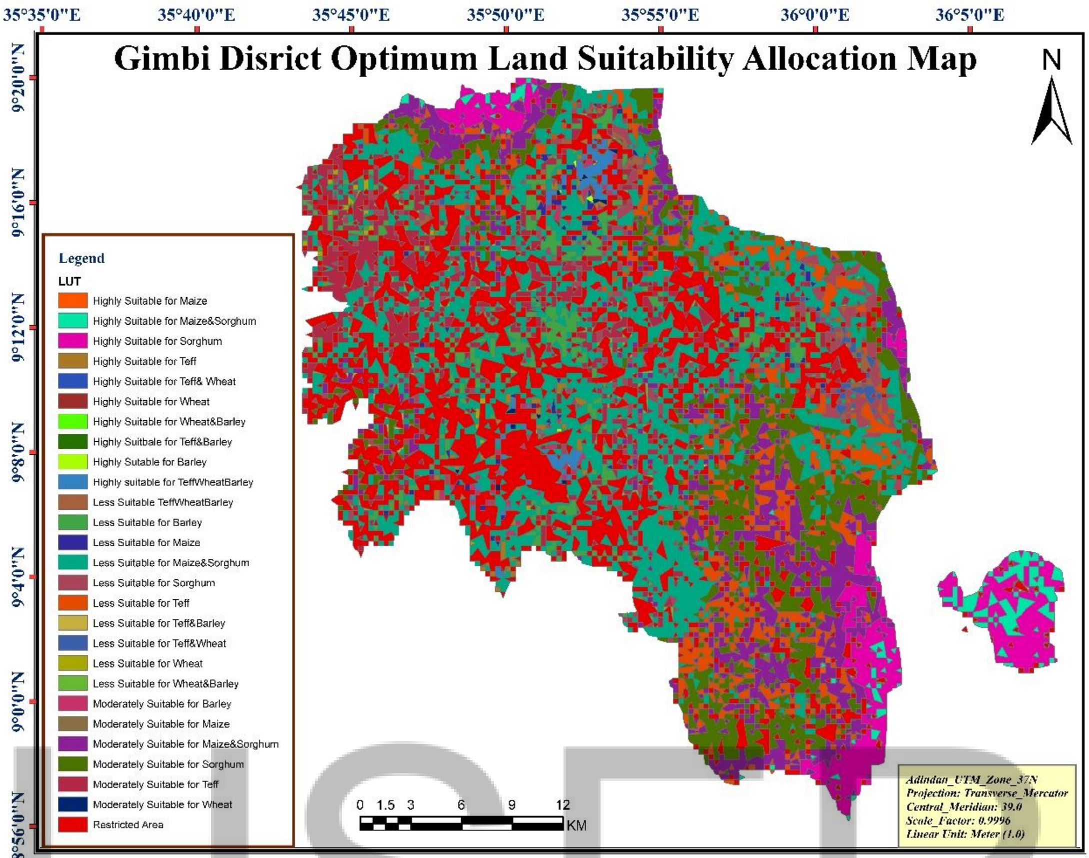

Figure 14: Appropriate Land Allocation Map with their Respective Degree of Suitability for Teff, Wheat, Barley, Maize and Sorghum

As shown on figure 15; from the total area 3,946 hectare (3.84%) of the area is highly suitable for all the crops reviewed; whereas 13,312hectare (12.9%) is moderately suitable for teff, wheat, barley, maize and sorghum production. The rest area has a mixed suitability status for all the analyzed crops. As shown in [11] at Mojo watershed reveals similar results. For instance, 4.03% of a single plot of land is highly suitable for both teff and wheat; whereas 26.79% of the study area is moderately suitable for teff and wheat at the same geographical area.

4. CONCLUSIONS AND RECOMMENDATIONS

This research was intended to evaluate the physical land suitability for *selected cereal crops by integrating* GIS and Remote Sensing with Multi-criteria Evaluation in Gimbi district. The evaluation of physical land qualities of the area has huge potential for cereal crops production.

Based on the findings topographic factors (altitude) and climatic factors (temperature and rainfall) are the dominant factors that influence the suitability of land for cereal crops in the study area. Teff, barley and wheat are most suitable at high altitude, low temperature and high amount of rainfall and While maize and sorghum were most suitable at middle and low altitudes of the study area. Most crops require deep soil depth for their growth. The soil root depth ranges between 30 and 150cm. The soil depth of the study area ranged from less than 30cm to greater than 150cm.Those places having soil depth 70-150cm are very suitable for cereal crops. Generally soils having 70-150cm depth, well drainage, having pH 5.5-7.5 and with texture of loam, clay, silty clay are most suitable for cereals.

As per the physical land suitability analysis results for selected cereal crops 0.85%, 0.35%, 0.2%, 1.63 % and 2.44 % of the study area are classified as highly suitable for teff, wheat, barley, maize and sorghum production, respectively. Similarly, 4.87%, 3.37%, 2.5%, 9.83% and 10.44 % were found to be moderately suitable while 19.89%, 12.02%, 8.9%, 42.66% and 44.09 % is marginally/less suitable land for teff, wheat, barley, maize and sorghum respectively.

The vector overlay analysis results to showed the best suitable land and places for which land utilization types compete at the same level of suitability class. The result indicated that 223 ha (0.22%) of the land is highly suitable for teff, wheat and barley, 1359 ha (1.32%) is moderately suitable for teff, wheat, and barley. On the other hand, the output of this vector overlay analysis revealed that only 0.11%, 0.03%, 0.2%, 0.65% and 0.96 % of the study area is highly suitable to specific individual land unit for teff, wheat, barley, maize and sorghum, respectively. Based on this land utilization types results farmers could prefer LUTs with higher level of suitability than others for plots of land that showed different suitability level for different land utilization types.

As the land suitability has been analyzed, Gimbi district has a high potential for cereal crop production having untouched potential. Thus:

a) The district has to do more to use land at its optimum standard.

b) A parcel of land has to be studied to provide its maximum yield.

c) The land use types considered in this study are limited to four selected cereal crops. To increase the choice for the decision makers as well as for the stake holders, further analysis for different land use types is necessary. Therefore, further research has to be conducted for different land use types which include other cereals pulses, oil seeds, cash crops, livestock, etc to identify the best alternative use for a specific parcel of land.

d) The policy makers should consider this physical land suitability to enhance agriculture and for the better livelihood of the community.

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