Article

Land suitability evaluation for coffee Arabica production in Gidami District, Western Ethiopia: Using GIS and remote sensing

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Abstract
Land suitability evaluation is a prerequisite for sustainable agricultural production. This study was focused to assess land suitability analysis for coffee Arabica production in Gidami district, western Ethiopia. GIS and RS techniques with a multi criterion evaluation approach were used for evaluating the land suitability for coffee Arabica production.The evaluation of suitability classes was based on the method described in FAO guideline for land evaluation. Factors that were considered for evaluation of the land suitability for coffee Arabica production were topography (slope, elevation), climate (rainfall and temperature), soil texture, and landscape (land use land cover). The influence of each factor was computed by pair-wise comparison technique (AHP) method. The final coffee Arabica suitability map was developed based on the linear combination of factors with their respective weights in ArcGIS overlay extension. The results for coffee Arabica suitability classes show that highly suitable (S1), moderately suitable (S2) and marginally suitable (S3). From the total land of the study area 34.46 %(69048.65ha) is high suitable while 114917.33ha (60.69%) and 5369.52ha (2.83%) moderately suitable and marginally suitable for coffee Arabica cultivation respectively. The findings for the research indicate that the study area has a potential area for coffee Arabica production.

Keywords Arabica coffee. land suitability; GIS and RS; APH.

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1 Introduction

Growing conditions for crops in agriculture like coffee Arabica is shifting to track climate change. Potential environmental impacts of shifting cropping patterns, including impacts on water, wildlife, pollinator interaction, and carbon storage and nature conservation on national to global scales (Hidayat et al., 2020). Multiple crops will be moving in response to shifting climatic suitability, and the cumulative environmental effects of these multi-crop shifts at global scales is not known (Chang et al., 2018). Coffee Arabica is an extremely important agricultural commodity produced in about 80 tropical countries with an estimated 125 million people depending on it for their livelihoods in Latin America, Africa, and Asia, with an annual production of about 9 million tons of green coffee beans (Hannah et al., 2020).

Ethiopia is the home of Arabica coffee and the largest coffee producer in Africa and the 5th largest in the world, following Brazil, Vietnam, Colombia and Indonesia (Melaku Amare, 2021). According to (Ovalle-Rivera et al., 2015) there are an estimated 15 million people of the country’s total population who derive their livelihoods from coffee. According to Wakuma (2022) in Ethiopia about 25 % of the total populations of the country are dependent on production, processing, distribution and export of coffee.

Even though the issue of agricultural productivity and food security is widely studied in different parts of the world, the impact of unwise use of land resource and absence of utilization of the land according to its potential suitability is still a serious problem particularly in developing countries. In order to increase agricultural production and provide food security, therefore crops need to be grown in areas where they are best suited (Biniyam et al., 2015). Thus, in order to build up an efficient crop production system, evaluation of land suitability is essential. This study also aims to identify the suitable areas for coffee Arabica production using land qualities such as topography, soil, and climate and land use land cover in the study area by using GIS and remote sensing application integrating with multi criteria decision making approach (Chang et al., 2018).

2 Methodology

2.1 Description of study area

The study is conducted in Gidami Woreda, Oromia National Regional State, and Western Ethiopia. The area is located between 34.6165 longitudes and 8.9834 latitude with an elevation between 1776 and 1928 meters above sea level.

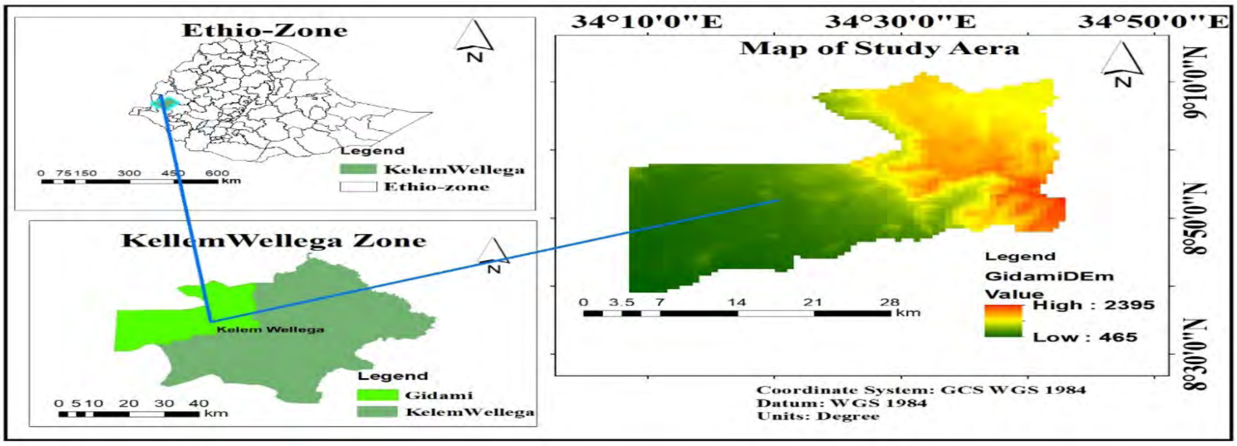

Fig. 1 Map of the study area.

2.2 Physical characteristics

2.2.1 Climate

The average temperature of the area is range between 18.25 c^o and 25 c^o. The average annual rain fall of the area is range between 1297.02 mm and 1800 mm.

2.2.2 Topography

District is characterized by different land forms prominently high lands and low lands. It is highly dominated by rugged topography that greatly affects the constructions of roads to connect the district with the neighboring. The elevation within the study area ranges between 465 and 239 5m.a.s.l.

2.3 Data and materials used

The GIS-based suitability analysis method and multi-criteria evaluation techniques were used in this study. Some software was applied in this study for data acquisition, design, analysis and presentation of the final research results: ArcGIS 10.8 for map making and different analysis like mapping, reclassification, and accuracy assessment; ERDAS Imagine 2015 was employed for satellite image processing and classification; in this case Landsat 8 (OLI multispectral bands) has been used.

Table 1 Dataset and source of data that were used.

Dataset	Data Format	Data Source	Resolution	Application
Climate data (Rainfall and temperature)	TIFF	NASA	30m	Temperature and Rainfall map
Topography data (DEM)	TIFF	Landsat 8	30m	Elevation and Slope map
Soil Data	TIFF	ISRIC web	250m	Soil texture
LULC	TIFF	Landsat 8	30m	LU/LC map

2.4 Criteria determination

For land suitability analysis of coffee Arabica production, there is no uniform standard in the overall procedure of the operations; rather, it is applied based on nature, situation and available resource in a given geographic area. Criteria were established from the literature review, coffee experts knowledge and agronomists expert of the study area. The casual factors were chosen based on the four main criteria by considering the data availability, local expert knowledge and literature inputs (Nzeyimana et al., 2014).

Hence, four main criteria and six factors namely: topography (elevation and slope), climate (temperature and rainfall), soil texture, and landscape (land use land cover) were selected considering the nature of the study area and the available information, time and resource.

Table 2 General criteria and factors that were used in the study.

No	General Criteria	Sub-criteria	Suitability range	Suitability class	Reference
	Climate	Temperature	20-22.5	S1	FAO,1984
			17.5-20	S2	
			22.5-23.3	S3	
		RF	1400-1600mm	S1	(Nzeyimana et al., 2014)
			1300-1400mm	S2	
			1600-1710mm	S3	
	Landscape	LULC	Forest	S1	Local Expert

			Agriculture	S2	knowledge
			Bare Land	S3	
			Water Body	N	
			Settlement	N	
	Topography	Elevation	1500-1800	S1	(Nzeyimana et al., 2014)
			1100-1500	S2	
			1800-2200	S3	
			863-1100 and 2200-2655	N	
		Slope	0-4	S1	FAO, 1984
			4-12	S2	
			12-25	S3	
			25-50	N	
			>50	N	
	Soil	Soil texture	loam	S1	(Nzeyimana et al., 2014)
			Clay loam	S2	
			Clay	S3	

2.5 Methods of land suitability evaluation

Land evaluation is formally defined as the assessment of land performance when used for a specified purpose, involving the execution and interpretation of surveys and studies of land forms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation (FAO, 1993). For land suitability evaluation, degrees of suitability classes have been applied in this study for analyzing land evaluation for the coffee Arabica production based on FAO (1993) guidelines. The suitability map of the Coffee Arabica classified based on their land use quality priority for specified land use requirements. According to FAO (1993), based on land suitability classes that reflect the degrees of suitability, a land can be divided in to five classes. These include very suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N).

2.6 Assigning criterion weights

A weight is a value assigned to an evaluation criterion that indicates its importance relative to the other criteria under consideration. There have been a number of methods used for assessing criterion weights (Zhang, 2019). Pairwise comparison method is based on the assumption of spatial homogeneity of preferences and assigns a single weight to each criterion (Astuti et al., 2021).

Pairwise comparison matrix has been computed in excels. The process of converting data to such numeric scales is most commonly called standardization. This method used, to derive ratio scales from paired comparison. The pair wise comparison technique developed by Saaty in the context of a decision making process is a ratio (reciprocal matrix) where each aspect is compared with the other criteria, relative to its importance on a scale (Chairani et al., 2017; Zhang et al., 2017; Zhang, 2019).

3 Results and Discussions

3.1 Climate data (rainfall and temperature)

The area has annual temperature of between 17 °C and 23°C. Similarly, rainfall ranges between 1396 mm and 1710 mm annually. This is as per average temperatures computed for over 30 years. It is also apparent that rainfall increase proportionately with decrease in temperatures.

3.1.1 Rainfall suitability evaluation

Crops need specific requirements of temperature and rainfall for growth. Based on rainfall requirement of coffee Arabica, rainfall of the study area was classified in to three suitability classes according to land suitability analysis classification of (Nzeyimana et al., 2014). Its suitability ranges from high suitable to marginal suitable. The result revealed that the rainfall ranges between 1400 and 1600 mm (82.12%), 1300 and 1400 mm (17.7%), 1600 and 1710 mm (0.1%) were classified as highly suitable, moderately suitable and marginally suitable for coffee Arabica production respectively in the study area.

Table 3 Rainfall suitability class.

Rainfall (mm)	**rainfall suitability class**	**Area(hectare)**	**Area%**
1400-1600	S1	155482.3126	82.12%
1300-1400	S2	33512.3835	17.7%
1600-1710	S3	340.8039	0.18%
	Total	189335.5	100.00%

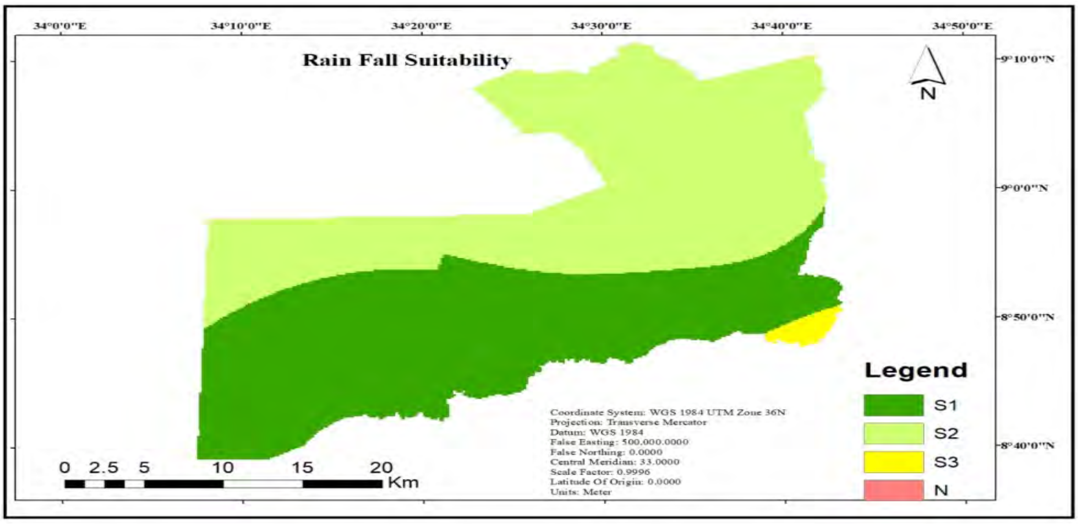

Fig. 1 Map of Rainfall suitability class.

3.1.2 Temperature suitability evaluation for coffee Arabica

Temperature is one of the limiting factors for crop production (Attiogbé et al., 2022). Based on temperature requirement of Coffee Arabica production, temperature of the study area was reclassified in to three suitability classes according to land suitability analysis classification of (FAO, 1984). These were highly suitable, moderately suitable and marginally suitable. Temperature that ranges between 20° and 22.5°, 17.5° and 20° and 22.5° were classified as highly, moderately and marginally suitable respectively for coffee Arabica production. The result is revealed that 87.9% of total area of the Woreda was highly suitable for coffee Arabica production with respect to temperature whereas, 6.5% and 5.4% of total area of the study area was moderately and marginally suitable for coffee Arabica cultivation respectively with respect to temperature.

Table 4 Temperature suitability class.

Temperature in °C	Temperature suitability class	Area(hectare)	Area%
20-22.5	S1	166425.9	87.9%
17.5-20	S2	12685.48	6.7%
22.5-23.3	S3	10224.12	5.4%
	Total	189335.5	100.00%

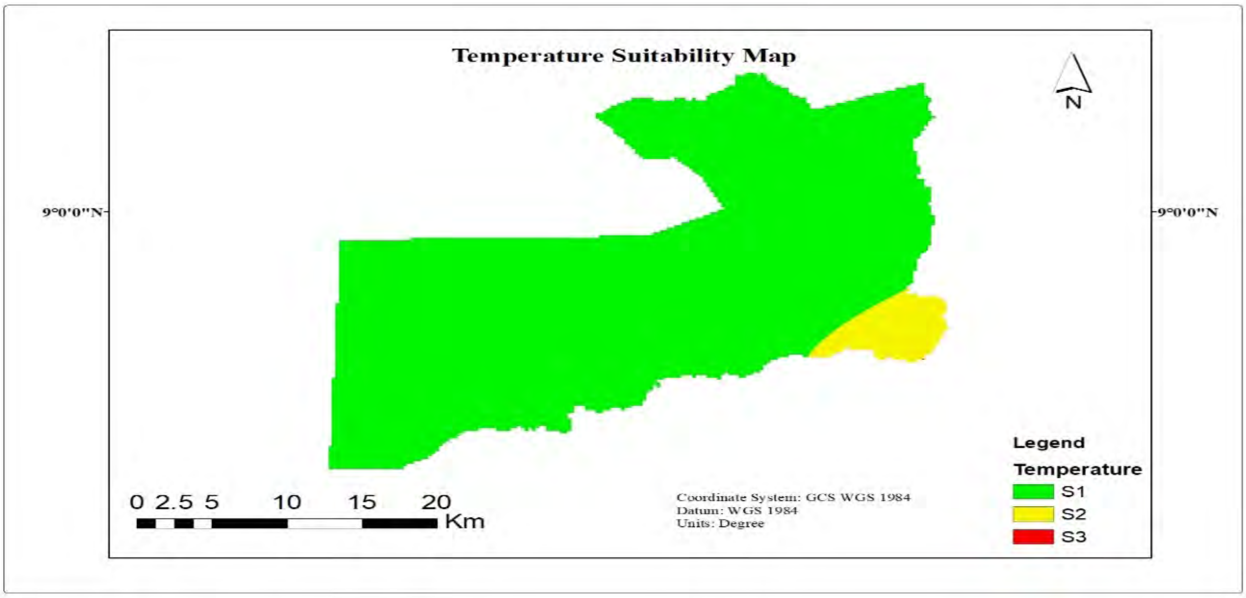

Fig. 2 Map of Temperature suitability class.

3.2 Suitability evaluation for coffee Arabica cultivation

Some of earlier studies suggested that elevation is the major factor that influence land suitability of coffee Arabica production (Nzeyimana et al., 2014). The Elevation of the study area was reclassified in to four classes according to its land qualities and characteristics of the altitude for the selection of the land for suitability of coffee Arabica production. The elevation was classified according to land suitability analysis classification of (FAO, 1984). Its suitability ranges from high suitable to not suitable. The result revealed that the elevation range between 1500 and 1800 m (20%) is reclassified as highly suitable for coffee Arabica production. Elevation ranges between 1100 and 1500 m (18%), 1800 and 2200 m (16%) were classified as moderately and marginally suitable for coffee Arabica production respectively; whereas, Elevation range between 863 and 1100 m and 2200 to 2655 m classified as not suitable for coffee Arabica cultivation.

Table 5 Elevation suitability class of the study area.

Elevation in (m)	Elevation suitability class	Area(hectare)	Area%
1500-1800	S1	40328.4615	21.3
1100-1500	S2	34269.7255	18.1
1800-2200	S3	31429.693	16.6
863-1100 and 2200-2655	N	83307.62	44

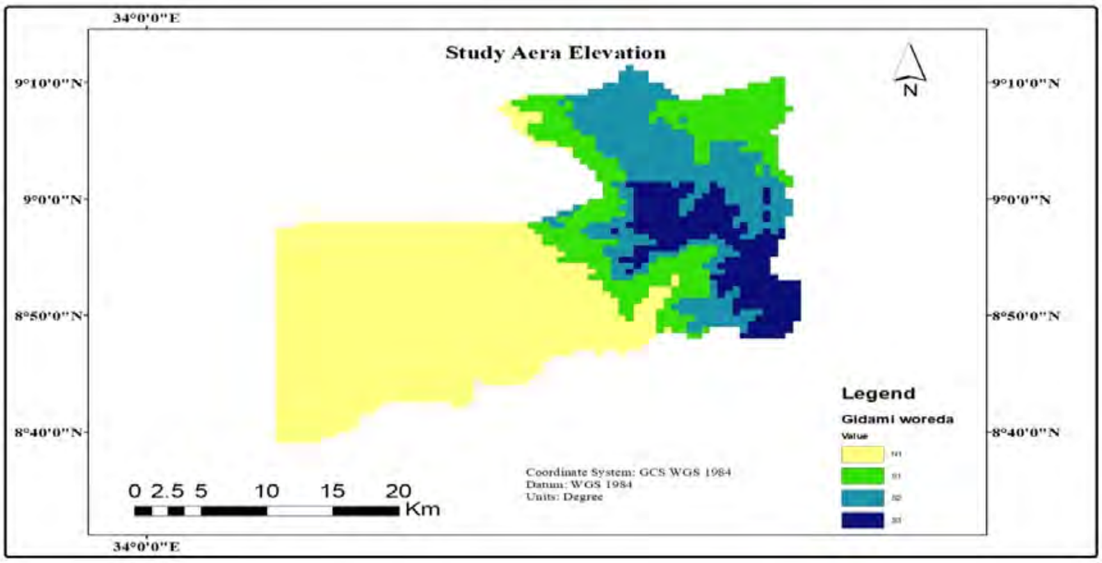

Fig. 3 Map of Elevation suitability class.

3.3 Slope suitability evaluation

Slope has been considered as one of the evaluation parameters in coffee Arabica suitability analysis (Nzeyimana et al., 2014). The slope of the study area is expressed in percentage. The Slope of the study area was reclassified in to four classes according to land suitability analysis classification of (Nzeyimana et al., 2014). These classes include very suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N). Slope ranges between 0 and 4 %, 4 and 12%, 12 and 25% were classified as highly, moderately and marginally suitable for coffee Arabica production respectively, whereas slope range between 25% and 50 % and greater than 50% were classified as not suitable for coffee Arabica production.

Table 6 Slope suitability class of the study area.

Slope Class	% Range	Slope Suitability Class	Area (ha)	Area %
Almost flat	0-4	S1	10224.117	5.40
Undulation plain	4-12	S2	49227.23	26
Hill to rolling	12-25	S3	70054.135	37
Steep and Very steep	25-50 and >50	N1	59830.018	31.60

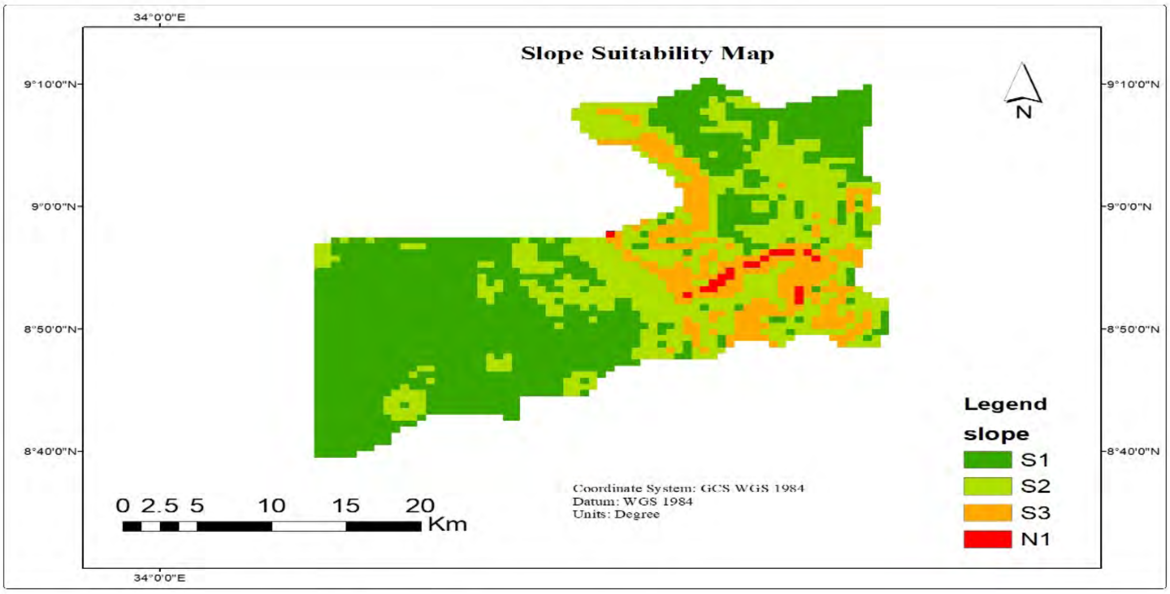

Fig. 4 Map of Slope suitability class of the study area.

3.4 Soil texture suitability evaluation

The suitability of soil texture for coffee Arabica cultivation was evaluated through its suitability potential for coffee Arabica production. Soil texture has been considered as one of the evaluation parameters in land suitability analysis for coffee Arabica production. Based on soil texture requirement of coffee Arabica production, soil texture of the study area was re classified in to three suitability classes according to land suitability analysis classification of (FAO, 1984). Its suitability class range from high suitable to marginal suitable. Loamy, clay loam and clay soil were re classified as highly, moderately, and marginally suitable for coffee Arabica Production. The result in revealed that 59.1 % of total area of the study area soil texture is dominated by clay loam and moderately suitable for coffee Arabica production. From the total area 39% of the area is loam and highly suitable for coffee Arabica cultivation, whereas, 0.11% the study area is clay and marginally suitable for coffee Arabica cultivation.

Table 7 Soil texture suitability class of the study area.

Soil texture	**Soil texture suitability class**	**Area (hectare)**	**Area%**
Loam	S1	73,840	39
Clay loam	S2	111,708	59
Clay	S3	3787.5	2

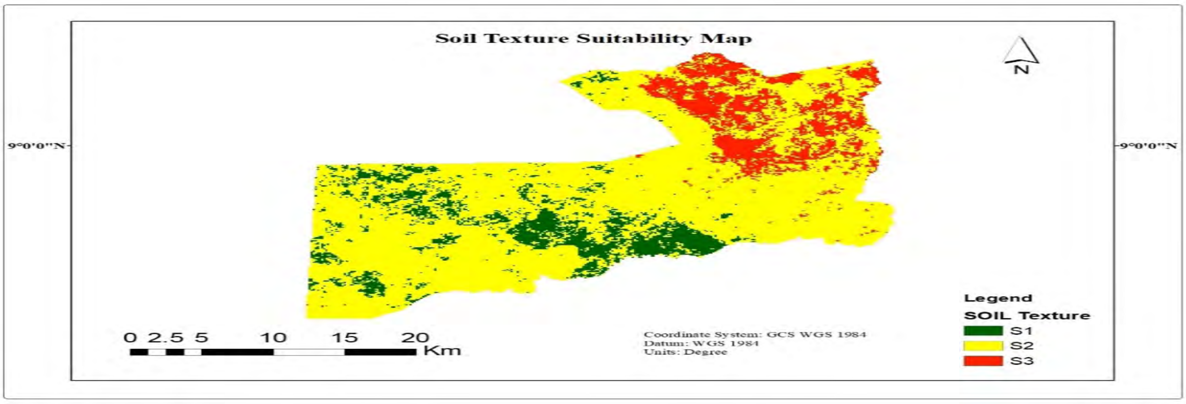

Fig. 5 Map of Soil texture suitability class of the study area.

3.5 Current LU/LC classification of study area

The Landsat 8 (OLI) of 2023 satellite image was used to classify the land use or cover of the study area. The satellite image was classified by the supervised image classification technique. The area was classified in to five main classes. These classes are Agricultural land, forest land, Grass land, water body and settlement. The results revealed that Agricultural land is dominant as compared to the other land cover or use types in the study area. It covers 93404.3 hectare (43.27%) of the total area of the Woreda. Forest area is the second dominant land cover in the study area .It covers 39.23% of total area of the Woreda. From the total land 13920 hectare (6.45%) was covered by Bare land. 22884.6 hectare (10.60%) was covered by settlement. 963.8 hectare (0.45%) was covered by water body.

Table 8 LU/LC classes and area coverage of Gidami.

Class Name	Suitability Class	Area (hectare)	Area %
Forest Area	S1	74276.32	39.23%
Agricultural land	S2	81925.47	43.27%
Bare Land	S3	12212.14	6.45%
Settlement	N	20069.56	10.60%
Water Body	N	852.0098	0.45%
Total		189335.5	100%

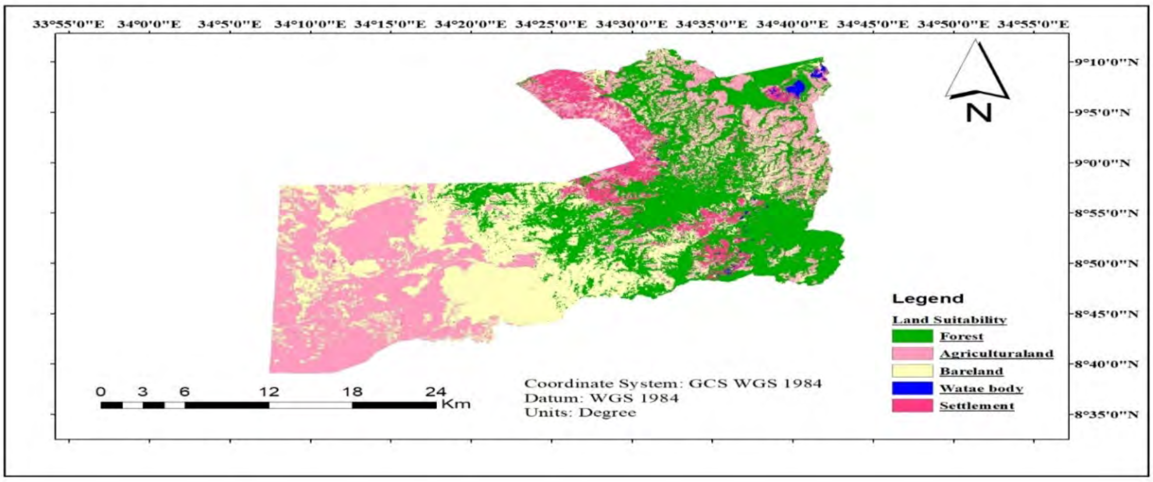

Fig. 6 Map of LULC Class suitability class of the study area.

3.6 Determining criterion weights

All the six factors, which were selected for the evaluation of Land suitability for coffee Arabica production in the study area, were weighted using pair wise comparison method. This comparison matrix was filled decided with the expert participation of natural resource in Gidami district, coffee expert and depending on (Jingade et al., 2019). After the Pairwise comparison matrices were filled, the weight module was used to identify consistency ratio and develop the best fit weights. The consistency ratio (CR) computed and the result is 0.03, which was accepted able for weighting the factors to assess the land suitability of coffee Arabica in the study area.

Table 9 Pairwise weight matrix for nine factors used in the study area.

Factor	Temperature	RF	LULC	Elevation	Slope	Soil texture
Temperature	1	2	3	3	5	5
RF	0.5	1	2	3	5	5
LULC	0.3	0.5	1	3	3	3
Elevation	0.3	0.3	0.3	1	2	2
Slope	0.2	0.2	0.3	0.5	1	2
Soil texture	0.2	0.2	0.3	0.5	0.5	1
Total	2.56	4.3	7	11	16.5	18

To determine the weight of each factor map, normalization process is needed. To normalize the above pairwise matrix value, each cell value is divided by its column total. To get the weight of each class, the mean value of the row calculated.

Table 10 Normalization result.

Factor	Temperature	RF	LULC	Elevation	Slope	Soil texture	Sum	Criteria weight	CW %
Temperature	0.39	0.47	0.43	0.27	0.30	0.28	2.14	0.36	35.74
RF	0.19	0.24	0.29	0.27	0.30	0.28	1.57	0.26	26.17
LULC	0.13	0.12	0.14	0.27	0.18	0.17	1.01	0.17	16.86
Elevation	0.13	0.08	0.05	0.09	0.12	0.11	0.58	0.10	9.66
Slope	0.08	0.05	0.05	0.05	0.06	0.11	0.39	0.06	6.50
Soil texture	0.08	0.05	0.05	0.05	0.03	0.06	0.30	0.05	5.07

Maximum eigenvector =6.198, n= 6, CI= 0.039, CR= 0.03 which is less than 0.1 (acceptable). The percentage influence of temperature was assigned as 35.74% of the total layers of the study area maps. The highest weight was given to temperature. This is the same with research done by (Adane & Bewket, 2021) who give highest weight to temperature. This is because of temperature is the most limiting factor in the identification of land suitability analysis for coffee cultivation. Rainfall was assigned the percentage influence of 26.17%. It was the second most limiting factor in identification of land suitability analysis for coffee Arabica cultivation .The Land use/cover map assigned 16.86%. Elevation and slope were assigned 9.66% and 6.5% percentage influence respectively. Soil texture was assigned the percentage influence of 5.07%.

Using a model builder from ArcGIS Arc toolbox, a suitability analysis model was designed and used in processing the suitability map. The model which generated the preliminary suitability map was as shown in Fig. 8.

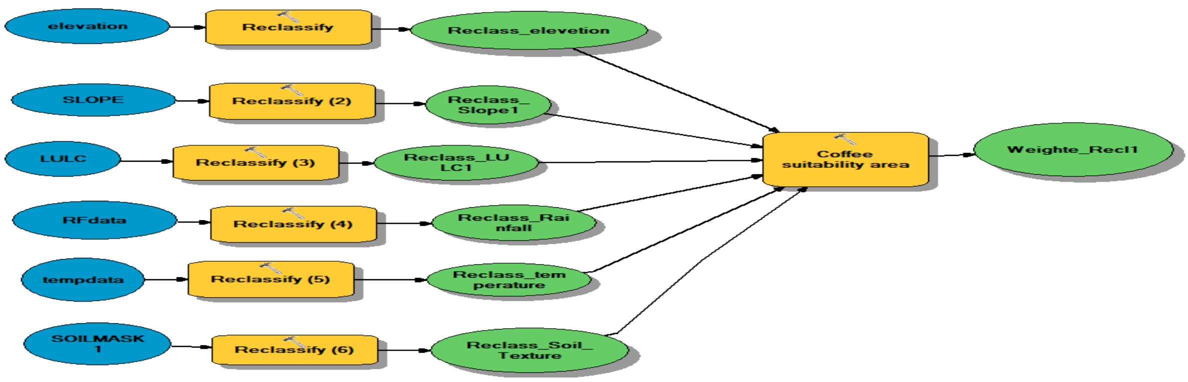

Fig. 7 Map of Model suitability.

3.7 Weighted overlay analysis

After reclassifying each factor to common scale or suitable class and Assigning criterion weights each factor were added to weighted overlay tool. The added criteria (factors) were rated from 1 to 5 (most suitable to least suitable) to its suitability class range in ranking method. The area covered by water body was restricted from the use of suitability for coffee Arabica production. The final land suitability map of coffee Arabica in the study area was developed. The final output of weighted overlay tool was named as map coffee Arabica production .The map of land suitable for coffee Arabica was further analyzed and queried.

The values which were obtained from the result were classified in to three suitability classes. These were very suitable, moderately suitable and marginally suitable. The final map of the study area was revealed that the Woreda has land that is suitable for coffee Arabica production. From the suitability range of highly suitable to marginally suitable, the total land of the study area 69048.65.47 ha (36.46%) was very suitable, 114917.33 ha (60.69%) moderately suitable and 5369.52 ha (2.83%) marginally suitable for coffee Arabica cultivation.

Table 11 Land suitability of the study area for coffee Arabica production.

No	Suitability Class	Area	Area in %
1.	Highly Suitable	69048.65	36.46
2.	Moderately Suitable	114917.33	60.69
3	Marginally Suitable	5369.52	2.83

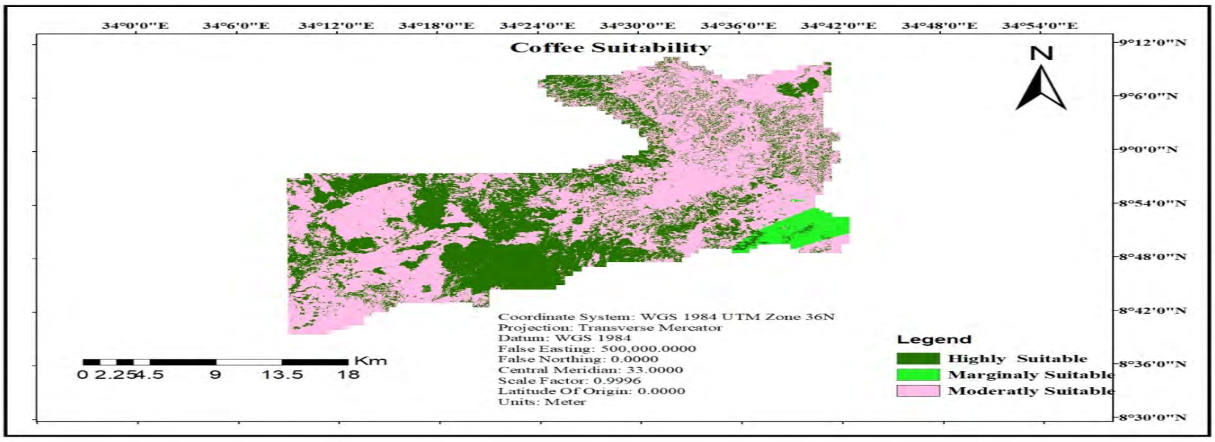

Fig. 8 Map of Land suitability of the study area.

4 Conclusion

This study was primarily focused on the identification of the suitable site for coffee Arabica production in the Gidami district. The parameters used for land suitability analysis were topography (elevation, slope), climate (temperature and rainfall), soil (soil texture) and LULC. Geographical Information System (GIS), Remote Sensing application and Multi-Criteria Decision making methods have been used to interrogate and verify the conditions which favor growing of coffee in Gidami District. Land suitability analyses performed by using the AHP method through assigning different weights to all parameters. The parameters were placed in well-defined hierarchy after passing through hit and trial method and also incorporated with expert knowledge from various discipline and literature review. On the basis of all these factors suitability maps were generated base on FAO guideline. In this model all required parameters work together and according to their suitability ratios, highly, moderately and marginally suitable areas were identified for coffee Arabica production. This finding indicates that the study area has a potential for coffee Arabica cultivation. The results revealed that, 36.46%, 60.69% and 2.83% of the total land area is highly, moderately and marginally suitable for coffee Arabica production. Hence, the suitability of land classification analysis assured that more area of land is available which is suitable for coffee Arabica cultivation.

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