Hindawi
Applied and Environmental Soil Science
Volume 2022, Article ID 4436417, 13 pages
https://doi.org/10.1155/2022/4436417

Research Article

Land Suitability Assessment for Apple (*Malus domestica*) Production in Sentele Watershed in Hadiya Zone, Southern Ethiopia

Getachew Beyene,[1] **Nigussie Dechassa**,[2] **Alemayehu Regasa**,[3] **and Lemma Wogi**[4]

[1]*Department of Natural Resources Management, Wachemo University, Hosaena, Ethiopia*
[2]*School of Plant Sciences, Haramaya University, Dire Dawa, Ethiopia*
[3]*Department of Natural Resources Management, Jimma University, Jimma, Ethiopia*
[4]*School of Natural Resources Management and Environmental Sciences, Haramaya University, Dire Dawa, Ethiopia*

Correspondence should be addressed to Getachew Beyene; gechbeye1260@yahoo.com

Received 9 February 2022; Revised 30 April 2022; Accepted 18 May 2022; Published 13 June 2022

Academic Editor: Upaka Rathnayake

Apple (Malus domestica) is cultivated in Southern Ethiopia. However, the crop is being grown in without affirming the suitability of the land for its cultivation. Therefore, this research was conducted to assess the suitability of the land of Sentele Watershed for apple production in Southern Ethiopia. Integrating GIS and analytic hierarchy process (AHP) method, which is widely used in multi-criteria decision-making for tackling multi-attribute decision-making problems in real situations, was used in this study. In the application techniques, most attributes that determine apple growth, climate, edaphic, topography, and current land use/land cover were combined. In determining the weights of the attributes, the opinions of experts and experienced apple orchard workers were considered, and an agricultural land suitability map was produced as highly suitable, moderately suitable, marginally suitable, and least suitable. The methodology was based on the land evaluation developed by FAO (1976) that suggests biophysical diagnostic factors, which most strongly influenced the cultivation of apples. Criteria were defined, background information was gathered, and a raster surface was created. The layers are reclassified, weighed, and then the output layers are overlaid with the background information such as a map of topography to see the best potential sites and to prepare the final suitability map. The final apple suitability map showed that only 2.2% of the total land is highly suitable, 32% is moderately suitable, and 52.1% is marginally suitable, and it requires detailed investigation and careful decision over other land uses to invest in it. 13.7% is the least suitable for apple cultivation. It is concluded that about 34% of the total land of the study area is suitable for apple production, and about 66% is unsuitable. The results imply that it is necessary to take improvement measures such as irrigation, species selection, removing leaves (defoliation), and appropriate land-use planning in most of the land of the watershed before investing in apple cultivation and production, and it is necessary to expand apple production in the future only in areas that are highly and moderately suitable for producing the crop in the study area.

1. Introduction

Land suitability analysis evaluates the factors responsible for the suitability of crops in a given area. The concept of land evaluation is the assessment of land performance when used for a specific purpose, involving the execution and interpretation of surveys and studies of topography, climate, soil, vegetation, and other aspects of land [1]. Land suitability analysis provides information on the constraints and opportunities for the use of land and, therefore, guides decision on optimal utilization of resources. Also, such a kind of analysis allows for identifying the major limiting factors for agricultural production and enables decision-makers to develop a crop management scheme able to overcome such limitations and increase productivity [2]. The primary objective of land suitability evaluation [3] is the prediction of the inherent capacity of the land to support a specific land use for a long time without deterioration and with minimum costs of socioeconomic and environmental values.

The knowledge on apple cultivation was acquired from literature, local experts, development agents, and farmers engaged in apple production and land use/land cover (LULC). Each factor has some degree of contribution towards the suitability for apple cultivation. The temperature has a profound effect on all aspects of apple tree physiology; at extremes, high or low temperatures can cause death, while, at intermediate temperatures, all physiological processes are affected [4]. Soil properties are one of the most important factors in agricultural land suitability assessment [5]. Apple grows best on well-drained, loam soils having a depth of above 60 cm and a pH range of 5.6 to 6.8 [6], which is rich in organic matter free from hard substrata and water-logged conditions. Extreme soil pH values result in nutrient tie-up or toxicity and poor tree and fruit development. High yields are obtained on freely drained soils where water is not limited [7].

In Southern Ethiopia, where this research was conducted, no similar research had been undertaken with research on land suitability assessment for apple production. Some studies have been conducted in different regions that focus on land suitability assessment for apple production [8–11]. These researches are restricted to a few areas and give inadequate information to utilize resources in Sentele Watershed, characterized at a small scale with high-level generalization, and locally adopted evidence such as climatic, edaphic, topographic, and current land use/land cover is needed for decision-making on proper resource utilization. Thus, there is an urgent need for land suitability assessment for sustainable apple production in the area.

Several procedures have been used for land suitability assessment [1], ranging from expert knowledge based on farmers' experience to process-oriented simulation methods. The evaluation process requires contributions from different fields such as natural science, the technology of land use, economics, and sociology [12]. Torrieri and Batà [13] mentioned that land managers and land-use planners are encouraged to use multi-criteria decision-making tools in combination with GIS for integrating and managing numerous and heterogeneous factors. The analytical hierarchy process (AHP) developed by Saaty [14] is also widely used for solving a variety of problems based on complex parameters across various levels where the interaction among parameters is common characteristics [15]. Saaty and Vargas [16]; AHP is a widely used method in decision-making and developed for selecting the best from several alternatives to several criteria. Thus, AHP is a mathematical method that established a hierarchal model for solving highly complex problems of land management with the best alternatives [17]. Experts and scientific knowledge were weighted with analytic hierarchy (AHP) (Dadeoğlu and Dengiz) [18]; the weight assignment approach was used [19]. The GIS method is a technique that provides greater flexibility and accuracy for handling digital spatial data.

Therefore, in this study the analytical hierarchy process (AHP) integrated with the geographic information system (GIS) was applied to delineate suitable apple *(Malus domestica)* cultivation locations in Sentele Watershed, Southern Ethiopia, using the relevant variables of climatic condition (temperature, rainfall), soil parameters (pH, drainage, texture), topographic characteristics (elevation, slope, aspect), and land use/land cover that have been analyzed, and a land suitability map was produced. The map generated is hoped to provide information for apple-growing farmers, extension agents, experts, and researchers along with the valuable information on the suitability of the land for growing apples based on important land conditions and considering the quality of land characteristics on scientific bases on future.

2. Materials and Methods

2.1. Description of the Study Area. This study was carried out in the Sentele Watershed located in Hadiya Zone, Southern Ethiopia, about 245 km southwest of the capital of Ethiopia (Figure 1), at 7°36′00″ to 7°39′30″ N and 37°48′24″ to 37°50′522″ E, with an elevation of 2270 to 2680 meters above sea level. Sentele Watershed has slopes of 2 to 30 percent. The total annual rainfall in the area is 1178 mm, and the mean annual maximum and minimum temperatures are 22.8°C and 9.2°C, respectively (Figure 2). As the area is located at higher elevations, it enjoys a temperate climate with three distinct seasons, namely Bega, Belg, and Kremt. Climatic data used for evaluating the climatic characteristics of the study area were obtained from Ethiopian Meteorological Agency data registered from Hossaina Station. The data set comprises maximum and minimum temperatures and rainfall (Figure 2). The geology of the studied watershed is Phanerozoic quaternary period volcanic with associated sediments revealing basaltic ignimbrite parent material. Therefore, it exposes rocks of the Cenozoic era mostly formed during the quaternary period as a result of the widespread volcanism induced by extensive fracturing and subsequent faulting [20].

Agriculture is the main source of livelihood for the community, and subsistence-type mixed crop-livestock systems characterize the farming system. Mixed agriculture has been a dominant economic activity in the area. Like many parts of Ethiopia, Hadiya Zone is mainly characterized by rain-fed mixed farming with traditional technologies. Both crops and livestock production systems are the mainstays of the livelihood in the area.

2.2. Materials Used and Methods of Data Collection. After having the preliminary site visit, the topographic map with a semi-detailed scale (1 : 50,000) was obtained from the Ethiopian Mapping Agency and used to generate DEM layers. The global positioning system (GPS) records the watershed boundary points. To develop the land use and land cover map, Landsat 8 images were obtained from the USGS website and accessed using Earth Explorer via https://earthexplorer.usgs.gov. Cloud-free images of the area were acquired on October 10, 2021. Climate data for the last 29 consecutive years were taken from the Ethiopian Meteorological Agency. The data for this research were conducted using a survey method to determine land conditions. Sample points were done based on homogeneous land units from an overlay of maps, and soil sampling was carried out from pedons excavated at each land mapping unit. The

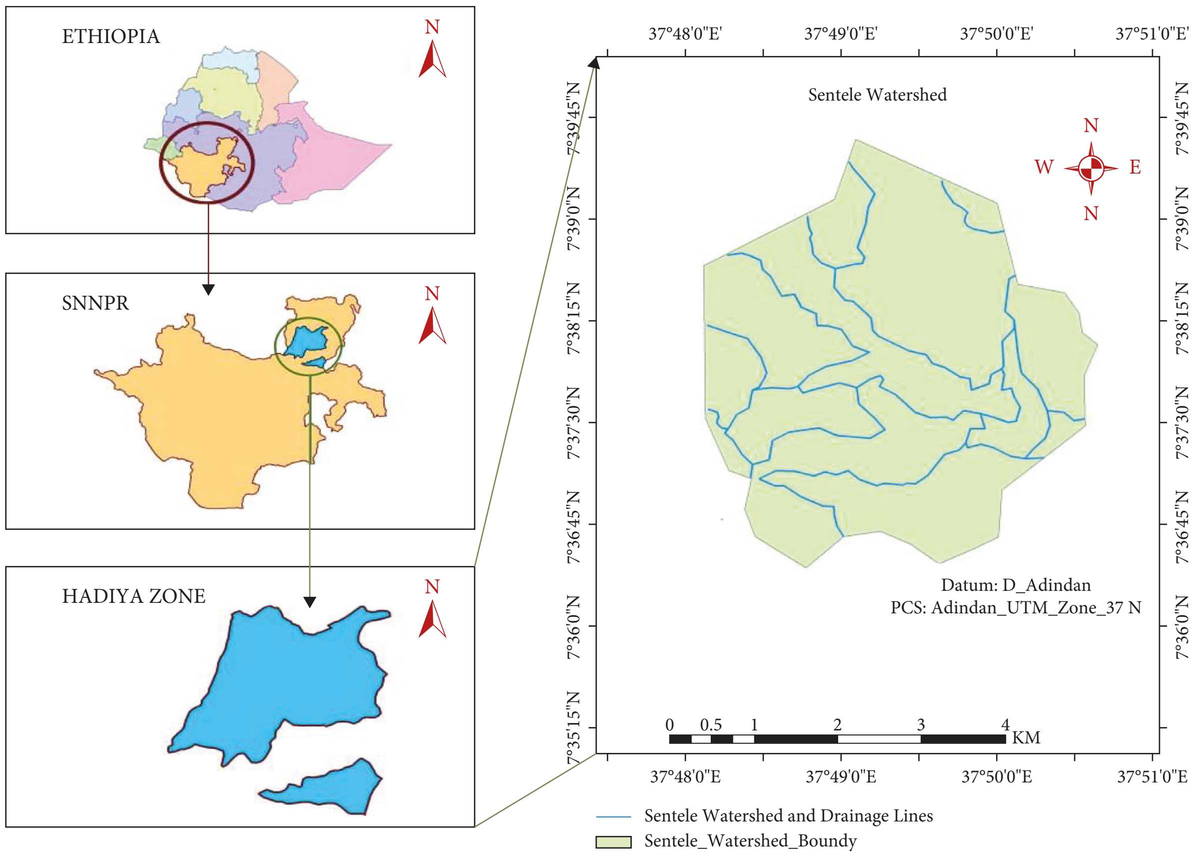


Figure 1: Location map of study area.

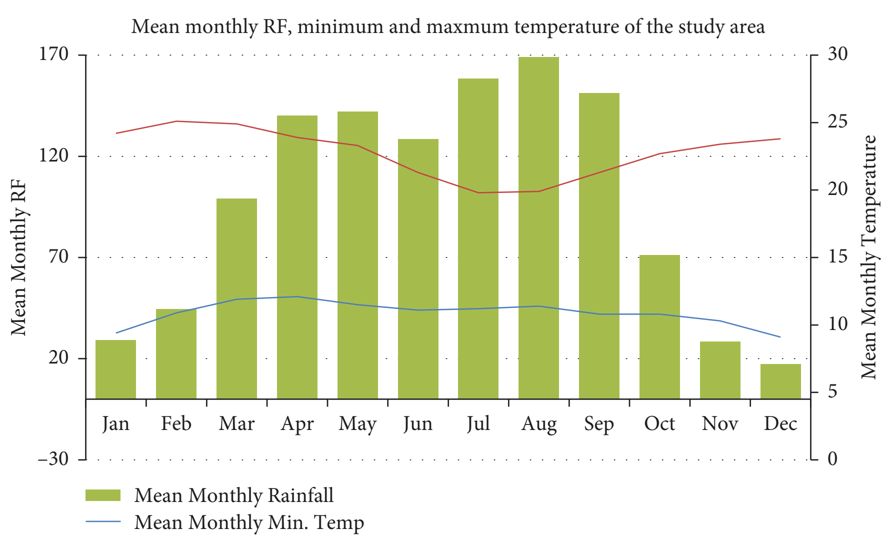


Figure 2: Climate data collected from Hossaina, a center nearest to the study site (1991–2018).

topographic characteristics, soil parameters, climatic condition, and land use/land cover of the area are considered the most important determinant factors of land suitability analysis for apple cultivation in this study [8, 9]. Therefore, land suitability assessment was done by comparing site conditions with the apple requirement concerning the characteristics of topographic characteristics (slope, altitude, aspect), soil parameters (depth, drainage, soil pH, texture), climate condition (mean temperature, growing period temperature, and rainfall), and land/use land cover (LULC). Rainfall and temperature point data were converted into polygon using the Thiessen polygon in ArcGIS. After that, they were converted into raster using the conversion tool.

2.3. Field Work. Data on the area were collected including a topographic map (1 : 50,000), climatic data, and land-use requirements for apple growth. With the aid of a location map to identify land units, a free survey method was used and the identified land units were geo-referenced using a global positioning system (GPS). Four land units were identified, and in each land unit, a profile pit was excavated. At each LMU, pedons having 2 m × 2 m × 1.5 m were excavated, which represents that land units and soil samples were collected from each identified genetic horizons of the soil profiles, starting from the lowest to the uppermost, to prevent cross-contamination. 15 soil composites from four profiles pits were taken for physical and chemical analysis of soil parameters.

Soil data used for evaluating the soil characteristics of the study area were obtained from field identification and soil samples analyzed at the SNNPR Bureau of Agriculture Hawassa Soil Testing Laboratory. There were four major types of soils identified in the studied area according to WRB [21] soil classification. These are Chromic Luvisols, Silandic Andosols, Rhodic Nitisols, and Vertic Luvisols, which were formed as a result of elevation, slope, soil attributes, land use, and landforms on which land suitability assessment was based.

3. Data Analysis of Research

3.1. Establishing Evaluation Criteria. Expert information on apple crop cultivation was collected through interviews with key informants. The key informants were chosen according to their professional career and knowledge developed through experience in apple cultivation. Therefore, this study established 11 key criteria organized into four groups (climate, soil, topographic characteristics, and land use/land cover) [22] and key informant opinions.

3.2. Creation of Thematic Maps. Thematic maps in this study include climate maps (growing period temperature, mean annual temperature, and rainfall), soil maps (soil depth, drainage, soil texture, pH), topographic maps (slope, elevation, aspect), and land use/land cover (Figure 3). These thematic maps were created and edited, overlaid, and visualized based on the suitability analysis using ArcGIS software of ESRI. The application of GIS for overlaying thematic layers to establish land databases requires that the layer maps are converted into a common coordinate system. This involves a stepwise arrangement and organization of acquired data in a manner that is appropriate for analysis. All these maps were again reclassified into four classes of suitability as defined in the growth condition requirement table of apple. The reclassification of each thematic map generates the individual suitability map of each parameter that is further used for evaluating the final suitability map of apple using AHP (Figure 4).

3.3. Assigning Weights of Factors and Variables. The results from the key informant interviews were used to derive the relative importance of one criterion to another using the analytical hierarchy process (AHP) [23], which has been used in a pairwise comparison technique to assign individual parameter weights for each factor. So, the analytical hierarchy process is adjusted to weight various factors and variables effectively, setting relatively higher values for more important factors based on the opinions of key informants [9]. The weighted overlay tool applies one of the most used approaches for overlay analysis to solve multi-criteria problems and suitability models. As land suitability analysis requires both spatial and attribute data in many data layers, GIS can be used to combine biophysical and socioeconomic characteristics for land evaluation and a multi-criteria evaluation tool can be developed to support the decision-makers the balance among different stakeholders' interests. Then, integration of GIS and AHP combines decision support methodology with powerful visualization, mapping, and analyzing capabilities.

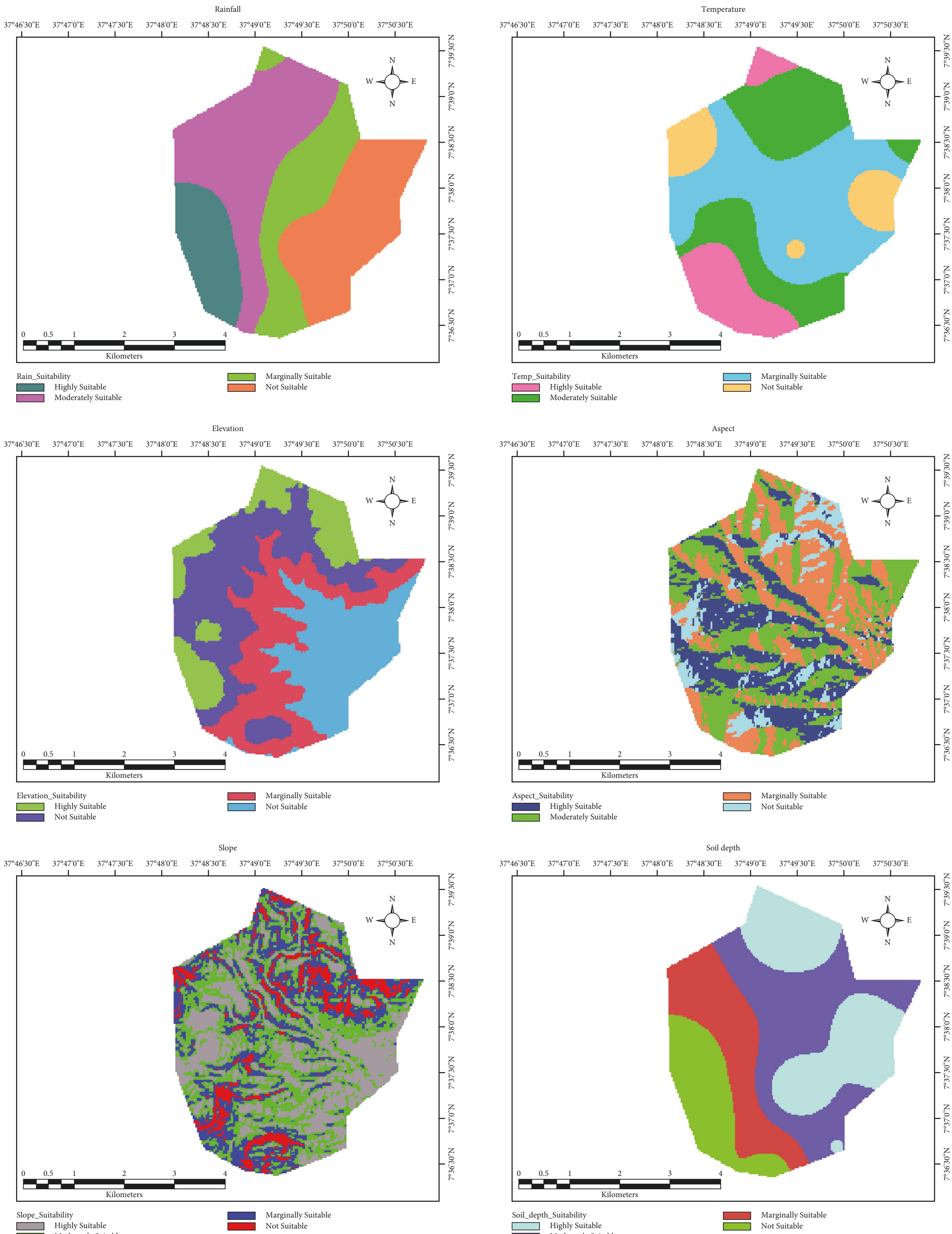
According to Saaty [23], there are three steps to process the AHP technique: the first step of the AHP technique is to structure the overall goal (land suitability) into several criteria and sub-criteria in a hierarchy. The second step of the AHP technique involves a comparison of the alternatives, criteria, and sub-criteria. They are compared in pairs for each factor of the next higher level. The third step of the AHP technique is to synthesize the comparisons to get the priorities of the alternatives for each criterion and the weights of each criterion to the goal (Table 1).GPT = growth season temperature; LULC = land use/land cover.

The consistency ratio was calculated according to the matrix that was formed for the significance level of the analytic hierarchy process (AHP) parameters, and the result was found to be $0.09 < 0.1$. According to this consistency ratio, the weight values obtained in Table 2 were used in the weighted overlay analysis. The ratings of the sub-parameters of each parameter were also used in the analysis.

3.4. Land Suitability Analysis for Apple Using Weighted Overlay. The weighted linear combination (WLC) class of map combination (overlay) was used to prepare a map of suitability. Simple additive weighting is based on the concept of a weighted average in which continuous criteria are standardized to a common numeric range and then combined using a weighted average [24]. The decision-maker assigns the weights of relative importance directly to each attribute map layer. The total score (Table 3) for each alternative is obtained by multiplying the importance of weight assigned to each attribute by the scaled value given for that attribute to the alternative and then summing the product's overall attributes [25].

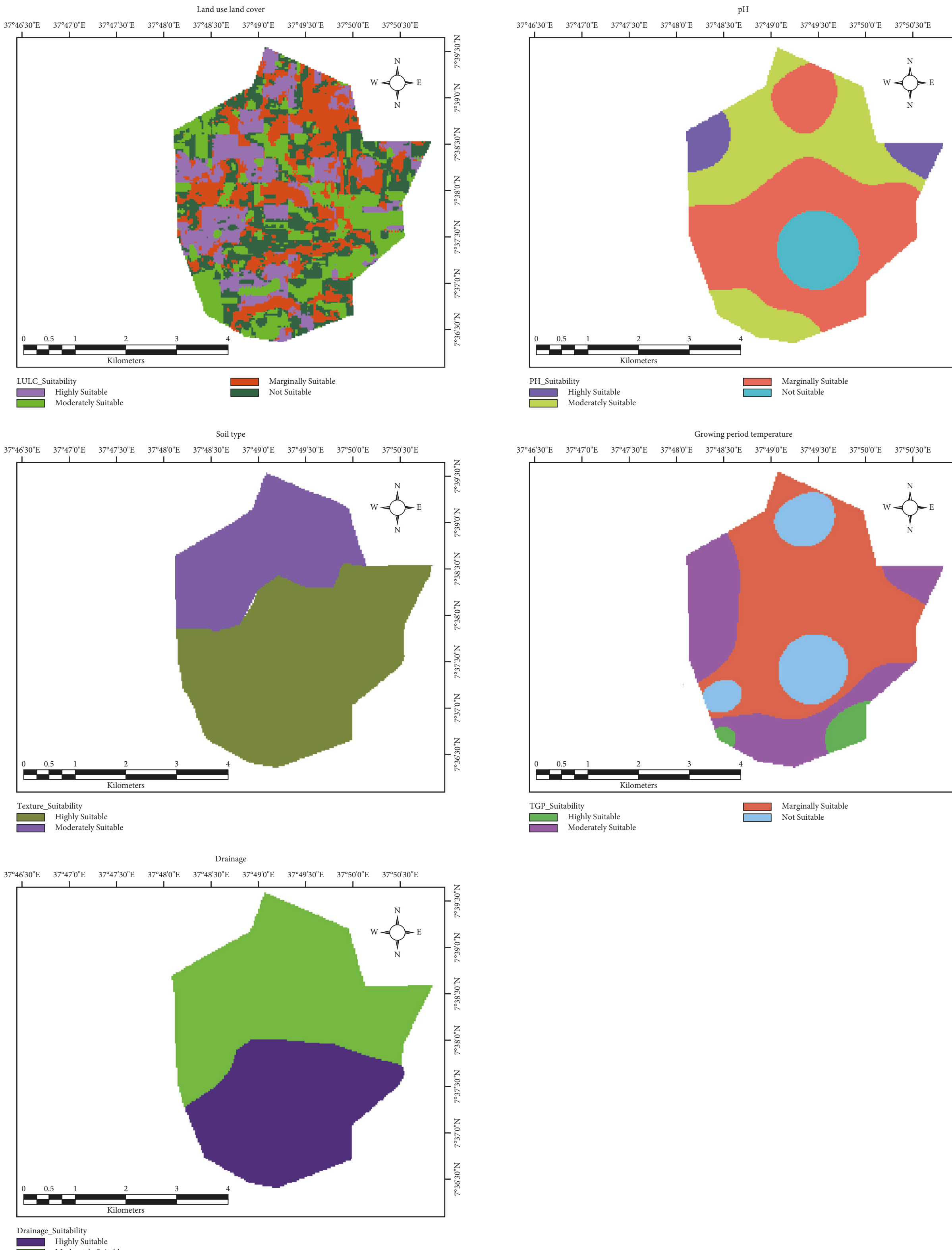
3.5. WLC Is Computed as $H = \sum wixi$. where H is the composite suitability score, xi is factor scores (cells), wi is weights assigned to each factor, and $\sum$ is the sum of weighted factors.

For the assessment of land suitability for apple production in the study area, eleven factors that influence apple growth were selected and prioritized. From these factors, the possibilities and constraints for apple production were evaluated. These were elevation, slope, aspect, GPT, mean temperature, rainfall, soil depth, soil pH, drainage, current land use, and land cover and soil texture (Table 4).



(a)

Figure 3: Continued.



(b)

FIGURE 3: Suitability maps of criteria.

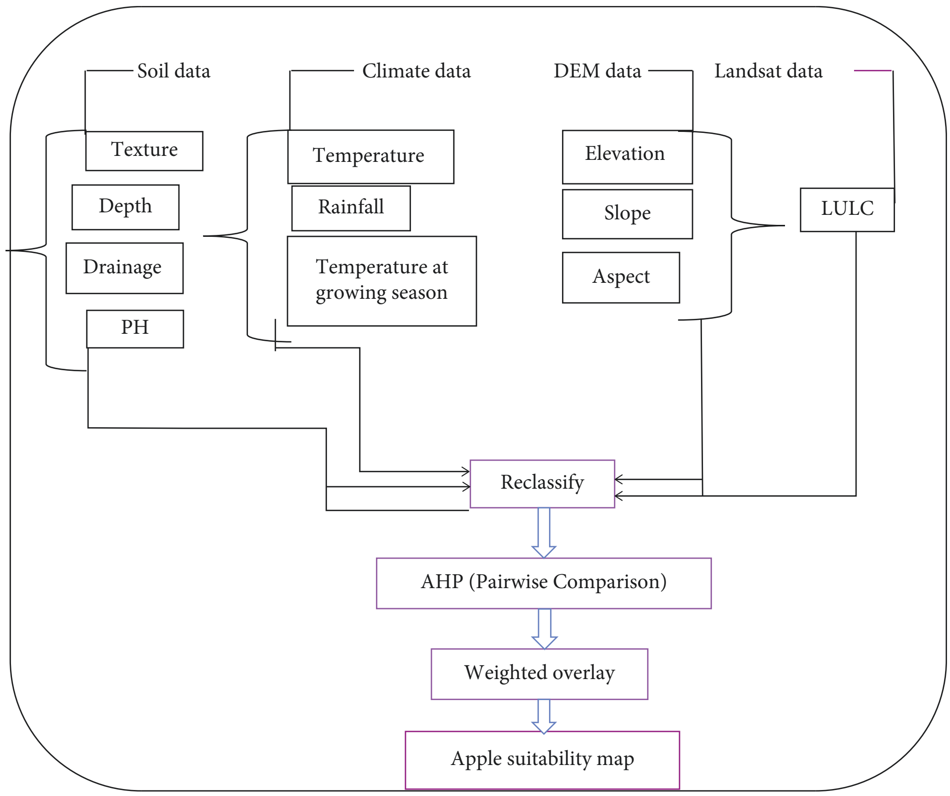


Figure 4: Flow chart of data collection and data analysis.

Table 1: Pairwise comparison matrix of the criteria and their weights.

	Aspect	Drainage	Elevation	GPT	LULU	pH	Rainfall	Slope	Soil depth	Temp	Texture
Aspect	1	1	1/7	1/5	1	1/3	1/3	1/3	1/3	1/5	1
Drainage	1	1	1/5	1/3	1	1	1/3	1/3	1/3	1/3	1
Elevation	7	5	1	1	3	3	3	3	3	3	5
GPT	5	3	1	1	5	3	3	3	3	3	5
LULU	1	1	1/3	1/5	1	1/3	1/5	1/3	1/3	1/5	1
pH	3	1	1/3	1/3	3	1	1/3	1	1/3	1/3	1/3
Rainfall	3	3	1/3	1/3	5	3	1	3	3	1/3	5
Slope	3	3	1/3	1/3	3	1	1/3	1	1/3	1/3	3
Soil depth	3	3	1/3	1/3	3	3	1/3	3	1	1/3	3
Temp	5	3	1/3	1/3	5	3	3	3	3	1	5
Texture	1	1	1/5	1/5	1	1/3	1/5	1/3	1/3	1/5	1

Table 2: Eigenvector of weights.

Aspect	0.0258
Drainage	0.0397
Elevation	0.2037
GST	0.1895
LULC	0.9339
pH	0.0578
Rainfall	0.1142
Slope	0.0640
Soil depth	0.0884
Temperature	0.1402
Texture	0.0428

GST = growing season temperature; LULC = land use/land cover.

4. Results and Discussion

4.1. Factors Affecting Apple Growth. Every crop has its requirements for growth. Various geo-environmental factors influence the suitability of the land for different agricultural products [26]. The importance of each factor, namely elevation, growing period temperature (GPT), mean annual temperature, rainfall, soil depth, slope, soil reaction (pH), soil texture, drainage, land use/land cover, and aspect, was identified (Table 5). Each factor has been represented by limits and degree of suitability to apple production in each unit of area based on experts' judgment and different literature.

Table 3: Weights of the parameters and scores of sub-parameters.

Criteria	Optimal values	Eigenvector weight	Weight	Suitability
Elevation	2500–2700 2300–2500 2100–2300 1900–2100	0.2037	20.37	S1 S2 S3 S4
Slope	0–10 8–18 18–28 28–58	0.0640	6.4	S1 S2 S3 S4
Aspect	359–256 256168 168–89 89– (−1)	0.0258	2.58	S1 S2 S3 S4
pH	5.52–5.8 5.8–5.83 5.83–6.15 6.15–6.30	0.0578	5.78	S1 S2 S3 S4
LULC	Grassland Agricultural land Open land Settlement	0.0339	3.39	S1 S2 S3 S4
Mean annual temperature	9–11 11–14 14–16 16–18	0.1402	14.02	S1 S2 S3 S4
The temperature during the growing season	15–15.5 15.5–16 16–17 17–17.5	0.1895	18.95	S1 S2 S3 S4
Rainfall	1500–2000 2000–1500 1500–1000 1000–500	0.1142	11.42	S1 S2 S3 S4
Texture	Clay loam Clay	0.0428	4.28	S1 S2
Soil depth	200–150 150–100 100–70 <70	0.0884	8.84	S1 S2 S3 S4
Drainage	Well-drained Moderately drained	0.0397	3.97	S1 S2

GST = growing season temperature; LULC = land use/land cover.

Table 4: Land suitability criteria classification for apple cultivation [8, 9, 51].

Criteria	Unit	Land suitability classes			
		S1	S2	S3	S4
Elevation	Meter a.s.l	2500–2700	2300–2500	2100–2300	2900–3100
Slope	%	0–8	8–18	18–28	28–40
Aspect	Direction	359–256	256–168	168–89	89-(-1)
GPT	°C	15–17	17–19	19–21	21–23
Mean temp	°C	9–11	11–14	14–16	16–18
Rainfall	Mm	1000–1200	1200–1300, 800–1000	1300–1400, <800	>1400
Soil depth	cm	150–200	100–150	70–100	<70
pH	-log (H^+)	6.0–6.5	5.7–6.0	5.6–5.7	<5.6
Drainage	%	Well-drained	Moderately drained		
LULC	Type	Grassland	Agricultural land	Open land	Settlement
Soil texture	Texture	Loamy clay	Clay		

m.a.s.l = meter above sea level; GPT = growth season temperature; LULC = land use/land cover.

Table 5: Evaluation criteria and land area under different land suitability classes.

Criteria	S1 Highly suitable		S2 Moderately suitable		S3 Marginally suitable		S4 Least suitable	
	%	Ha	%	Ha	%	Ha	%	Ha
Elevation	16.4	308.8	31.9	600.7	26.5	499.0	25.2	474.5
GTP	3.6	67.8	27.9	525.4	53.4	1005.5	15.1	284.3
Mean temp	14.4	271.2	31.6	595.0	42.9	807.8	11.1	209.0
Rainfall	13.5	254.2	36.2	681.7	21.5	404.8	28.8	542.3
Soil depth	30.5	574.3	31.9	600.7	21.4	403.0	16.2	305.0
Slope	29.4	553.6	32.5	612.0	26.3	495.2	11.8	222.2
pH	6.6	124.3	34.8	655.3	48.2	907.6	10.4	195.8
Soil type	66.2	1,246.6	33.8	636.4	-		-	
Drainage	43.5	819.1	56.5	1,063.9	-		-	
LULC	22.1	416.1	25.6	482.1	26.3	495.2	26.0	489.6
Aspect	26.9	506.5	33.0	621.4	28.0	527.2	12.1	227.9

Area

Source: calculated from scores of suitability maps and AHP technique.

4.1.1. Elevation. The elevation is an important factor affecting any plant growth due to its role in temperature change [27]. Whence, elevation has got a high weight value of 0.2037. In the study area, the elevation suitability map shows that about 1/6th of the land has an elevation of 2500–2700 meters above sea level, which is highly suitable, and about 1/3rd of the land has an elevation range of 2300–2500 m.a.s.l, which is moderately suitable, while about 1/4th of the land has an elevation range of 2100–2300 meters above sea level, which is marginally suitable for apple cultivation, and the other 1/4th of the land has an elevation range of 1900–2100 meters above sea level, which is least suitable (Table 5). The results indicated that more than half of the land is not suitable for apple cultivation from an elevation point of view. The elevation is an important factor affecting any plant growth due to its role in temperature changes and thus in a variation of plant cover [27]. At the high altitudes in the tropics, average temperatures are lower, which allows easier reaching of chilling conditions, but seasonal amplitudes remain low [28]. Apple can be grown at an elevation ranging between 1800 and 2700 m.a.s.l. However, altitude ranges from 2500 to 2700 meters above sea level, which is highly suitable for apple cultivation because the apple gets its chilling requirement fulfilled at a temperature below 7°C to overcome its dormancy [29]. Therefore, the chilling requirement of the apple can be satisfied by the higher elevation of the watershed. In this study, after browsing through literature and experts' opinions, the elevation parameter has been given the highest priority weight in preparing the land suitability map of apple for the study area.

4.1.2. The Temperature during the Growing Season. The temperature during the growing season is another environmental factor affecting the growth of apples after elevation, and it has got the second-highest priority of 0.1895. During the growing period (October to January) in the studied area, temperatures average around 15–23°C (Figure 2). However, the most suitable temperatures required for apple growth during this period are 15–17°C [9]. Thus, only 3.6% of the land has a temperature during the growing season of 15–17°C, which is highly suitable for apple development. About 1/6th of the land has an average temperature of 17–19°C, which is moderately suitable. However, about half of the land has an average temperature ranging between 19 and 21°C, which is marginally suitable for apple production, whereas about 1/6th of the land has an average temperature of 21–23°C, which is the least suitable for apple production during the growth period. This result indicated that no land in the study area is highly suitable, and more than 2/3rd of the land is not suitable for apple production. Apple is very sensitive to temperature during early growth, which greatly affects final fruit size [30]. Therefore, it is considered one of the criteria for land suitability assessment and was assigned the priority weight of 0.1895. The studied variety "Anna" requires 120 days of development period on MM106 [31].

4.1.3. Mean Annual Temperature. Temperature affects the net carbon exchange, carbon balance, and carbon partitioning in the apple tree [32]. Mean annual temperature has got the third-highest priority of 0.1402. Apple trees require a cool temperature for proper growth and development. The yearly mean maximum temperature of the study area is 22.8°C, and the yearly mean minimum temperature is 9.2°C. The results showed that about 1/7th of the land has a temperature condition of 9–11°C, which is highly suitable for apple production, whereas about 1/3rd of the land has a temperature range between 12 and 14°C, which is moderately suitable for apple production. However, about 3/7th (42.9%) of the land has a yearly average temperature of 14–16°C, which is marginally suitable for apple production. However, it was found that about 1/10th of the land has 16–18°C, which is the least suitable for apple production. The results implied that more than half of the land has a yearly average temperature not suitable for apple cultivation. The apple tree requires a temperate climatic regime for growth and fruit development [33]. Low temperature is the most significant factor in affecting dormancy completion [34]. Temperature is a main environmental factor affecting the net carbon exchange, carbon balance, and carbon partitioning in the apple tree [35]. The buds of the apple tree may not bloom or may be uneven if the chilling requirements are not satisfied [36]. Hester and Cacho [37] stated that temperature affects both photosynthesis and respiration of the apple.

4.1.4. Rainfall. Rainfall is one of the most important factors affecting the growth of plants. Both highest rainfall and lowest rainfall are harmful to plant growth. Excessive rainfall is harmful to plant growth, and also, its deficit causes a serious effect on plant growth. Rainfall has got the fourth highest priority weight of 0.1142. The meteorological data (1991–2018) obtained from the area revealed that the lowest and highest annual rainfall in the area ranged between 914 and 1499 mm (Figure 2). The optimum range of annual rainfall for apple production is 1000–1250 mm [38]. The results indicated that about 1/8th of the land has rainfall ranging between 1100 and 1200 mm, which is highly suitable for apple production, whereas about 1/3rd of land receives about 1200–1300 mm of annual rainfall, which is moderately suitable for apple production. About 1/5th of the land has rainfall ranging between 1300 and 1400 mm, which is marginally suitable for apple production. However, more than 1/4th of the land has rainfall of <800 mm and >1400 mm, which is least suitable for apple production. In general, about half of the area has received rainfall not suitable for apple production.

4.1.5. Soil Depth. Soil depth is also one of the important factors affecting apple growth. It has got the fifth priority of 0.0884. The results indicated that about 1/3rd of the land has a soil depth of more than 150 cm, which is highly suitable for apple production, and about 1/3rd of the land has soil depth ranging between 100 and 150 cm, which is considered moderately suitable. However, about 1/5th of the land has a soil depth ranging between 70 and 100 marginally suitable cm depth. However, about 1/6th of the land has <70 cm soil depth, which is least suitable for apple production (Table 5). Soil depth determines root growth, as well as the presence of volumes of water and air in the soil [39], and the roots of cultivated plants can reach and use the available water and nutrients [40]. Soil depth is the most important soil property affecting the hydrologic properties of soils. According to Fu et al. [41], variation in soil and depth is connected with soil formation processes, loss of materials through weathering and transportation, and deposition of soil through erosion.

4.1.6. Slope. The slope is an important indicator of land suitability since it influences drainage, irrigation, and soil erosion [42]. An increase in slope degree slows down the development of soils and decreases soil depth and fertility [43]. The slope has been given the priority of 0.0640. The growth of apples is determined by slope, and it was determined using the digital elevation model (DEM). Each land mapping unit is described according to its respective slope classes. The results indicated that about 1/4th of the land has a slope of less than 10%, which is considered highly suitable for apple production, and about 1/3rd of the land has a slope ranging between 10% and 20%, which is moderately suitable. However, about 1/4th of the land has a slope ranging between 20 and 30%, which is marginally suitable for apple production, and about 1/10th of the land has a slope of above 30%, which is as least suitable for apple production. Therefore, about 62% of the land in the study is suitable in terms of slope for apple production, whereas about more than 38% is not suitable for apple production. Sites with higher degrees of slope should be avoided as they cause problems with equipment used for apple cultivation [44].

4.1.7. Soil pH. Soil pH provides information about the solubility and thus potential availability of elements for crop growth and subsequently specifies the soil suitability for the specific crop [45]. Soil pH has got a priority of 0.0578. In the soils of the study area, pH value ranges from 5.6 to 6.41. According to the [46] rating, the soils of the study Watershed rated as moderately to slightly acidic. Apple can be grown in a wide range of soil pH; however, it performs best with a pH of 6.0–6.5 [47]. Thus, the results show that about 1/15th of the land has a soil pH range between 6.0 and 6.5, which is highly suitable for apple cultivation, and about 1/3rd of the land has a soil pH range between 5.8 and 6.0, which is moderately suitable, and about half of the land has pH value range between 5.6 and 5.8, which is marginally suitable for apple cultivation. However, about 1/10th of the land has pH values below 5.6, which is least suitable for apple production. The results indicated that about 4/7th of the land soils have pH, which is not suitable for apple production, while 3/7th of the land is suitable for apple growing from a pH point of view. Soil pH provided information about the solubility and potential availability of nutrients for crops and then identifies soil suitability for the specific crop grown [48]. Soil pH below 5.5 and greater than 7.5 growth limitations has been observed.

4.1.8. Soil Texture. Soil texture is one of the important soil parameters and major soil physical characteristics determining plant growth [48]. Apple should be grown on soils that have good drainage, aeration, and permeability. Therefore, soil texture has got a priority of 0.0428. The thematic soil texture map of the study area showed that 2/3rd of the land has clay loam soil texture, which is highly suitable for apple cultivation, whereas about 1/3rd of the land has clay textured soil, which is moderately suitable for apple production. Therefore, soil texture is not a limiting factor for apple production in the study area since clay loam and clay soil characteristics are classified as the most suitable and moderately suitable soil textures for apple production (Table 5). Soil texture is a controlling factor of soil reaction, nutrient availability, water-holding capacity, soil porosity, air-water circulation, soil density, and root growth [49].

4.1.9. Soil Drainage. Apple tree needs well-drained and not too wet soil. Soil drainage has got a priority value of 0.0397.

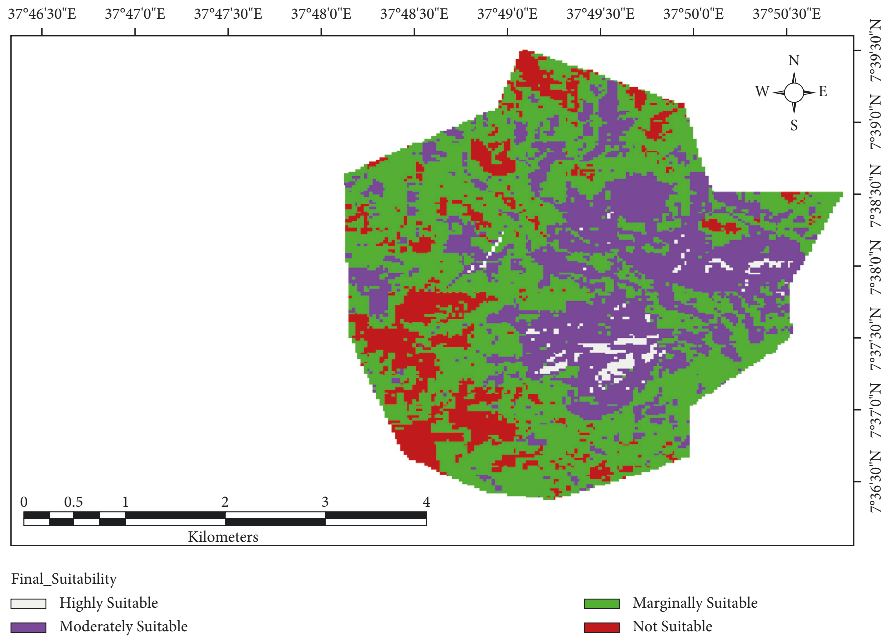


Figure 5: Final land suitability map of study areas for apple cultivation.

Based on the results of the drainage suitability map, the drainage classes of the study area were classified into two soil permeability property classes: well-drained and moderately drained. Thus, about 3/7th of the land has well-drained soils, which are highly suitable for apple production. However, about 4/7th of the land has moderately drained soils, which are moderately suitable for apple production. Thus, the soils of the study area are well-drained and moderately drained due to clay loam and clay soil properties and have no limitation in drainage. The assessment of the soil drainage requirement is a critical characteristic in selecting land for crop production because it permits the normal growth of plants. Chattopadhyay [50] stated that the apple requires a well-drained soil for its growth. Well-drained soils are regarded as the best for apple cultivation [51].

4.1.10. Land Use/Land Cover. Land use is the different uses of land made by human beings, and land cover is the physical material at the part of the Earth's surface. Land use/land cover (LULC) has been considered one of the influencing factors for apple cultivation and has got a priority of 0.0339. For this study, LULC was classified into four classes: grassland as highly suitable, agricultural land as moderately suitable, open land as marginally suitable, and settlement as least suitable for apple production. Therefore, about 1/5th of the land was covered with grass, which is highly suitable for apple production because of its possibility to cultivate apples, and about 1/4th of the land was used as an agricultural field, which is moderately suitable for apple production, while about 1/4th of the land is covered by vegetation, which is marginally suitable for apple cultivation, and about 1/4th of the land is used as a settlement, which is considered as least suitable for apple production. Thus, more than half of the land is not suitable for apple production from the current land use/land cover point of view. The increment of settlement vegetation decreases the chance of expansion.

4.1.11. Aspect. The aspect of an area is one of the important factors affecting the crop growth as it determines how much sunlight will be available for the growth of a particular crop; thus, the aspect is considered an assessment criterion for land suitability assessment for apple cultivation and has got a priority of 0.0258. The results showed that the east-facing slope has about 1/4th of the land, which is highly suitable for apple production, and about 1/3rd of the land has a southeast-facing slope, which is moderately suitable for apple production. However, about 1/4th of the land has a slope facing to the west and southwest aspect, which is marginally suitable, and 1/10th of the land has a slope facing to the north, northeast, and northwest direction, which is least suitable for apple production. The spatial variation of aspects had important effects on apple yield and quality. Aggelopoulou et al. [52] suggested that changes in topography and aspect had important effects on apple yield and quality. To maintain their physiological activities, apples need sun exposure at certain intervals. Light and apple fruit quality are strongly associated [53]. 30% of total light is needed to ensure quality fruit [54]. Thus, more than half of the land has an aspect suitable for apple production.

4.2. Final Suitability Map of Apple. With the help of individual thematic maps and their apple growth-influencing percentage, the final suitability map of apples has been prepared (Figures 3 and 5). The thematic maps are climatic maps (GPT, mean temperature, and rainfall), soil maps (depth, pH, texture, and drainage), topographic maps (elevation, slope, and aspect), and land use/land cover maps (LULC). The weight values of each selected parameter calculated in the analytic hierarchal process (AHP) and designated scores of sub-criterion were used in weighted overlay analysis to generate the final suitability map of apple in Sentele Watershed Southern Ethiopia. The final suitability map as shown in Figure 5 stipulated small patches of sites into four suitability categories: most suitable, moderately suitable, marginally suitable, and least suitable. The result showed that 2.2% of the land is most favorable and the best biophysical, climatic, soil, and land use/land cover condition for apple cultivation, and 32% moderately suitable land for apple cultivation indicates a secondary priority, which also bears all the favorable conditions but not as the highly suitable. However, more than half (52.1%) of the land is marginally suitable, which indicates that the third priority class for apple cultivation needs detailed scrutiny of all influencing factors and decides on the feasibility of the investment over other land use options. The other 13.7% of the land is least suitable for apple cultivation and represents currently unsuitable for apple cultivation.

5. Conclusion

The study has delineated the potentially suitable land areas for apple cultivation in Sentele Watershed and drew special attention to the need of evolving an appropriate land planning. It can be inferred from the final land suitability maps that about 2.2% and 32% of the land are highly suitable and moderately suitable for apple cultivation, respectively. However, about 52.1% and 13.7% of the land are marginally suitable and least suitable for apple cultivation, respectively. From the actual suitability view, the main limitations to apple production were found to be rainfall, land use/land cover (LULC), and elevation and growing period temperature. From the total land area, more than half is moderately suitable. From the suitability maps of potentiality, some limitations can be improved with the application of soil amendments, irrigation, species selection, and removing leaves (defoliation). The output enables the users to select management options to alleviate the identified limitations. The techniques and methods of this study can be also applied to land suitability of other important crops in the study area and elsewhere with additional and more refined parameters. The apple suitability map can serve as a basis for a decision support tool for policymakers, land-use planners, and farmers by providing information alike regarding the land suitability of apple production. One of the limitations to this research is the absence of published source materials concerning the major characteristics such as climate, topography, and soil. The other limitation was the knowledge gap on apple cultivation among experts and apple-producing farmers. This study focuses only on the suitability of apple cultivation, but also further research can be conducted for determining the optimum locations for different types of crops to enhance the sustainable crop in the study area.

Data Availability

Tables and figures included in the document are uploaded.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] FAO, *A Framework For Land Evaluation*, FAO, Rome, Italy, 1976.

[2] S. Bandypadhyay, R. K. Jaiswal, V. S. Hegde, and V. Jayaraman, “Assessment of land suitability potentials for agriculture using remote sensing and GIS-based approach,” *International Journal of Remote Sensing*, vol. 30, no. 3/4, pp. 879–895, 2009.

[3] W. Verheye, P. Koohafkan, and F. Nachtegraele, “The FAO guidelines for land evaluation,” *Land Use, Land Cover and Soil Sciences*, vol. 2, 2003.

[4] J. W. Palmer, J. P. Prive, and D. S. Tustin, *CAB International 2003. Apples: Botany, Production, and Uses*, D. C. Ferree and I. J. Warrington, Eds., , 2003.

[5] K. Juhos, S. Szabó, and M. Ladányi, “Explore the influence of soil quality on crop yield using statistically-derived pedological indicators,” *Ecological Indicators*, vol. 63, pp. 366–373, 2016.

[6] A. Handbook, *Soil and Plant Analysis, A and L*, Agricultural Laboratories, Memphis, TN, USA, 2001.

[7] F. Magdoff and H. Van Es, *Building Soils for Better Crops: Sustainable Soil Management*, Sustainable Agriculture Research and Education (SARE) Program, Waldorf, MD, USA, 2009.

[8] K. Chozom and G. Nimasow, “GIS- and AHP-based land suitability analysis of malus domestica borkh. (apple) in west kameng district of Arunachal Pradesh,” *Applied Geomatics*, vol. 13, 2021.

[9] H. Kim and K. Shim, “Land suitability assessment for apple (Malus domestica) in the Republic of Korea using integrated soil and climate information, MLCM and AHP,” *International Journal of Agriculture and Biological Engineering*, vol. 11, no. 2, pp. 139–144, 2018.

[10] S. Y. Madrigal-Martinez and R. J. Puga-Calderon, “Land suitability and sensitivity analysis for planning apple growing in mala’s valley, Peru,” *Bioagro*, vol. 30, no. 2, pp. 95–106, 2018.

[11] S. Sonmez, M. Coslu, and H. R. Turkkan, “Determination of Suitable Areas of apple (*Malus domestica)* cultivation with AHP and GIS Techniques,” *International Journal of Agriculture, Forestry and Life Science*, vol. 3, no. 1, pp. 1–8, 2019.

[12] FAO, “Land evaluation towards a revised framework,” *Land and water discussion paper* 6, FAO Electronic Publishing Division, Rome, Italy, 2007.

[13] F. Torrieri and A. Batà, “Spatial multi-criterial decision support system and strategic environmental assessment,” *A Case Study*, vol. 7, no. 4, p. 96, 2017.

[14] T. L. Saaty, *The Analytical Hierarchy Process*, McGraw-Hill, New York. NY. USA, 1980.

[15] D. N. Tiwari, R. Roof, and G. N. Paudyal, “Environmental-economic decision-making in lowland irrigated agriculture using multi-criteria analysis techniques,” *Agricultural Systems*, vol. 60, pp. 99–112, 1999.

[16] T. L. Saaty and L. G. Vargas, “Models, methods, concepts and applications of analytical hierarchy process,” *International Series in Operations Research and Management Sciences*, Springer, Berlin, Germany, 2001.

[17] T. L. Saaty, *Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World*, RWS Publications, Pittsburgh, PA, USA, 2012.

[18] M. Dadeoğlu and O. Dengiz, "Generating of land suitability index for whet with hybrid system approach using AHP and GIS," *Computers and Electronics in Agriculture*, vol. 167, 2019.

[19] O. Dengiz, "Soil quality index for paddy fields based on standard scoring functions and weight allocation method," *Archives of Agronomy and Soil Science*, vol. 66, no. 3, 2020.

[20] GSE (Geological Survey of Ethiopia), *Geological Map of Ethiopia*, GSE, Addis Ababa, Ethiopia, 2005.

[21] WRB (World Reference Base), *FAO the World Reference Base for Soil Resources 2014*, WRB, Rome, Italy, 2014.

[22] A. H. Rabia and F. Terribile, "Introducing a new parametric concept for land suitability assessment," *International Journal of Environment and Sustainable Development*, vol. 4, 2013.

[23] T. L. Saaty, "A scaling method for priorities in the hierarchical structure," *Journal of Mathematical Psychology*, vol. 15, no. 3, 1997.

[24] J. Malczewski, "Local weighted linear combination," *Transactions in GIS*, vol. 15, no. 4, pp. 430–455, 2000.

[25] N. H. Zardari, K. Ahmed, S. M. Shirazi, and Z. Yusop, *Weighting Methods and Their Effect on Multi-Criterial Decision-Making Model Outcomes in Water Resources Management*, Springer, Berlin, Germany, 2015.

[26] R. Elsheikh, A. R. B. Mohamed Shariff, F. Amiri, N. B. Ahmad, S. K. Balasundram, and M. A. M. Soom, "Agriculture Land Suitability Evaluator (ALSE): a decision and planning support tool for tropical and subtropical crops," *Computers and Electronics in Agriculture*, vol. 93, pp. 98–110, 2013.

[27] A. Bozdag, F. Yavus, and A. S. Gnay, "AHP and GIS-based land suitability analysis for Cihanbeyli County," *Environmental Earth Sciences*, vol. 75, p. 813, 2016.

[28] P. Osborne, *Tropical Ecosystems and Ecological Concepts*, Cambridge University Press, Cambridge, UK, 2000.

[29] E. Fadon, S. Herrera, B. I. Guerrero, M. E. Guerra, and R. Javier, "Chilling and heat requirements of temperate stone fruit trees (prunus sp.)," *Agronomy*, vol. 10, p. 409, 2020.

[30] I. J. Warrington, T. A. Fulton, E. A. Halligan, and H. N. De Silva, "Apple fruit growth and maturity are affected by early season temperature," *Journal of the American Society for Horticultural Science*, vol. 124, pp. 468–477, 1999.

[31] G. Fischer, "Ecophysiological aspects of fruit growing in tropical highlands," *Acta Horticulturae*, vol. 531, no. 531, pp. 91–98, 2000.

[32] G. C. Zavala, "Temperature effects on fruit and shoot growth in apple (Malus domestica) early in the season," *Acta Horticulturae*, vol. 636, no. 636, pp. 447–453, 2004.

[33] K. R. Krishna, *Agroecosystems, Soils, Climate, Crops, Nutrient Dynamics, and Productivity*, CRC Press, Boca Raton, FL, USA, 2014.

[34] F. Ramirez and J. Kallarackal, "Ecophysiology of temperate fruit trees in the tropics," *Advances in Environmental Research*, vol. 31, 2014.

[35] G. Calderon-Zavala, A. N. Lakso, and R. M. Piccioni, "Temperature effects on fruit and shoot growth in the apple (Malus Domestica) early in the season," *Acta Horticulturae*, vol. 636, 2004.

[36] D. L. Abbott, "The role of bud scales in the morphogenesis and dormancy of apple fruit bud," in *Physiology of Tree Crops*, L. C. Luckwill and C. V. Cutting, Eds., pp. 65–80, Academic Press, Cambridge, MA, USA, 1970.

[37] S. M. Hester and O. Cacho, "Modelling apple orchard systems," *Agricultural Systems*, vol. 77, no. 2, pp. 137–154, 2003.

[38] A. K. Randev, "Impact of climate change on apple productivity in Himachal Pradesh," *60th International Executive Council Meeting and 5th Asian Regional Conference*, 2009.

[39] J. Dhami, S. Roy, A. S. Nain, and R. Panwar, "Suitability analysis of apple and pear using remote sensing and GIS in Uttarakhand," *Journal of Agrometeorology*, vol. 14, no. 4, pp. 464–474, 2012.

[40] H. Akinci, A. Y. Ozalp, and B. Turgut, "Agricultural land-use suitability analysis using GIS and AHP techniques," *Computers and Electronics in Agriculture*, vol. 97, pp. 71–82, 2013.

[41] Z. Fu, Z. Li, C. Cai, Z. Shi, Q. Xu, and X. Wang, "Soil thickness effect on hydrological and erosion characteristics under sloping lands: a hydropedological perspective," *Geoderma*, vol. 167-168, pp. 41–53, 2011.

[42] W. G. Wu, J. K. Huang, and X. Z. Deng, "Potential land for plantation of Jatropha curcas as feedstock for biodiesel in China," *Science in China - Series D: Earth Sciences*, vol. 53, no. 1, pp. 120–127, 2009.

[43] I. Atalay, "The effects of mountainous areas on biodiversity: a case study from the northern Anatolin mountains and the Taurus Mountains," *Grazer Schriften der Geographie und Raumforschung*, vol. 41, pp. 17–26, 2006.

[44] B. F. Finnegan, W. M. Colt, and E. Fallahi, *Growing Apple for Local Markets in Cold Climates*, University of Idaho, Moscow, Idaho, 2000.

[45] J. C. Halder, "Land suitability assessment for crop cultivation by using remote sensing and GIS," *Journal of Geography and Geology*, vol. 5, no. 30, pp. 65–74, 2013.

[46] T. Tadesse, *Soil, Plant, Water, Fertilizer, Animal Manure and Compost Analysis*, International Livestock Research Center for Africa, Addis Ababa, Ethiopia, 1991.

[47] P. R. Anderson, "Low-chill apple cultivars for North Florida and North Central Florida," 2015, https://edis.ifas.ufl.edu.

[48] A. A. Mustafa, M. Singh, R. N. Sahoo et al., "Land suitability analysis for different crops: a multi-criteria decision-making approach using remote sensing and GIS," *Researcher*, vol. 3, no. 12, pp. 61–84, 2011.

[49] K. Chakraborty and B. Mistri, "Importance of soil texture in the sustenance of Agriculture: a study in Burdwan −1 C.D. Block, West Bengal," *Eastern Geographer*, vol. 1, pp. 475–482, 2015.

[50] T. K. Chattopadhyay, *A Textbook on Pomology (Temperate Fruits)*, Kalyani Publishers, Chennai, India, 2009.

[51] K. L. Chada, *Hand Book of Horticulture*, Indian Council of Agriculture Research (ICAR), New Delhi, India, 2009.

[52] K. D. Aggelopoulou, D. Wulfsohn, S. Fountas, T. A. Gemtos, G. D. Nanos, and S. Blackmore, "Spatial variation in yield and quality in a small apple orchard," *Precision Agriculture*, vol. 11, no. 5, pp. 538–556, 2010.

[53] L. Morales-Quintana, J. M. Waite, L. Kalcsits, C. A. Torres, and P. Ramos, "Sun injury on apple fruit: physiological, biochemical and molecular advances, and future challenges," *Scientia Horticulturae*, vol. 260, Article ID 108866, 2020.

[54] A. N. Lakiso, "Correlation of fisheye photography to canopy structure, light climate, and biological response to light in apple trees," *Journal of the American Society for Horticultural Science*, vol. 105, pp. 43–46, 1980.