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Editors

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Table of Contents

Morphological diversity Assessment on the Current Status of Coffee Arabica (Coffea Arabica L) in Coffee Belt Areas of Western Oromia, Ethiopia

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Abstract

The survey was carried out in three western Oromia zones: East Wollega, West Shoa, and Horoguduru Wollega. The assessment was carried out over the cropping seasons of 2020 and 2021. A total of 306 coffee farms were addressed from all zones, with 15 farms from each Woreda. Coffee landrace diversity was measured using plant height, cherry size, cherry color, and canopy habits. The landrace differences were identified using coffee phenotypic markers. As a result, coffee landraces showed genetic variation in all variables studied. In total, 38.24 percent of observations were open canopy, 46.08 percent were small cherry size, 44.12 percent were tall plant height, and 43.79 percent were light red. Around half of the entire landraces in the east Wollega Zone had small cherry sizes, open canopy habits, and recent had small cherry sizes, 30.37 percent had medium cheery sizes, and 21.03 percent had large cherry sizes. The open canopy habit made up 43.46 percent of the canopy, while the intermediate and compact canopy habits made up 34.11 percent and 22.44 percent of the canopy, respectively. Most landraces in the Horoguduru Wollega Zone were modest and cheerful. More than half of the landraces assessed developed tall plants with pale red cherry colors. The majority of landraces in the west Shoa Zone exhibited intermediate canopy habit (40 percent). More than half (60%) of the cherries sampled were medium in size and plant height. About 80percent of the assessed landraces were possess light red cherry color. As a result of the findings, a significant quantity of genetic variation in coffee arabica was observed, leading to the recommendation of landrace collection and conservation for future breeding programs.

Keywords: Assessment, Landrace, Diversity, C. Arabica, Traits

Introduction

Coffee (Coffea arabica L.) is the most important woody crop in the world [13]. The Coffeae (Rubiaceae) tribe includes 11 genera, including the closely related Coffea and Psilanthus [10]. The subgenus Coffea, includes 103 species and all species are containing with different amount and type [12]. The other species of coffea is liberica coffee and it is grown in Africa and Asia which accounts 1 % of global. Coffea arabica is the only tetraploid species in the genus and is self-fertile, while other species are diploid and generally self-incompatible [20]. Commercial coffee production relies only on two species, Coffea arabica and Coffea. canephora Pierre ex Froehner contributing 60% and 40%, respectively, of the global market [27]. Coffee is grown in more than 60 nations throughout the globe. Three countries, namely Brazil, Honduras, and Columbia, account for more than two-thirds of global production. Africa contributes 12% of global production, down from 30% in the 1970s. Arabica coffee accounts for over 60% of total world production. In Ethiopia, more than 90% is produced in the Western, Southern, South

Western and Eastern parts of the country. The total area coverage of coffee in Ethiopia is estimated to be around 800,000 ha, of which about 95% is produced by 4 million small scale farmers [8].

Ethiopia is the origin of Arabica coffee and produces high-quality coffee for both domestic use and export [23],[24],[5]. Ethiopia is first in Africa's in Arabic coffee growing and ranking fifth and tenth in the world in terms of production and exports respectively [18], [19]. In 2020 cropping season, the total area covered by productive coffee is estimated to 540,000 hectares and 450,000 metric tons yield was collected [26] (USDA, 2020). From total yield produced in the country, more than half of it is consumed in local market [9], [1]. Still coffee is number one foreign exchange source and known as "green gold" for the country. In total production, smallholder producers account more than 90% which are in the Western, South Western, Eastern, and Southern regions [4], [22]. Coffee production employs an estimated 1.2 million smallholder farmers [4], [22]. Total land under coffee production in Ethiopia reaches 700474.69 ha with estimated production of 469091.124tons. The production per hectare is 0.67ton/ha. Coffee production is a time and labor consuming, manual operation that most growers enlist the help of their immediate family to complete. In Ethiopia coffee can grow in an altitude range of 550 to 2750masl Gambella to southeast and northern respectively. But coffee Arabic best performed and produced in 1300-1800masl with rainfall distribution of 1500mm to 2500mm. Ideal temperature for coffee production is 15 to 25oc. The soil requirement of coffee varies from sandy loam to heavy clay while the dominant soil types are acidic (pH 4.2-6.8) red, reddish brown lateric loams or clay loams of volcanic origin and total annual rainfall varies from 750 to 2,400 mm [11], [14]. The Ethiopian coffee is the central High genetic diversity of coffee Arabica was reported by different scholars [31] [17]. The existence of such high genetic diversity of a self-pollinated Arabica coffee is believed to be attributed to the availability of extremely diverse agro-ecological variations under which coffee grows in Ethiopia, evolutionary tendencies or changes of the species or natural mutations occurring to the population of the crop [6]. Over 90% of the world's Arabica coffee genetic diversity found in Ethiopia indicating the significance of Ethiopian coffee genetic resources to the future of the world coffee industry [29].

In a coffee improvement effort, having access to both primary and secondary gene pools is critical. However, in recent years, genetic erosion and habitat destruction caused by modern agriculture has increased from time to time, while old coffee stumping and uprooting is widely practiced in western Oromia, resulting in the direct extirpation of coffee landraces and a big coffee improvement crisis. As a result, the following activity was devised to evaluate the existing diversity of coffee arabica in the study region and to document coffee diversity information for coffee research.

Study Procedure and Materials

Study Area

The research was carried out in three zones in western Oromia: East Wollega, Horo guduru Wollega, and West Shoa. East Wollega had 12 coffee belt districts surveyed, Horo Guduru Wollega had three districts surveyed, and west Shoa had only one district surveyed. The presence of old coffee trees or landraces with zonal and district approved personnel led to the selection of districts and kebeles. Coffee plants were characterized by coffee experts and breeders after samples were gathered purposefully from selected kebeles. Coffee characterization was done based on Arabica coffee morphological descriptors for characterization purpose, as described by the International Plant Genetic Resources Institute [16].

Method of Data Collection

The coffee farm must be the same age, similar cultural practice, shade status and healthy plants was selected for these data. Data were collected plant based; a given plant was selected based on the morphological appearance from the whole farm. Data was collected from the selected mother plant. The history of the plant was recorded and plant height, cherry color, cherry size and canopy of the plant data was collected as follows

Plant height: above grown height of the plant was considered. The plant above 5m was considered as tall, the plant above three below five meter was considered as medium plant height, the plant below two meter was considered as short plant height.Canopy habit: plants were classified as based on [30] as compacted below one meter canopy, intermediate between one and two meter and above three meter was considered as open canopy habit.

Cherry color: a cherry color was identified by observation and indicator.

Data Analysis

Collected data was subjected to R-computer software and Microsoft excel computer program.

Results

In total, 306 coffee farms were assessed. The findings revealed a wide range of landrace variation across the whole area of study in plant height, cherry size, cherry color, canopy habits , tip leaf color, cherry shape

Table 1. Study area description and major coffee production system of the area.

Districts	Number of farms assessed	Latitude range	Longitude range	Altitude range (masl)	Major production system practiced
Sibu Sire	16.00	090 13.620’-090 11.221’	0360 53.085'-0360 50.628'	1930-2078	Garden and semi forest
Diga	54.00	090 03’939’’-080 43.304’	0360.26’452’’-0360 35’008’’	1298-1508	Semi forest
Nunu kumba	9.00	080 44.814’-080 43.304’	0360 46.283’-0360 35.008’	1498-2198	Garden
Sasiga	25.00	090 13.657’-090 08.713’	0360 28.241’-0360 28.348’	1582-1876	Semi forest
Limu	15.00	090 46.556’-090 43.436’	0360 27.998’-0360 27.401’	1912-2122	Garden and semi forest
Gidda Ayana	29.00	090 49.881-’090 10.145’	0360 40.917’-0360 38.262'	1745-2078	Garden
Wayu tuka	16.00	08057’.106’’-08057’.569’’	036041’.177’’-036040’.293’’	1644-1890	Garden
Haro Limu	7.00	09055’.920’’-09055.846’	036018’.136’’-036017’.735’’	1822-1892	Semi forest
Ebantu	5.00	09058’.504’’-09058’.502’’	036022’.489’’-036022’.486’’	1889-1990	Garden
Kiremu	6.00	09050’.537’’-09050’.810’’	036053’.946’’-036057’.430’’	1704-1821	Garden and semi forest
Gudaya Bila	15.00	09015’.820’’-	036059’.955’’-	1926-1984	Garden

Districts	Number of farms assessed	Latitude range	Longitude range	Altitude range (masl)	Major production system practiced
Jima arjo	17.00	09015’.952’’ 080 42’.770’’-08047’.692’’	036059’.971’’ 036'27.391-036'32.369	1620-2011	Garden
Abe Dongoro	70.00	090 36’.768’’-090 38’.102’’	0360 53.252'-0360 49.909'	1603-1952	Semi forest
Guduru	6.00	090 28’.396’’-090 30’.713’’	0370 28.404'-0370 28.854'	2018-2347	Garden
Ababo Guduru	6.00	090 39’.224’’-090 41’.860’’	0370 31.244'-0370 32.316'	1970-2344	Garden
Danno	10.00	08043’.354’’-08049’.190’’	037017.339’-037022.064’	1796-1944	Garden

Morphological Traits

Canopy habit: The coffee landraces were classified into three types based on canopy habit: compact, moderate, and open. There were 26.80 percent compacted canopy habits, 34.97 percent intermediate canopy habits, and 38.24 percent open canopy habits among the total assessed farms. The majority of the coffee landraces had an open canopy habit, according to the observations (Table 2).

Cherry size: Landraces were classified as small, medium, and large depending on cherry size. Among the total observations, 46.08 percent were small cherry sizes, 32.67 percent were medium cherry sizes, and 21.24 percent were large cherry sizes. According to the observations, the most of the coffee landraces had small cherry sizes (Table 2).

Table 2. Diversity of C. arabica across different districts in canopy habit and cherry size, Western Oromia, Ethiopia.

Woredas	Average year	Number assessed farms	Canopy habit			Cherry size		
			Compact	Intermediate	Open	Small	Medium	Large
Sibu Sire	33.00	16.00	18.75	12.50	68.80	50.00	25.00	25.00
Diga	32.00	54.00	18.52	35.19	46.30	29.63	46.30	24.07
Nunu kumba	25.00	9.00	22.22	33.33	44.40	55.56	22.22	22.22
Sasiga	60.00	25.00	20.00	32.00	48.00	36.00	24.00	40.00
Limu	32.00	15.00	26.67	53.33	20.00	66.67	26.67	6.67
Gida Ayana	33.00	29.00	17.24	44.83	37.90	68.97	17.24	13.79
Wayu Tuka	36.00	16.00	25.00	25.00	50.00	62.50	25.00	12.50
Haro Limu	40.00	7.00	14.29	28.57	57.14	71.43	28.57	0.00
Ebantu	38.00	5.00	20.00	20.00	60.00	60.00	40.00	0.00
Kiremu	50.00	6.00	16.67	16.67	66.67	66.67	16.67	16.67
Gudaya Bila	46.00	15.00	33.33	53.33	20.00	67.00	20.00	13.00
Jima Arjo	32.00	17.00	41.18	29.41	29.41	24.00	41.00	35.29
AbeDongoro	60.00	70.00	38.00	64.00	3.00	38.00	64.00	3.00
Guduru	25.00	6.00	50.00	50.00	0.00	33.33	50.00	16.67
Ababo Guduru	26.00	6.00	50.00	33.33	16.70	66.67	16.67	16.67
Danno	38.00	10.00	30.00	40.00	30.00	20.00	60.00	20.00
Total		306	26.80	34.97	38.24	46.08	32.67	21.24

Plant height: based on plant height, landraces were classified as tall, medium and short type. From total observations 44.12% was tall, 35.29% was medium height while 20.59% was short. From the results of the observations, most of the landraces were tall in height while some of them were short (Table 3).

Cherry color: Cherry hue landraces were divided into three groups: light red, red, and brown. Light red color observations accounted for 43.79 percent of total observations, followed by red color observations accounting for 38.89 percent. Brown cherry color 17.32 percent is the lowest observation (Table 3)

Table 3. Diversity of C. arabica across different Woredas Western Oromia, Ethiopia in plant height and cherry color.

Woredas	Average year	Number assessed farms	Plant height			Cherry color		
			Tall (%)	Medium (%)	Short (%)	light red (%)	Red (%)	Brown (%)
Sibu Sire	33.00	16.00	25.00	25.00	62.50	12.50	37.50	37.50
Diga	32.00	54.00	18.52	29.63	59.26	11.11	57.41	24.07
Nunu kumba	25.00	9.00	11.11	33.33	55.56	11.11	33.33	55.56
Sasiga	60.00	25.00	20.00	48.00	20.00	32.00	40.00	40.00
Limu	32.00	15.00	20.00	66.67	20.00	13.33	26.67	53.33
Gida Ayana	33.00	29.00	13.79	31.03	51.72	17.24	41.38	44.83
Wayu Tuka	36.00	16.00	25.00	43.75	31.25	25.00	25.00	50.00
Haro Limu	40.00	7.00	28.57	42.86	42.86	14.29	14.29	57.14
Ebantu	38.00	5.00	20.00	40.00	40.00	20.00	20.00	60.00
Kiremu	50.00	6.00	33.33	33.33	33.33	33.33	16.67	50.00
Gudaya Bila	46.00	15.00	33.33	66.67	20.00	13.33	33.33	33.33
Jima Arjo	32.00	17.00	17.65	41.18	35.29	23.53	23.53	58.82
Abe-Dongoro	60.00	70.00	22.86	57.14	28.57	14.29	67.14	10.00
Guduru	25.00	6.00	0.00	66.67	16.67	16.67	33.33	66.67
Ababo Guduru	26.00	6.00	16.67	16.67	50.00	33.33	33.33	50.00
Danno	38.00	10.00	20.00	40.00	40.00	20.00	20.00	60.00
Total		306	44.12	35.29	20.59	43.79	38.89	17.32

Table 4. Diversity of C. arabica across different Woredas Western Oromia, Ethiopia in tip leave color and cherry shape

Woredas	Average year	Number assessed farms	Tip leave color (%)			Cherry shape				
			Greenish	Green	Brown	Roundish	Obovate	Ovate	Elliptic	Oblong
Sibu Sire	33.00	16.00	18.75	50.00	31.25	18.75	6.25	37.50	12.50	25.00
Diga	32.00	54.00	18.52	55.56	25.93	27.78	7.41	29.63	16.67	18.52
Nunu kumba	25.00	9.00	33.33	44.44	22.22	33.33	11.11	33.33	11.11	11.11
Sasiga	60.00	25.00	20.00	56.00	24.00	24.00	16.00	20.00	32.00	8.00
Limu	32.00	15.00	20.00	46.67	33.33	20.00	33.33	26.67	20.00	0.00
Gida Ayana	33.00	29.00	10.34	68.97	20.69	31.03	13.79	20.69	24.14	10.34
Wayu Tuka	36.00	16.00	12.50	62.50	25.00	12.50	25.00	12.50	37.50	12.50
Haro Limu	40.00	7.00	14.29	57.14	28.57	42.86	14.29	28.57	14.29	0.00
Ebantu	38.00	5.00	20.00	60.00	20.00	20.00	0.00	40.00	0.00	40.00
Kiremu	50.00	6.00	0.00	66.67	33.33	33.33	0.00	16.67	33.33	0.00
Gudaya Bila	46.00	15.00	13.33	53.33	33.33	20.00	13.33	33.33	20.00	13.33
Jima Arjo	32.00	17.00	11.76	64.71	23.53	35.29	11.76	11.76	23.53	17.65
AbeDongoro	60.00	25.71	42.86	31.43	21.43	14.29	20.00	28.57	15.71	25.71
Guduru	25.00	33.33	50.00	16.67	16.67	0.00	33.33	33.33	16.67	33.33
Ababo Guduru	26.00	16.67	33.33	50.00	16.67	16.67	33.33	16.67	16.67	16.67
Danno	38.00	30.00	40.00	30.00	20.00	20.00	20.00	20.00	20.00	30.00
Total		306	20.00	46.67	33.33	20.00	33.33	26.67	20.00	0.00

The Diversity of Landraces Across Zones

East Wollega Zone

The results revealed that from the total observations 48.60 percent was small cherry sizes, 30.37 percent had medium cherry sizes, and 21.03 percent had large cherry sizes. The open canopy habit accounted for 43.46 percent of the canopy, whereas intermediate and compact canopy habits accounted for 34.11 percent and 22.44 percent, respectively (Figure 1). In plant height, 44.12% of total observations were tall while the 35.95% and 19.39% was medium and short, respectively (Figure 2). In cherry color, 43.79% was light red while the other 38.89% and 17.32% was red and brown color, respectively (Figure 2).

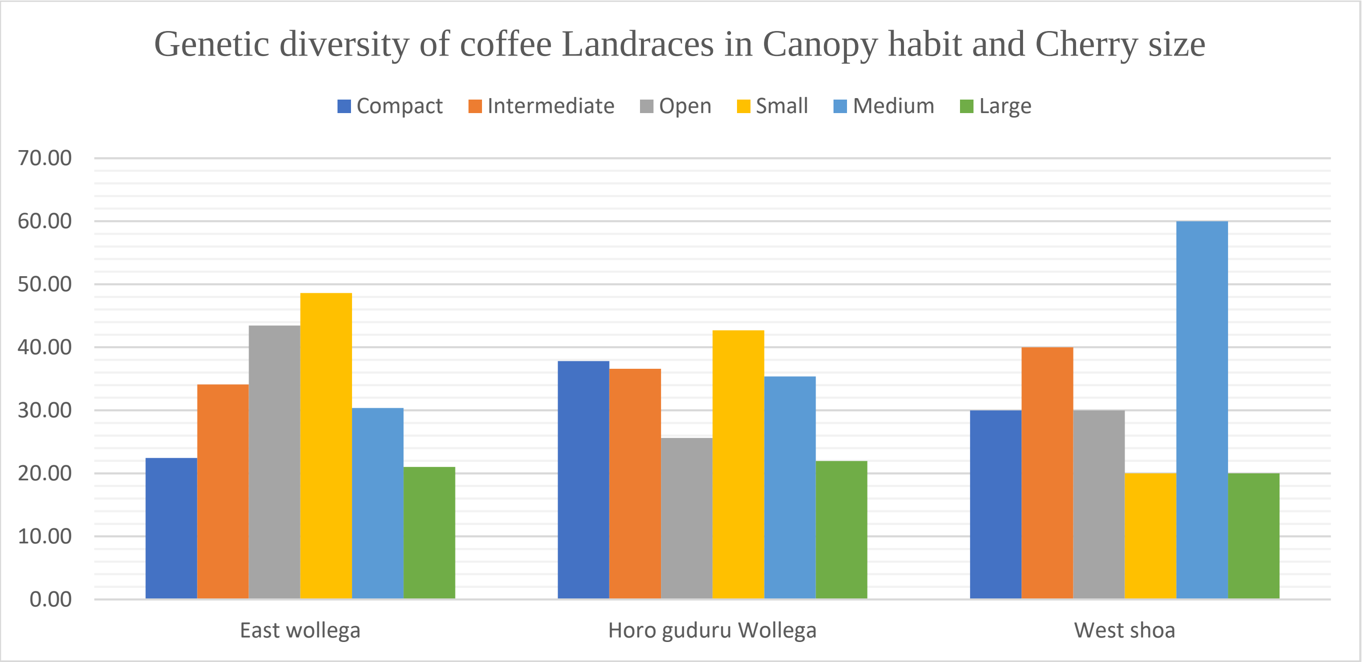


Figure 1. Coffee arabica landrace diversity in Canopy habit (compact, Intermediate, Open) and cherry size (small, medium, large) assessed from different Western Oromia Zones in percentile.

Picture I. A visual presentation of the coffee landraces found in Jima Arjo Woreda, East Wollega

Horo Guduru Wollega Zone

The result of the analysis showed that, small cherry sizes accounted for 42.68 percent of all cherry sizes, while medium and large cherry sizes accounted for 35.37 percent and 21.95 percent, respectively. The compact type accounted for 37.80 percent of canopy habit, while the intermediate and open types accounted for 36.59 percent and 25.61 percent, respectively (Figure 1). More than half (62.62%) was tall while the other 17.07% and 20.73% was medium and short plant height, respectively. In cherry color more than half (54.88%) of the total observations were light red color while 29.27% was red color and 15.85% was brown cherry color (Figure 2).

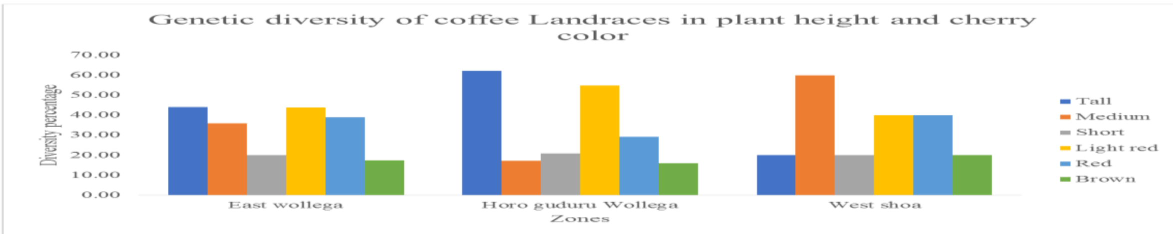
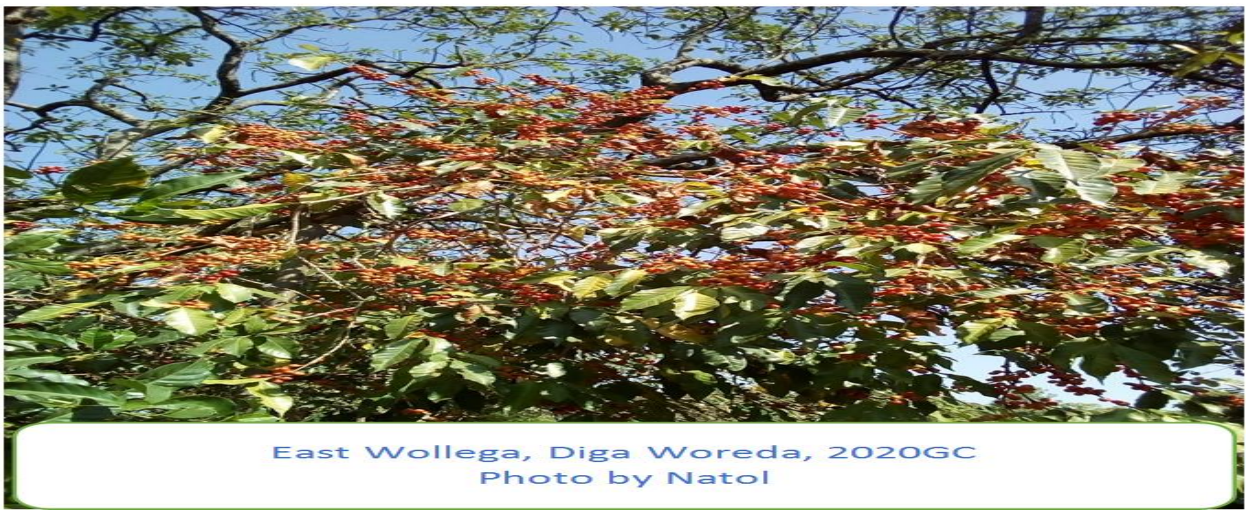


Figure 2. Coffee arabica landrace diversity in plant height (tall. Medium and short) and Cherry color (Light red, Red and Brown) assessed from different Western Oromia Zones in percentile.



Picture II. A visual presentation of the coffee landraces found in Diga Woreda, East Wollega

3.2.3. West shoa Zone

The result showed that, the majority of the landraces had intermediate canopy habits (40%) whereas the remaining 30% had compacted and open canopy habits. More than half of the observations (60%) were of medium cheery size, with the remaining 20% being of small and large happy size (Figure 1). 60% of total observations were medium height while the other 40% was tall (20%) and short (20%) plant height. In cherry color, 20% was brown in color and the other 80% was light red (40%) and red (40%) (Figure 2).

Picture III. A visual presentation of the coffee landraces found in Abe Dongoro, East Wollega

Picture IV. A visual presentation of the coffee landraces found in Sasiga Woreda, East Wollega

4. Conclusions and recommendation

The observed genetic diversity among landraces may be due to the genetic differences among individuals within a population. In the study area, high diversity was observed in East Wollega which is due to the availability of the landraces. The variability observed is the core of plant breeding and an opportunity for plant breeders and big resource as a whole for the country [15], [7], [3], [28]. Also, [21] found a genetic diversity among Limu coffee landraces molecularly. In the same line, [25] were found a tremendous diversity of among different collected coffee landrace in different morphological traits in different parts of Ethiopia. Different authors [2], [6], [15], [7] reported the availability of high genetic diversity in southwestern parts of Ethiopia, but our study revealed that there is also un ample genetic diversity of coffee landraces in western parts of the country like East Wollega and Horro guduru Wollega.

Current assessment substantiated the existence of sufficient diversity among coffee landraces in the study area in various morphological traits. Since Almost all of the Woredas under investigation displayed diversity in various features. Landraces were once endangered in most coffee-growing areas due to climate change, stumping and uprooting of old coffee trees due to low productivity. As a result, coffee's diversity is endangered. Hence there is a chance to take use of these opportunities to generate genotypes that perform better than existing varieties for improved coffee productivity, and it's a valuable resource in the future coffee improvement program.

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2. Effect of pot size and different organic matter on the emergence and growth of coffee seedlings

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Abstract

Coffee is one of the most important cash crops and the first most traded produce in Ethiopia. In the coffee seedling production, soil fertility management is a very important activity for seedling growth, and subsequent growth after field establishment. The experiment was conducted at Mechara Coffee nursery site during 2021 cropping season with the objective to evaluate the effects of different organic matter and pot size on the germination and early growth of coffee seedling. Completely Randomized Block Design (RCBD) with three replications of 18 treatments was used for the study. Analysis of variance showed that emergence at 60th date, seedling growth parameters and most of fresh and dry weight of the coffee seedlings were significantly affected by the organic matter and potting media. The 45 % topsoil + 45 % sand soil + 10 % coffee husk + 14 cm diameter by 22 cm height pot gave the highest emergence at 60th date, plant height and leaf number per plant. This might due to the smaller pot size had suitable soil temperature and water holding capacity than the larger pot size that helps the coffee seedlings to use efficiently the available moisture and nutrients and hence, enhance their early growth. Fresh leaf weight, fresh and dry root weight, root volume and total dry weight were significantly affected by potting media and pot size. However, non-significant different were recorded for fresh and dry stem weight, dry leaf weight, and root volume. Therefore, 45 % top soil + 45 % sandy soil +10 % coffee husk compost +14cm x 22cm polythine tube was recommended for raising coffee seedlings.

Keywords: pot size, organic matter, Seedling emergence, seedling growth

Introduction

Coffee is one of the most important cash crops and the first most traded produce in Ethiopia. Ethiopia's coffee is exclusively of the arabica type (Coffea arabica L.) which belongs to the genus Coffea and family Rubiaceae. Coffee is one of the most important commodities in the international agricultural trade, representing a significant source of income to several Latin American, African and Asian countries. It originated from the humid, high rainfall forests of south western Ethiopia. The significance of coffee in the Ethiopian economy is enormous in that it accounts for 29 % of the total export earnings of the nation, 4.7 million small-holders directly involved in producing coffee and about 25 million people directly or indirectly depends on coffee sector for their livelihoods (CSA, 2015).

Despite the existence of enormous genetic diversity of Arabica coffee and its importance in the country's economy, productivity of the crop is very low (0.7 ton ha-1 green coffee) as compared to other coffee producing countries (Central Statistical Agency, CSA, 2012). Such low level of productivity of the crop stems from erroneous management of the plant during the initial stage of establishment in the field and the use of weak and whippy seedlings with undesirable shoot and root growth for field planting. This emanates mainly from poor seed preparation and handling, use of deteriorated seeds and growing media not suitable for germination and seedling growth, improper depth of seed sowing, and pre-germination practices (Wondyifraw, 1994; Tesfaye et al., 2006; Anteneh et al., 2008). Pre-germination is the primary cause of multiple and crooked tap roots and eventual tree death in the field (Anteneh, 2015). Currently, among the problems identified in the production of Arabica coffee at Kafa is low survival rate of coffee seedlings after field transplanting (Endale et al., 2008). Fertilizer is any substance used to add nutrients to the soil for promoting soil fertility and increasing plant growth. Fertilizers can change rate of plant growth, maturity time, size of plant parts, and biochemical content of plants and seed capabilities. Solid waste composting is a low costing, low technology demanding, less polluting, and more environmentally acceptable method. Organic manures act not only as a source of nutrients and organic matter, but also increase microbial biodiversity and activity in soil, influence structure, nutrients get turnover and many other changes related to physical, chemical and biological parameters of the soil (Albiach et al., 2000). The soil having higher organic matter concentrations have been proved to enhance the growth and yield of different crops (Sarwar, 2005) as well as soil aeration, soil density and maximizing water holding capacity of soil for seed germination and plant root development (Zia et al., 1998). Vermicompost is a type of organic fertilizer produced by biodegradation of organic material through interactions between earthworms and micro-organisms, contains nearly all types of nutrients necessary for the plant growth and also is rich in microbial growth and activities (Orozco et al., 1996). Abbasi et al. (2002) who reported that composted coffee husk contains considerable quantities of nutrients.

In recent years due to erratic rainfall pattern, abnormal weather and soil situation the establishment of seedlings in main field is found to be unsatisfactory as the six month old seedlings were unable to survive in the long dry spells that follow after field planting. So media preparation may affect to produce health and vigorous coffee seedlings. Due to that view of the above, a need will be felt to revisit certain management in rising of coffee seedlings at nursery and thereby to produce healthy and vigorous seedlings for field planting by adding organic matter to the media. With this ideology, current work is developed to evaluate the effects of different organic matter and pot sizes on the germination and early growth of coffee seedling at nursery level. Therefore this study was initiated with the objective to evaluate the effects of different organic matter and pot size on the germination and early growth of coffee seedling.

Materials and methods

Description of the Study Area

The experiment was conducted at Mechara coffee nursery site during 2021 cropping season. Mechara is located 434 km to the east of Addis Ababa in Daro Labu district of West Hararghe Zone in Oromia Regional State. It is 110 km from Chiro (Zonal Capital) to the south on a gravel road that connects to Arsi and Bale Zones. The area is geographically located at altitude of 1760 m.a.s.l and receives an average annual rainfall of about 900mm with monthly mean maximum and minimum temperatures of 26o C and 14o C, respectively. The major soil type of the center is sandy clay loam which is reddish in color.

Experimental Design and Treatment Combinations

The experiment was conducted with a factorial experiment arranged in Randomized Complete Block Design (RCBD) with three replications. Eighteen (18) treatment combinations with two levels of pot size (width by height) (14cm x22cm and 16cm x 22cm) and different proportions of organic compost was used. Mechara-1 coffee seedlings were raised at coffee nursery site and all important seedling management was applied uniformly for all treatments.

Table: 1 Treatment combinations

Sr/no	Treatments
1	45 % topsoil +45 % sand soil + 10 % VC + 14 cm diameter * 22 cm height
2	40 % topsoil + 40 % sand soil + 20 % VC + 14 cm diameter * 22 cm height
3	35 % topsoil +35 % sand soil + 30 % VC + 14 cm diameter * 22 cm height
4	45 % topsoil +45 % sand soil + 10 % FYM + 14 cm diameter * 22 cm height
5	35 % topsoil +35 % sand soil + 30 % FYM + 14 cm diameter * 22 cm height
6	45 % topsoil +45 % sand soil + 10 % CHC + 14 cm diameter * 22 cm height
7	40 % topsoil +40 % sand soil + 20 % CHC + 14 cm diameter * 22 cm height
8	35 % topsoil +35 % sand soil + 30 % CHC + 14 cm diameter * 22 cm height
9	Top soil, sand and manure in 2:2:1 ratio (control) + 14 cm diameter * 22 cm height
10	45 % topsoil +45 % sand soil+ 10 % VC + 16 cm diameter * 22 cm height
11	40 % topsoil + 40 % sand soil + 20 % VC + 16 cm diameter * 22 cm height
12	35 % topsoil +35 % sand soil + 30 % VC + 16 cm diameter * 22 cm height
13	45 % topsoil +45 % sand soil + 10 % FYM + 16 cm diameter * 22 cm height
14	35 % topsoil +35 % sand soil + 30 % FYM + 16 cm diameter * 22 cm height
15	45 % topsoil +45 % sand soil + 10 % CHC + 16 cm diameter * 22 cm height
16	40 % topsoil +40 % sand soil + 20 % CHC + 16 cm diameter * 22 cm height
17	35 % topsoil +35 % sand soil + 30 % CHC + 16 cm diameter * 22 cm height
18	Top soil, sand and manure in 2: 2: 1 ratio (control) + 16 cm diameter * 22 cm height

Vermi-compost =VC, Farmyard manure= FYM, Coffee husk compost =CHC

Data collected

Seedling emergence: emergency count was made from each experimental unit when just it was commenced (45 days after sowing) in seven days interval. This count was extended up to 90 days after sowing. Then, the number of seedlings that emerged above the soil surface and attained the soldier stage of growth were counted and recorded every 7 days till complete emergence. Then percentage of emerged seedlings (% E) was determined. Days required to 50% emergence (MDE) and the rate of seedling emergence (ER) were calculated using the formulae developed by Scott et al., (1994) described below (Eq 1 and 2).

Mean Days to Emergence (MDE) = $\frac{\sum(nt)}{\sum n}$………………… (Eqn. 1)

Emergence Rate (ER) = $\sum (\frac{n}{t})$……………………………….. (Eqn. 2)

Where, n = number of newly germinated seeds at time t, t = days from sowing. Percent of emergence at 45, 60, 75 and 90 days after sowing,

Seedling growth parameters: Plant height (cm), number of leaves, leaf area (cm2), stem girth (cm), fresh and dry weights of stems (gm), leaves and roots (gm), tap root length (cm), root volume (ml), and total dry matter were recorded by uprooting five randomly selected seedlings from each plot.

Five seedlings were selected randomly cut above ground part at collar point by scissor, then shoot parts were separated to leaves and stems and fresh weight of each weighed using sensitive balance. The polythene bag containing the roots of the seedlings then, were immersed in running tap water and roots were separated carefully from the soil still being in water. The roots were subsequently washed with clean water, dried with water adsorbent cloth and fresh weight of roots (g), leaves (g), stems (g) and total fresh biomass yield (g) were measured by using sensitive balance. After drying separately at 800C for 48 hrs in paper bags in oven dry machine until a constant weight attained as described by Adjet-Twum and Solomon (1992). Finally, shoot and root dry matter yields were weighted using a sensitive balance.

Data analysis

The collected data was subjected to R software program. Significant difference among treatment means was assessed using the least significant difference (LSD) at 0.05 level of probability

Result and Discussions

Seedling Germination and Emergence

Analysis of variance showed that percent of emergence rate, at 45th, 75th and 90th date, mean days to emergence, emergence percent were not significantly affected by the organic matter mixture and potting media. While emergence at 60th date was significantly different with the maximum mean of emerged seedlings (0.1) recorded from the treatment with 45 % top soil +45 % sand soil + 10 % coffee husk compost + 14 cm diameter by 22cm height sized pot.

Table 2: Effects of different organic matter and pot size on the germination of coffee seedling

Treatments	MDE	E%	ER 45th date	ER 60th date	ER 75th date	ER 90th date
45 % TS +45 % SS + 10 % CHC + 14cm*22cm	72.5	77.08	0	0.1	0.05	0.03
35 % TS +35 % SS+ 30 % VC + 14cm*22cm	68.3	68.75	0	0.06	0.05	0.04
35 %TS +35 % SS + 30 % FYM + 16cm*22cm	74.5	72.92	0	0.06	0.04	0.06
TS, SS FYM 2: 2: 1 ratio (control) + 14cm*22cm	70.83	68.75	0	0.06	0.05	0.04
45 %TS +45 % SS + 10 % FYM + 14cm*22cm	74.58	75	0	0.06	0.08	0.03
40 % TS + 40 % SS+ 20 % VC + 14cm*22cm	53.75	54.17	0	0.05	0.04	0.03
45 %TS +45 %SS + 10 % CHC + 16cm*22cm	75.83	72.92	0	0.05	0.04	0.06
40%TS + 40% SS + 20% CHC + 14cm*22cm	70	68.75	0	0.04	0.06	0.04
45 % TS +45 % SS+ 10 % VC + 16cm*22cm	61.67	62.5	0	0.04	0.07	0.02
35 % TS +35 % SS + 30 % CHC +14cm*22cm	69.17	66.67	0	0.04	0.05	0.05
35 %TS+35 %SS + 30 % VC + 16cm*22cm	70.42	68.75	0	0.04	0.07	0.04
45 % TS+45 % SS+ 10 % VC + 14cm*22cm	65.42	64.58	0	0.04	0.07	0.03
35 % TS +35 % SS+ 30 % CHC + 16cm*22cm	86.25	81.25	0	0.03	0.07	0.07
45 %TS +45 % SS+ 10 % FYM + 16cm*22cm	53.75	52.08	0	0.03	0.04	0.04
35 % TS +35 % SS + 30 % FYM +14cm*22cm	55	54.17	0	0.03	0.06	0.03
TS, SS, FYM 2: 2: 1 ratio (control) +16cm*22cm	56.25	54.17	0	0.03	0.05	0.04
40 % TS + 40 % SS + 20 % VC + 16cm*22cm	73.75	68.75	0	0.02	0.07	0.06
40 % TS +40 % SS + 20 % CHC + 16cm*22cm	60.42	56.25	0	0.02	0.05	0.05
Grand mean	67.4	66.09	0	0.04	0.06	0.04
CV	31.9	31.4	0	67.2	56.3	65.6
LSD	35.7	34.4	0	0.049*	0.05	0.04

Where; MDE=mean days to emergence, E%=emergence percent, ER= emergence rate at 45th, 60th, 75th and 90th date VC =Vermi-compost, FYM =Farmyard manure, CHC= Coffee husk compost TS=Top Soil, SS= Sand Soil respectively.

contrast the minimum mean of emerged coffee seedlings (0.016) were obtained from 40 % top soil + 40 % sand soil + 20 % Vermicomposting + 16 cm diameter by 22cm height sized pot and 40 % top soil +40 % sand soil + 20 % coffee husk compost + 16 cm diameter by 22cm height pot size as shown in (Table 1) . This shows due to the fact that the small sized pot and small mixture of coffee husk compost and the larger amount top and sand soil which resulted in optimum temperature, higher water retention ability and aerated condition, which ultimately enhance emergence rate and resulted to subsequent coffee seedling growth at early stage. The result contradict with the idea of (Mohammed et al., 2013) who reported that the large sized volume which favored good aerated condition, which ultimately led to good early growth.

Seedling Growth

Seedling height, stem diameter and leaf area were significantly affected by potting media and pot size. Seedling height and number of leaf per seedling from 22.8cm to 16.2cm and 4.73 to 6.6, respectively. The highest plant height (22.8cm), number of leaf(6.6) and stem diameter were recorded from 45 % top soil +45 % sand soil + 10 % coffee husk compost and pot size of 14 cm diameter by 22cm height than the remaining mixture of organic matter and pot size. While, treatment with Top Soil + Sand Soil + Farm Yard Manure in 2:2:1 Ratio and a pot size of 14 cm diameter by 22cm height resulted in the lowest plant height (16.28cm) and leaf area (18.06cm2). This result shows due to the smaller pot size had suitable soil temperature and water holding capacity than the larger pot size that helps the coffee seedlings to use efficiently the available moisture and nutrients and hence, enhance their early growth. This result opposes the result of (Mohammed et al., 2013) who reported that the larger growing media offers larger plant nutrient and increase vegetative growth at their early growth stage.

Table 3: Effects of different organic matter and pot size on the early growth of coffee seedling

Treatments	PH(cm)	NL	LA(cm2)	SG(mm)	TRL(cm)	RV(ml)
45%TS + 45% SS +10%CHC + 14cm* 22cm	22.8a	6.6a	23.7a-c	0.39a	19.47ab	3a
35%TS +35% SS +30% FYM+16 cm *22cm	21.4ab	6.07ab	24.27a-c	0.28b-d	17.1ab	2.33a
45%TS + 45% SS +20 %VC+14cm* 22cm	21.27ab	6.13ab	23.41a-c	0.28bcd	18.89ab	2.83a
45%TS+ 45% SS +10% CHC+16 cm *22cm	20.73ab	5.73a-e	24.98a-c	0.37a	18.29ab	2.42a
45%TS + 45% SS +10%FYM +14cm* 22cm	20.63ab	5.92a-e	18.6c	0.28bcd	17.06ab	2.17a
35%TS +35% SS +30%FYM + 14cm* 22cm	20.53ab	5.27b-e	22.29a-c	0.25cd	17.85ab	1.92a
45%TS + 45% SS +10%FYM 16 cm *22cm	19.89ab	6a-d	19.3bc	0.29bcd	18.76ab	2.92a
40%TS +40% SS +20%CHC 14cm* 22cm	19.3ab	6.2ab	26.71a	0.267b-d	18.99ab	3a
35%TS + 35% SS +30%CHC +14cm* 22cm	18.6ab	5.67a-e	23.39a-c	0.25cd	18.95ab	3.67a
35%TS +35%TS + 30%VC+16 cm *22cm	18.4ab	5.4a-e	23.25a-c	0.34ab	20.6a	3.67a
40%TS + 40%TS + 20% VC+16 cm *22cm	18.13ab	5.67a-e	21.6a-c	0.22d	17.72ab	1.83a
40%TS +40%TS +20% CHC+16 cm*22cm	17.53ab	5.50a-e	26.15ab	0.27bcd	18.74ab	3.08a
45%TS + 45%TS + 10% VC +14cm* 22cm	17.27b	6abc	18.61c	0.27bcd	20.55a	1.08a
TS + SS +FYM in 2:2:1 Ratio+16 cm *22cm	17.2b	5.2b-e	20.14a-c	0.32abc	18.3ab	1.17a
45%TS + 45% SS + 10% VC + 16 cm *22cm	16.87b	5.53a-e	18.31c	0.26cd	20.27a	1.08a
35%TS + 35% SS +30% CHC+16 cm *22cm	16.8b	5.73a-e	20.82a-c	0.24d	17.08ab	3.75a
TS + SS +FYM in 2:2:1 Ratio +14cm* 22cm	16.28b	5.07b-e	18.06c	0.29bcd	15.95	2.83a
35% TS +35% SS + 30% VC +14cm* 22cm	16.2b	4.73c-e	21.27abc	0.32abc	17.86ab	1a
Mean	18.88	5.69	21.94	0.287	18.47	2.431
CV	14.5	11.3	16.7	14.2	10.4	75
LSD	4.557	1.066	6.078	0.068	3.176	3.024

Means followed by the same letters indicate non significance difference at (p<0.05). Where, PH = plant height; NL= number of leaf; LA= leaf area; SG =stem diameter; LFW= fresh leaf weight; LDW= dried leaf weight; SFW =stem fresh weight; SDW =dried stem weight; RFW =fresh root weight; DRW =dried root weight; TRL= tap root length; RV= root volume; TDM =total dried matter respectively.

Fresh and Dry weight: Analysis of variance revealed fresh leaf weight, fresh root and dry root weight, root volume and total dry weight were significantly affected by potting media and pot size. However, fresh and dry stem weight, dry leaf weight, and root volume showed non-significant different among the treatment means (Table 3). Fresh and dry leaf weight had ranged from 2.90gm to 4.78gm and 0.93gm to 1.65gm, respectively. The highest fresh leaf weight was recorded from the application of 35% Top soil +35% Sandy soil + 30%Vermi-compost +16 cm *22cm potting media and pot size. The lowest fresh weight was recorded for Top soil + sandy soil + Farm yard manure in 2:2:1 ratio +14cm* 22cm.

Table 4: Effects of different organic matter and pot size on the fresh and dry weight of coffee seedling

Treatments	LFW (gm)	LDW (gm)	SFW (gm)	SDW (gm)	RFW (gm)	DRW (gm)	TDM (gm)
45% TS+ 45% SS +10% CHC + 14cm* 22cm	4.67ab	1.61a	2.39a	0.77a	4.89a-c	1.39a	3.78a
35% TS +35% SS +30% FYM+16 cm *22cm	4.55ab	1.50a	2.60a	0.84a	1.54e	0.92abc	3.28ab
45% TS + 40% SS +20 %VC+14cm* 22cm	5.56a	1.56a	2.49a	0.79a	1.28e	0.82bc	3.16ab
45% TS+ 45% SS +10% CHC+16 cm *22cm	4.68ab	1.45a	2.45a	0.89a	6.39a	1.29ab	3.64a
45% TS + 45% SS +10% FYM + 14cm* 22cm	4.82ab	1.65a	2.35a	0.88a	1.28e	0.94abc	3.45ab
35% TS +35% SS +30% FYM (14cm* 22cm)	4.11ab	1.29a	2.17a	0.79a	1.31e	0.87abc	2.96ab
45% TS + 45% SS +10% FYM +16 cm *22cm	4.66ab	1.42a	2.28a	0.82a	1.12e	0.79bc	3.04ab
40% TS +40% SS+20% CHC +14cm* 22cm	4.63ab	1.16a	2.10a	0.62a	1.30e	0.79bc	2.58ab
35% TS + 35% SS +30% CHC +14cm* 22cm	4.69ab	1.41a	2.50a	0.83a	2.60c-e	1.09abc	3.33ab
35% TS +35% SS + 30%VC+16 cm *22cm	4.78ab	1.42a	2.53a	0.84a	4.74a-d	0.98abc	3.24ab
40% TS + 40% SS + 20% VC+16 cm *22cm	4.29ab	1.18a	1.92a	0.70a	2.02de	1.03abc	2.91ab
40% TS +40% SS +20% CHC+16 cm *22cm	4.02ab	1.23a	2.04a	0.63a	1.55e	1.04abc	2.91ab
45% TS + 45% SS + 10% VC +14cm* 22cm	3.99ab	1.17a	1.88a	0.63a	1.23e	0.80bc	2.60ab
TS + SS +FYM in 2:2:1 Ratio+16 cm *22cm	3.27ab	1.01a	1.92a	0.71a	4.85abc	0.88abc	2.60ab
45% TS + 45% SS + 10% VC + 16 cm 22cm	3.54ab	1.08a	1.83a	0.64a	1.04e	0.78bc	2.51ab
35% TS + 35% SS +30% CHC+16 cm *22cm	3.69ab	1.17a	1.56a	0.57a	0.89e	0.69c	2.44ab
TS + SS +FYM in 2:2:1 Ratio +14cm* 22cm	2.90b	0.95a	2.43a	0.52a	3.45b-e	0.64c	2.12ab
35% TS +35% SS + 30% VC +14cm* 22cm	3.39ab	0.93a	1.60a	0.59a	5.53ab	1.02abc	2.55ab
Mean	4.237	1.29	2.17	0.73	2.62	0.94	2.95
CV	28.4	28.4	31.9	26.7	58.1	30.1	25.1
LSD	1.98	0.61	1.15	0.32	2.52	0.47	1.23

Means followed by the same letters indicate non significance difference at ($p<0.05$). Where, PH = plant height; NL= number of leaf; LA= leaf area; SG =stem diameter; LFW= fresh leaf weight; LDW= dried leaf weight; SFW =stem fresh weight; SDW =dried stem weight; RFW =fresh root weight; DRW =dried root weight; TRL= tap root length; RV= root volume; TDM =total dried matter respectively.

Conclusion and Recommendation

The treatments produced significant effect on the 60th date emergence, seedling growth parameters and fresh and dry weigh of the coffee seedlings. Application of different organic compost increased coffee seedlings height, number of leaf, leaf area, stem diameter, fresh leaf weight, dried leaf weight, fresh and dried root weight, tap root length and total dried matter. The largest plant height, number of leaf, stem diameter, dried root weight, and total dry were recorded from 45 % top soil +45 % sand soil + 10 % coffee husk compost and pot size of 14 cm diameter by 22cm height than the remaining mixture of organic matter. In contrast the minimum mean of emerged coffee seedlings (0.016) were obtained from 40 % top soil + 40 % sand soil + 20 % Vermicomposting + 16 cm diameter by 22cm height sized pot and 40 % top soil +40 % sand soil + 20 % coffee husk compost + 16 cm diameter by 22cm height sized pots. In addition, treatment with Top Soil + Sand Soil +Farm Yard Manure in 2:2:1 Ratio and a pot size of 14 cm diameter by 22cm height resulted in the lowest plant height, leaf area, dry root weight, total dry weight, respectively. However, mean days to emergence, emergence percent, emergence rate at

45th, 75th and 90th date, dried leaf weight; fresh and dried stem weight and root volume of coffee seedlings were not affected by the effects of different organic matter and pot sizes. Therefore, 45 % top soil +45 % sand soil + 10 % coffee husk compost and pot size of 14 cm diameter by 22cm was recommended for raising coffee seedlings production.

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4. Land Suitability Evaluation for Tea Cultivation using Geographic's Information System (GIS) and analytical hierarchical process (AHP) in Selected Districts of Buno Bedele, Southwest Ethiopia

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Abstract

Tea is a crops economically important export commodity for Ethiopia that generates foreign currency when exporting its products. Predicting the physical land suitability of tea is vital to avoid a sightless expansion of tea plantations and significant to recognize the potential suitable area for tea to disseminate of tea plantations in the country. Land suitability analysis is a basic premise for allocating specific land for specific purposes. The study integrate applications of Geographic Information System, Remote Sensing , and Analytical Hierarchical Process model to assign suitability weights to criteria that affect the tea plant's growth and produce a predictive suitability map for its cultivation. Topographic, soils, climatic and land use land cover features were considered in the model as an important contributing factor for tea plant's growth. The Analytical Hierarchical Process indicated that soils texture (25.98), Slope (14.01%) Aspect (13.31%) and elevations (10.72%) was highly contributed to the land suitability evaluation than other criteria followed by land use land cover (9.85%), soil pH (9.53%). soil drainage class (5.42%), soil depth (4.3%), Temperature (4.05%) and Rain fall (2.83%) had least impact influence on tea land suitability predictions. Studies area has great potential for tea plants production. From the generated land suitability map, results showed that about 97.66% of the total area was rated suitable for tea production, of which 94.03 % was rated suitable, 1.13% was rated highly suitable and 2.51% was rated marginally suitable. The findings further showed that only 2.34% of the area was not suitable for tea plant production. Soil Texture, Slope, Elevation and aspect were the main limiting factors for growing tea in the studies area as identified in the land capability analysis. Therefore, expansion of tea plantations is recommended in the area were for investment at large scale or small farm level as soil acidity were sever problem that limited other crop productions for alternative income generation mechanism.

Keywords: Tea cultivation, Land suitability evaluation, GIS, analytical hierarchy process

Introduction

Tea (Camellia sinensis L.O. Kuntze) is a perennial evergreen shrub and a high-value added cash crop, and it is renowned for its nutritional, medicinal, antimicrobial, and anticancer properties worldwide (Feng et al., 2019 and Chen et al., 2022). Discovered about 2700 B.C, it is one of the oldest beverages in the world today and it is available for consumption in six main varieties, based on the oxidization and fermentation techniques applied (FAO, 2015 and Hajiboland, 2017). Tea is one of the most popular and lowest cost beverages in the world, and consumed by a wide range of age groups in all levels of society with more than three billion cups daily worldwide (Kidanu et al., 2020).

The tea crop has rather specific agro-climatic requirements that are only available in tropical and subtropical climates because it needs a hot, moist climate. Tea requires a well-distributed minimum rainfall ranging from 1200mm to 2200mm that is well distributed throughout the year, and temperatures' ranging from 13ºC to 30ºC is optimum (FAO, 2015, Hajiboland, 2017, Kariuki, et al., 2017 Gahlod et al., 2017 and Chen et al., 2022). Elevations, slope and aspect are the most critical topographic factors for tea growth and chemical compositions as they influence microclimate that control water availability and soils drainage conditions. The tea plant requires gentle slope, ranging 5-10 Degree or 13-25% slopes and elevations of 1500 to 2250m for optimum growth (Hajiboland, 2017, Gahlod et al., 2017, Kamunya et al., 2019 and Kariuki, et al., 2022). Tea plant requires soil having optimum soils drainage conditions and soil pH 4.5-5.6 for the most favorable for growth (Hajiboland, 2017 and Kariuki et al., 2022)

Soil texture like sandy is significantly limited tea plant growth due to low water retention, low resistance to soil erosion, and insufficient nutrient were as clay loam, loamy clay and sandy clay loam are moderate soil texture for tea cultivation (Gahlod et al., 2017 and DENGİZ et al., 2018). Tea was introduced to Ethiopia around 1928 by British missioners in Gore area of Gumaro which is the oldest tea farm in the southwest Ethiopia (Ahmed, 2022). Ethiopia has 6 million hectares of land suitable for tea production, particularly the western part of country: however, up to date, only 2660 ha of land have been devoted to tea plantations (Erge et al., 2021).

Tea planting at wush wush Plantation at altitudinal average 1900m above sea level, rainfall is 1820mm and the minimum and maximum temperature is 12 and 240c respectively. Gumaro tea plantation is located at an altitude of 1718m above sea level and rainfall of 2089mm. The minimum and maximum temperature is 12 and 240c respectively (Kidanu et al., 2020). Despite the importance of tea production in Ethiopia, there is lack of basic information on tea cultivation land suitability which is vital to avoid a sightless expansion of tea plantations and significant to recognize the potential suitable area for tea plantations to disseminate of tea plantations in the country. Generally executed by examining natural and human factors, such as climatic conditions, topography conditions, and soil physical-chemical properties in response to the crop requirements for growth and production up to the extent of land unit quality which matches the necessity of a specific land use that influences tea cultivation to evaluate the potential and

limitations of particular land use (Gahlod et al., 2017 and Chen et al., 2022). GIS and Analytic Hierarchy Process (AHP) modeling-based approach is important for Physical Land Suitability Evaluation analysis for agricultural production. It enables all factors affecting land suitability to be considered and weighted under one umbrella to resolve highly complex decision-making problems involving multiple factors in suitability analysis for agricultural production and that enable all factors affecting land suitability to be considered (Saaty, 2008 and Goepel, 2013). The objective of this study was to assess the physical land suitability evaluation for tea production using GIS and analytical hierarchical process in Buno Bedele Zone, Oromia Region, Southwest Ethiopia.

Materials and Methods

Description of Study Area

The Studies was conducted in five Districts of Buno Bedele Zone, Oromia Region, Southwest Ethiopia. The selected districts covered about 340050.148 hectares of land. It includes Dega, Chora, Bedele, Gechi and Didesa districts. The Studies area location were extent from West to East is 35°58’52” to 36°48’28” east and south to north is 7°59’42” to 8°42’25” north (Figure 1). The mean annual temperature of basin was ranged from 18.52 to 20.65°C and receives annual rainfall of 1827.2 to 2179mm.

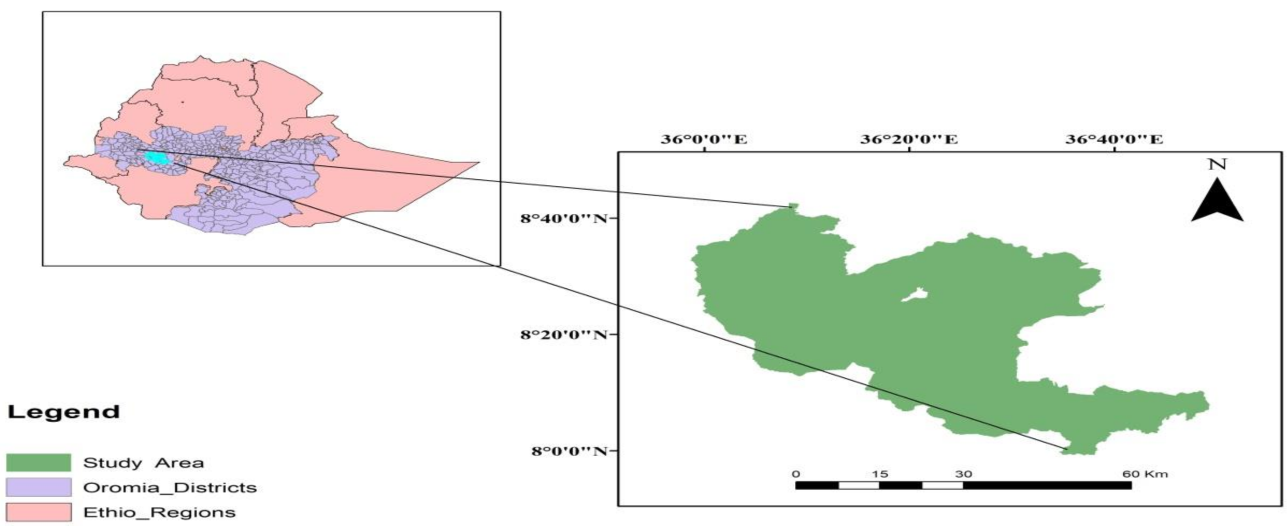


Figure 1: Study area

Data Source

To predict physical land suitability evaluation for tea cultivation using GIS and analytical hierarchical process in the Dega, Chora, Bedele, Gechi and Didesa districts. Dataset was obtained from primary and secondary data sources. High resolution climate data of mean temperature and annual precipitation data used in this study were obtained from the World Climate Data with a spatial resolution of 30 s (~1 km2) and they represent the average monthly climate data of the year 2011-2020 were downloaded from the world climate website (www.worldclim.org) (Karra et al., 2021).

Digital evaluation models of the study area were used as sources of for topographic features (Elevation, aspect, and Slope), soil data (soil texture and soil pH) was obtained from laboratory, Drainage and soil depth data was extracted from ISRIC Gird 250m 2017. Land use land cover of 2021 with 10m spatial resolution was obtained from ESRI 2021 (https://www.esri.com) used to produce the final land suitability map for tea. All raster layers used in this study were projected into WGS_1984_UTM_Zone_37N projection system. Climate data used in this study were obtained from the World Climate Data with a spatial resolution of 30 s (~1 km2) and they represent the average monthly climate data of the year 2011-2020.

Data Setting

In this study, a tea cultivation site selection model was developed based on the spatial analysis of multi-criteria decision making analysis. The process modeling has been done with the application of both spatial data and expert level opinions of decision makers in the integration of data and relationships between criteria. GIS has good ability for managing, manipulating, and analysis of spatial data, while AHP model-based multi criteria decision analyses were used for preparing a methodology for assessing and ranking decisions for tea cultivation site selection model development. Setting all of the criteria and their interrelationships is a crucial decision for developing an accurate model for the identification of suitable sites. The methodology and steps of applying AHP MCDA model for tea cultivation suitable site selection are presented in Figure 2.

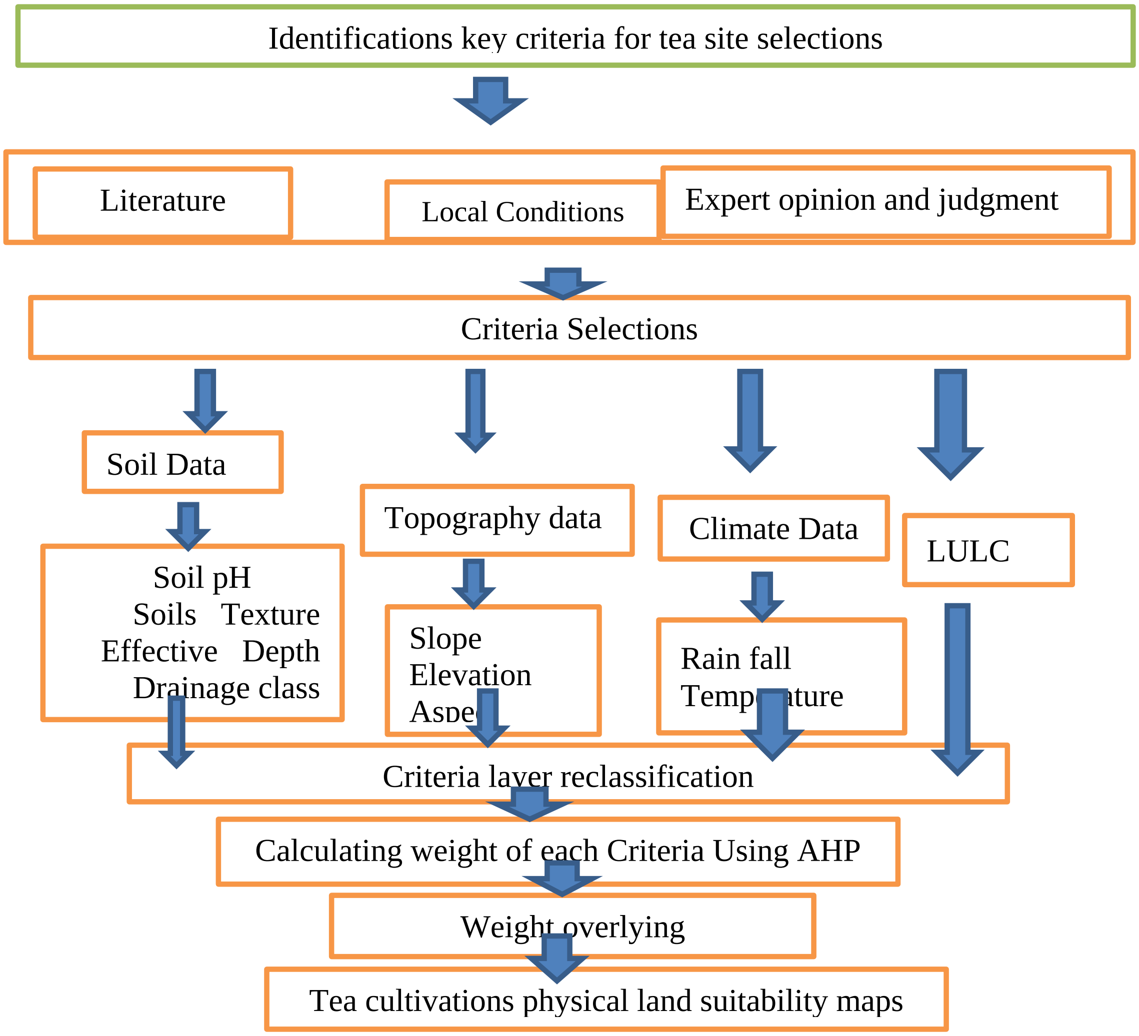


Figure 2: Flow chart of the methodology for the identification of tea cultivation.

Data Analysis

Methodology: AHP and GIS based agricultural land suitability analysis

The AHP is a mathematical method that may be applied to resolve highly complex decision-making problems involving multiple scenarios, criteria and factors (Saaty, 2000). The AHP is a powerful and flexible decision-making process to help people set priorities and make the best decision when both quantitative and qualitative aspects of decisions need to be considered (Weerakoon, 2014). The AHP applies to the decision problem after it is structured hierarchically at different levels, each level consisting of a finite number of elements (Srdjevic 2005). Proposed in the 1970s by Thomas L. Saaty, it constructs a ratio scale associated with the priorities for the various items compared. In his initial formulation in the conventional AHP, Saaty proposed a four-step methodology comprising of modeling, valuation, prioritization, and synthesis. At the first stage, a hierarchy representing relevant aspects of the problem (criteria, sub-criteria, attributes, and decision alternatives) is constructed. The goal or mission of the decision-making problem is placed at the top of this hierarchy. Other relevant aspects (criteria, sub criteria, attributes, etc.) are placed in the remaining levels (Patil et al., 2012).

The second stage involves the comparison of pairs of criteria, pairs of sub-criteria (pairs of sub–sub-criteria, etc.) and pairs of alternatives. The AHP uses a fundamental 9-point scale measurement to express individual preferences or judgments (Saaty, 1980) creating a matrix of pairwise comparisons (Table 1).

Table 1. Scale of rating influence of factors 1 to 9 Scale

Intensity of Importance	Definition	Explanation
1	Equal importance of i and j	Two activities contribute equally to the objective.
3	Weak importance of i over j	Experience and judgment slightly favor one activity over another
5	Strong importance of i over j	Experience and judgment strongly favor one activity over another
7	Demonstrated importance of i over j	Its dominance demonstrated in practice.
9	Absolute importance of i over j	The evidence favoring one activity over another is of the highest possible order of affirmation.
2,4,6 and 8	Intermediate values the two adjacent Judgments	When compromise is needed
Reciprocals of above Non zero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

Source: Saaty (2005)

After all, pairwise comparison matrices are formed, the vector of weights, w = [w1, w2, w3…wn] is calculated based on Saaty's eigenvector method. Then, this eigenvector is normalized by Eq. 1 and then the weights are computed by Eq. 2. The elements of the normalized eigenvector are weighted with respect to the criteria or sub criteria and rated with respect to the alternatives (Bhushan and Rai 2004; Carrion et al., 2008).

$$\boldsymbol{aij} = \frac{\boldsymbol{aij}}{\sum_{i=1}^{n} \boldsymbol{aij}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\boldsymbol{W\dot{i}} = \left(\frac{1}{n}\right) \sum_{i=1}^{n} \boldsymbol{aij}, (\boldsymbol{i}, \boldsymbol{j} = \mathbf{1}, \mathbf{2}, \mathbf{3} \ldots.\boldsymbol{n}) \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where i, j = 1, 2, 3….n.

The AHP also provides mathematical measures to determine the consistency of judgment matrix. Based on the properties of the matrix, a consistency ratio (CR) can be calculated. In a matrix, the largest eigenvalue (kmax) is always greater than or equal to the number of rows or columns (n). A consistency index (CI) that measures the consistency of pairwise comparisons can be written as (Saaty, 1980).

$$\lambda max = \frac{1}{n}\sum_{i}^{n} = 1 \left[\frac{\sum_{j=1}^{n} aijwj}{wi}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where CI is the consistency index (1), n is the number of elements being compared in the matrix, kmax is the largest or principal eigenvalue of the matrix. If this consistency index fails to reach a threshold level, then the answers to comparisons are re-examined. To ensure the consistency of the pairwise comparison matrix, the consistency judgment must be checked for the appropriate value of n by CR. The CR coefficients are calculated according to the methodology proposed by Saaty (1980). The CR coefficients should be less than 0.1, indicating the overall consistency of the pairwise comparison matrix (Chen et al., 2022). CR is defined as:

$$\mathbf{CR} = \left(\frac{\mathbf{CI}}{\mathbf{RI}}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where RI: is the average of the resulting consistency index depending on the matrix. The RI values for different numbers of n are shown in Table 2. If the CR less than 0.10, it means that the pairwise comparison matrix has an acceptable consistency. Otherwise, If CR C 0.10, it means that pairwise consistency has inadequate consistency. In this case, the AHP may not yield meaningful results unless one re-examines the judgments and changes them as necessary to reduce the inconsistency below 0.10. (Saaty, 1980 and Chen et al., 2022). In this study, the resulting CR for the pairwise comparison matrix was 0.061 for tea land suitability. These values indicate that the comparisons of land characteristics were perfectly consistent. Finally, the rating of each alternative is multiplied by the weights of the criteria and aggregated to get local ratings with respect to each criterion.

Table 2. Random index (RI)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

Source: Saaty (1980)

Selection of evaluation criteria and AHP application

For evaluating agricultural land suitability, ten criteria including soil Data (soil pH, soil texture, drainage class, and soil depth), topographic factors (slope, altitude and aspect) and climatic factors (temperature and rainfall). Were selected based on relevant literature review (Jayathilaka et al, 2012, Gahlod et al., 2017, Jayasinghe et al, 2018, Kumar et al., 2019 and Chen et al., 2022) and local expert interviews. These evaluation criteria were classified into four main groups (soil, topography, climate and Land use land cover) in context of how they affect tea land suitability in studies area.

Results and Discussions

Reclassification Evaluation criteria for Tea Land suitability classification

The spatial land suitability of tea cultivation was obtained after the analysis of selected evaluation criteria such as soil data (soil pH, soil texture, drainage class, and soil depth), topographic factors (slope, altitude and aspect) and climatic factors (temperature and rainfall). Identified evaluation criteria layers were converted into raster data format based on the value of the required attributed column to form each thematic layer and according to literatures and expert level judgments (Table 3). Reclassification was used to simplify the interpretation of raster datasets by changing a single input value into a new output value. By using reclassified layers, which results in a generalization and simplification of the original dataset, the input layers were categorized based on the same ranking scheme that can be used to compare and rank the least and most suitable sites. Soil-site characteristics and Climatic/land quality criteria was reclassified based on Gahlod et al. (2017) and Chen et al. (2022).

Table 2. Suitability criteria and class for production of tea cultivations

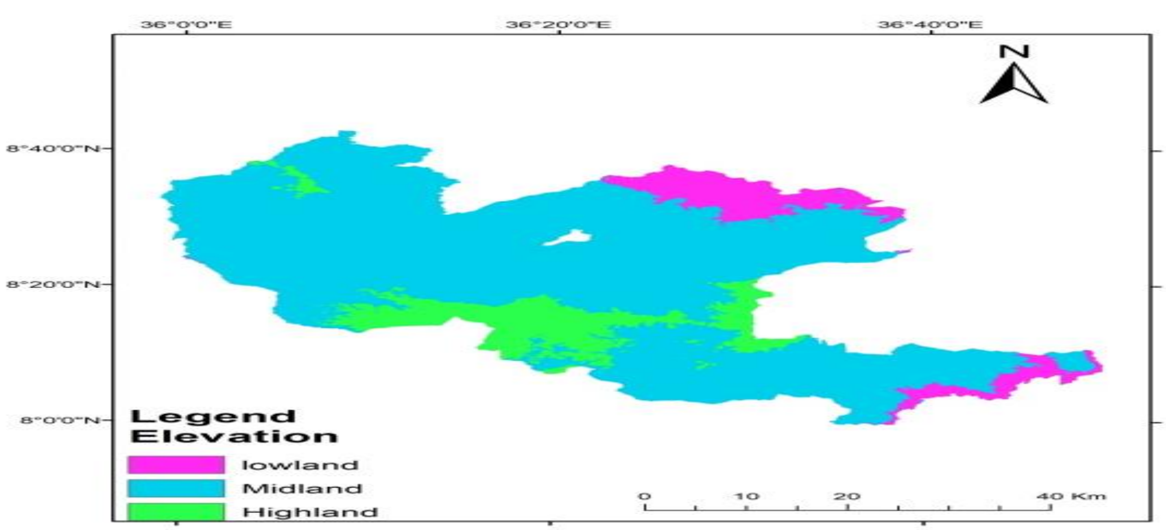
Parameters	Highly suitable	Moderately Suitable	Marginally suitable	Not suitable
Soil pH (H2O)	4.5-5	5.1-6 /4- 4.4	6.1-6.5/<4	>6.5/>3.5
Soil texture	Loam, Loamy sand, Sandy, Sandy loam	Clay loam, Sandy clay, Silty clay, Sandy clay loam	Clay	Clay heavy
Soil depth	>150	100-150	100-50	<50
Drainage	Excessive to moderate	Imperfect	Poor	Very poor
Elevation (m)	< 2000	2000-2500	>2,500	
Slope (percent)	< 13	13–25	25–55	>55
Aspect	[South, southeast, southwest]	[East, west, northeast, northwest]	[North]	-
Temperature (°C)	18-25	26-28 /15-17	29-30/13-14	>30/<13
Rainfall (mm)	1800-2,000	1600-1,800	1000-1600	<1000
LULC	Tea plantation/ Forest	Cropland	Farmland	Building area/water body

Reclassification of Topographic Characteristics of the Study Area

The unclassified elevation of the area ranges from 1,158 to 3,094 m a.s.l distributed to lowland (1158-1500 m) 4.94%; midland (1500-2300m) 70.31 and 24.75 % of the area was of highland (Figure 3). The reclassified elevation map shows that about 44.55 and 46.38% of area has highly suitable and suitable altitude for growth tea plant. This indicated that the Elevation influence tea plant growth in study the area. Elevation is one topographic feature that affects the growth, yield, and quality of tea crop performance through affecting water distribution and pedogenic process that influence soil properties in different landscape positions (Yaghmaeian et al., 2020). As elevation increases, the growth rates of tea crops especially shoot decreases that contribute towards slower growth at high altitudes. Yield and quality of black tea, particularly theaflavin and its fractions, aroma composition and water extract were positively affected by elevation which increased as elevation resulted in higher levels (Muthumani et al., 2013 and Hossain et al., 2021).

High elevations leads to higher concentrations of volatile compounds that include analgesic, antianxiety, antibacterial, anticancer, antidepressant, antifungal, anti-inflammatory, antioxidant, anti-stress, and cardio protective as compared with low elevations(site). In addition, teas grown in high elevations were sweeter, floral, honey-like compounds than tea growing in low elevation (Robbat et al., 2018).

Tea is planted on elevated land slopes at 1,900 - 2,500m; in addition, it is adaptive in a well-drained land at 1550 and 1800 m Rwanda (Ingabire, 2020). The unclassified slope of study the area from 0 to 169.48% that characterized by very steep sloping (0.26%), steep sloping (4.91%) moderately steep sloping (31.80%), strongly sloping (38.83%), sloping to gently sloping slope (22.33%) and 1.87% of the area was very gently sloping slope (Figure 3).



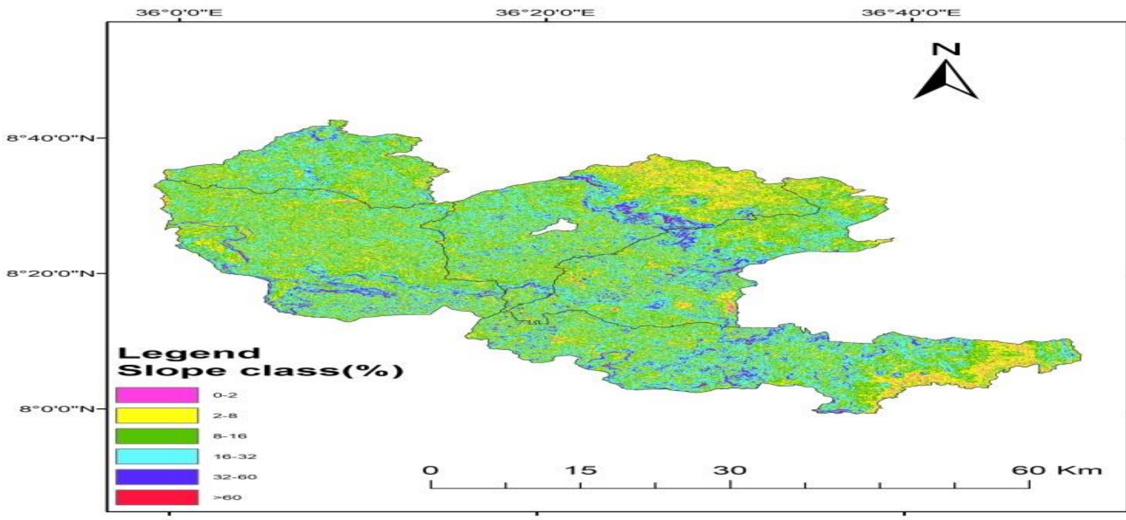


Figure 3. Elevation and slope of the study area

The reclassified slope map shows that about 29.58 and 39.11 % of study the area has highly suitable and suitable slope for growth tea plant respectively (Table 4 and Figure 4). However, 21.14% and 10.17 that represent less suitable and not suitable respectively affect tea plant growth significantly in study area. The slope tea cultivation affected growth and yield performance indirectly had significant effect on pedogenic process which highly affects solum thickness, thickness of the epipedons, saturated soil moisture, clay content, total N, calcium carbonate content, and exchangeable Mg.

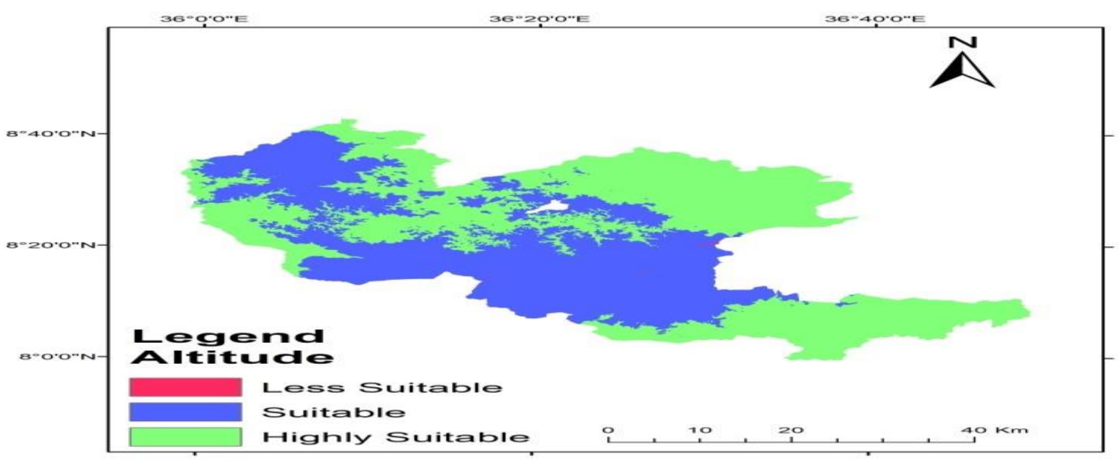
Generally, slope affects tea cultivation through affecting physical, chemical, and morphological properties of the soil such as nutrient movement in landscape position and drainage condition of the soil which had significant on tea cultivation (Khormali et al., 2007).The slope aspect is one topographic feature affecting the growth, yield and quality of tea through affecting microclimate due to the difference in surface runoff and risk of soil erosion as well as solar radiation difference received on different aspects (Khormali et al., 2007).Aspects influence the growth, yield, and quality of tea through affecting the hydrological cycle of landform and the rate of soil forming processes, particular affecting the infiltration rate and evapotranspiration by changing the microclimate of the specific area rapid evapotranspiration on southern aspect, and high rate of soil forming processes in the north facing slopes which results in a thicker solum with higher organic matter and denser vegetation were observed due doe to slopes aspects difference (Khormali et al., 2007).

The reclassified aspects results show that about 36.99 and 50.84%, of the study the area highly suitable and suitable aspects for growth tea plant respectively. However the remaining 12.17% aspects of the area faced to North, has significant affect tea plant growth in the study the area

(Table 4). Aspects are also an important indicator of land suitability as it influences drainage and soil erosion activity in specific areas.

Table 3. Suitability criteria and area coverage of Elevation, Slope and Aspect for tea cultivation

Factors	Reclassified	Classification	Area (ha)	Area (%)
Elevation (m.a.s.l)	< 2000	Highly suitable	196671.70	44.55
	2000-2500	Suitable	204718.60	46.38
	2500-3094	Less suitable	40039.67	9.07
Slope (%)	5< 13	Highly suitable	130571.60	29.58
	13– 25	Suitable	172620.20	39.11
	25 – 55	Less suitable	93331.58	21.14
	>55	Not suitable	44879.28	10.17
Aspects	South, southeast, southwest	Highly suitable	163259.60	36.99
	East, west, northeast, northwest	Suitable	224417.7	50.84
	North	Less suitable	53721.02	12.07



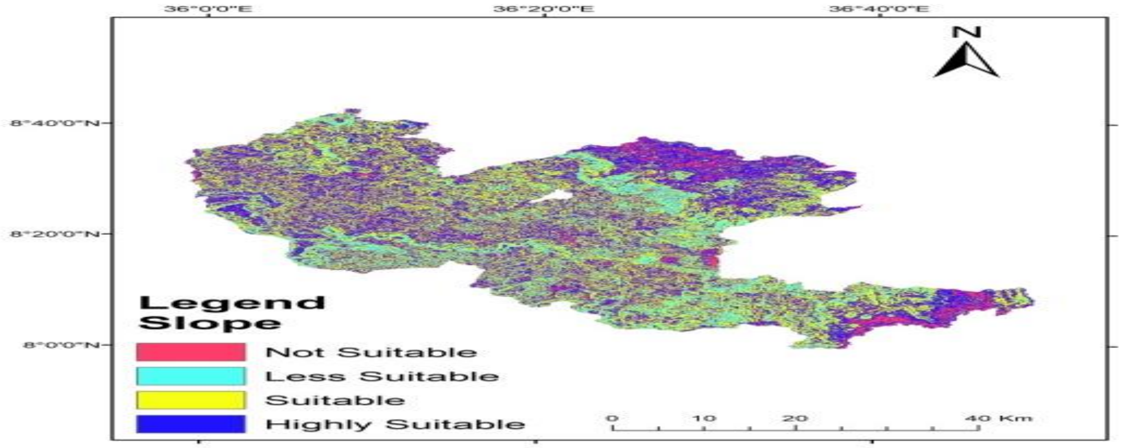
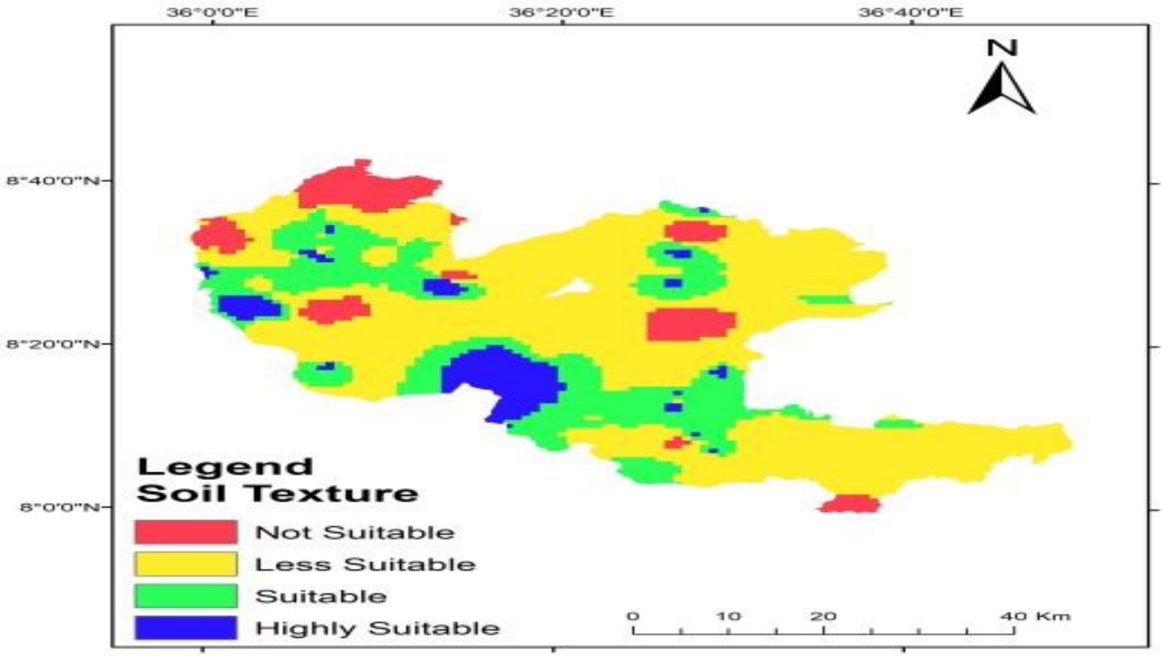


Figure 4. Elevation and slope Suitability Maps

Soil Factors Reclassification

The unclassified soil pH of Studies area ranges from 4.1 to 5.9 and the reclassified soil pH map shows that about 66.3 and 33.7% of Studies area has highly suitable and suitable soil pH for tea plant growth (Table 5 and Figure 4). This indicated that soil pH is the most important factors affect tea plant growth in Studies area. Generally, tea plants require acid soils with soil pH range 4.5-5.5 for growing better (Gahlod, et al., 2017 and Jayathilaka et al., 2012). The unclassified soil texture of the Studies area ranges from medium texture class to Heavy texture class and the reclassified soil texture map shows that about 61.82 and 23.29% of Studies area had marginally suitable and suitable soil texture class for growth tea plant where as 6.1% area were occupied by highly suitable class of suitability (Table 5 and Figure 5). This indicated that the soil texture had significant effect on tea plant growth in the studies area. Soil texture such as loam, sand, loamy, sandy clay loam, and clay loam are highly suitable for tea production, whereas clay, silty clay, and silty clay loam are considered as Moderately Suitable for tea cultivation (Gahlod et al., 2017 and DENGİZ et al., 2018).



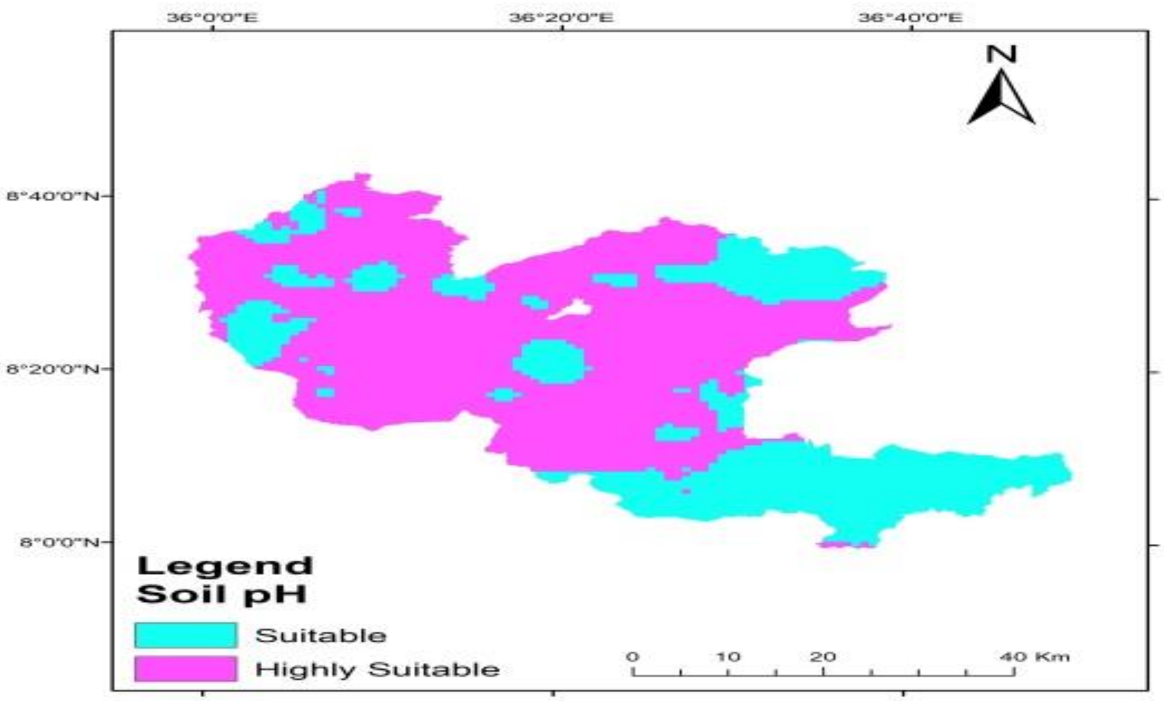
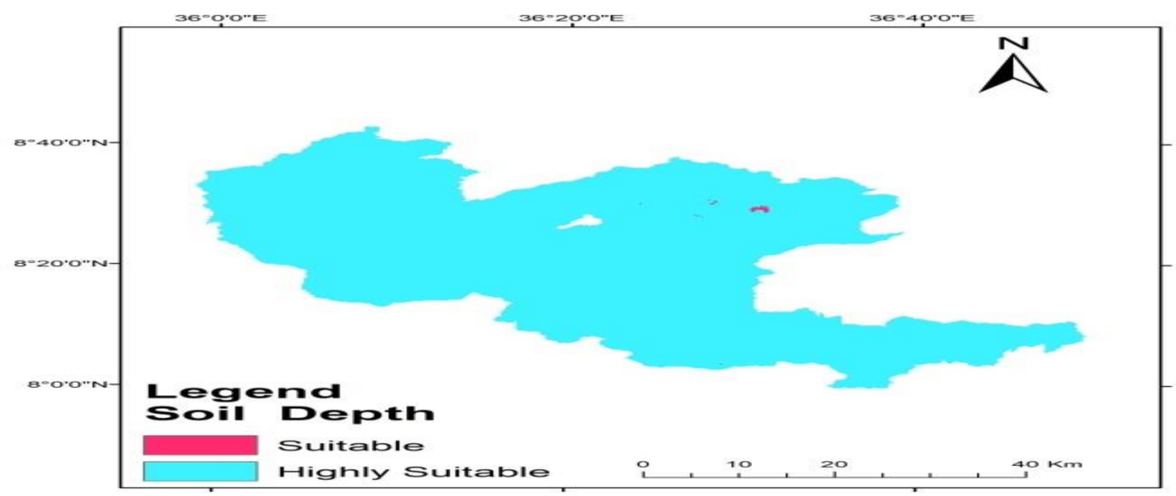


Figure 3. Soil Texture and pH suitability Map

The unclassified Drainage class of the studies area ranges from well drainage class to poorly drained class and the reclassified Drainage class map shows that about 93.21 and 4.78% of the studies area has highly suitable and suitable Drainage class for growth tea plant (Table 5 and Figure 6). This indicated that the Drainage classes limit tea plant growth in the studies area significantly. However poorly drained Drainage class occupied only 0.05% of the studies area. Tea is grown in well-drained soil drainage class, deep and well-aerated soil with more than 2% organic matter is the optimum soil condition soil for tea growing (Gahlod et al., 2017). The unclassified soil depths of the study area ranges from very deep to deep depths of less than 122 cm and the reclassified Drainage class map shows that about 99.91 and 0.09% of the studies area has highly suitable and suitable soil depths for growth tea plant (Table 5 and Figure 6). This indicated that the soil depth does not limit tea plant growth in the study area significantly. Soil depths of less than 50 cm, soil gravel of more than 50% in top 50 cm of the soil layer and a rockiness of 20% negatively affect tea growth. Tea cultivations do not tolerate prolonged flooding or poorly drained clay soils. This tree grows in a variety of soil types and conditions from fine drained sandy loam soils to heavier clay loam soils. Well-drained to moderately drained soils, deep and well-aerated soil were recommended as optimum soil conditions for tea growth (Hajiboland, 2017 and DENGİZ et al., 2018).



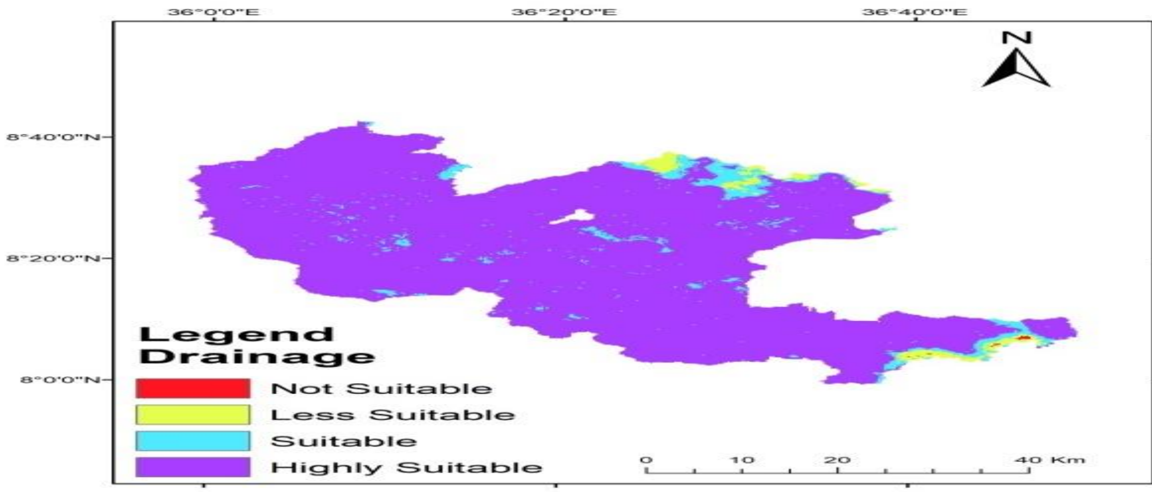


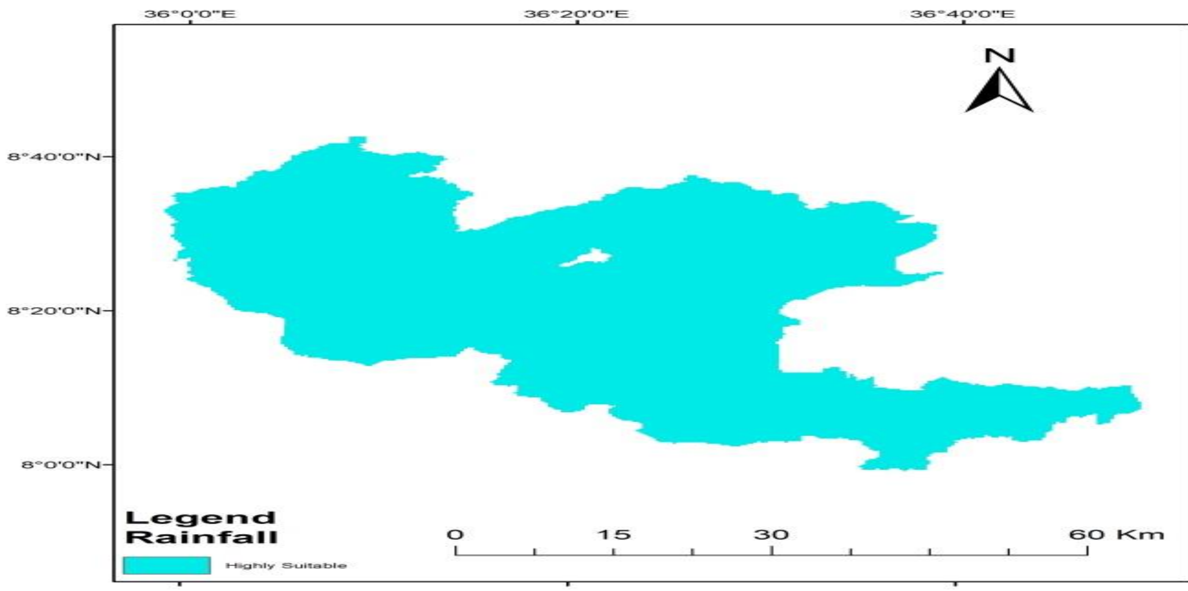
Figure 4. Soil Drainage class and soil depth suitability map

Table 4. Suitability criteria and coverage of soil pH, depth Texture and Drainage for tea cultivation

Factors	Classification	Area (ha)	Area (%)
Soil pH	Suitable	114596.9	33.7
	Highly suitable	225450.8	66.3
Soil depth	Suitable	269.89	0.09
	Highly suitable	339757.4	99.91
Soil texture	Not Suitable	29931.52	8.8
	Less Suitable	210225.3	61.82
	Suitable	79184.79	23.29
	Highly suitable	20705.31	6.09
Drainage	Not Suitable	156.26	0.05
	Less Suitable	6665.97	1.96
	Suitable	16266.43	4.78
	Highly suitable	316962.1	93.21

Climatic Parameters Reclassification

The unclassified annual rainfall of the basin ranges from 1827.2 to 2178.9 mm pear year and the reclassified annual rainfall map shows that about 100% of the studies area has highly suitable annual rainfall for growth tea plant (Table 6 and Figure 7). This indicated that the annual rainfall does not limit tea plant growth in the studies area as the studies areas receive highly suitable annual rainfall for tea plant growth. The unclassified mean temperature of the area ranges from 18.52 to 20.65°C and the reclassified mean temperature map shows that about 100% of the area has highly suitable mean temperature for tea plant growth (Table 6 and Figure 7). This indicated that the mean temperature does not limit tea plant growth in studies area as receive highly Suitable mean temperature for tea growth.



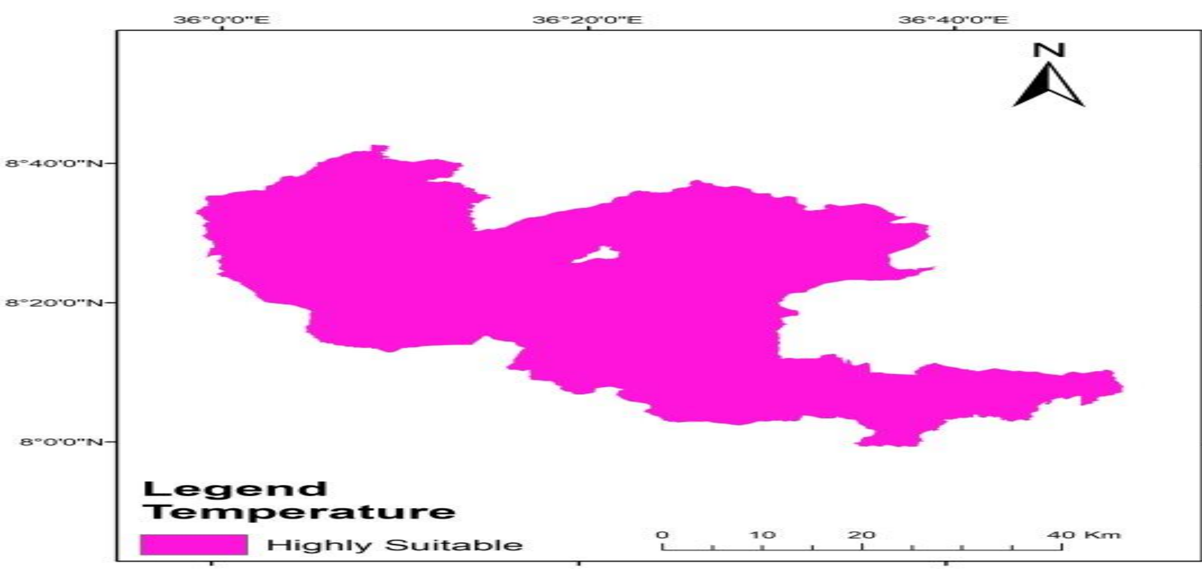


Figure 5. Rainfall and Temperature Suitability map

Its specific requirements are: temperatures ranging from 13-30oC, minimum annual precipitation of 1250 mm (Chen et al., 2022). Tea plant requires well-distributed rainfall and the optimum mean temperature in the range of 18 to 300C that receive an annual rainfall of at least 1200 mm per year (Hajiboland, 2017 and Kariuki et al., 2022). The tea plant requires a minimum rainfall of 1200mm per year, but 2500-3000 mm per years are considered optimum (Hajiboland, 2017 and Jayasinghe et al., 2019).

Table 5. Suitability criteria and area coverage of Rainfall and Temperature for Tea cultivation

Factors	Reclassified	Classification	Area (ha)	Area (%)
annual rainfall (mm)	>1800	Highly suitable	340046.68	100.00
Mean annual temperature (°C)	18-25°C	Highly suitable	340046.68	100.00

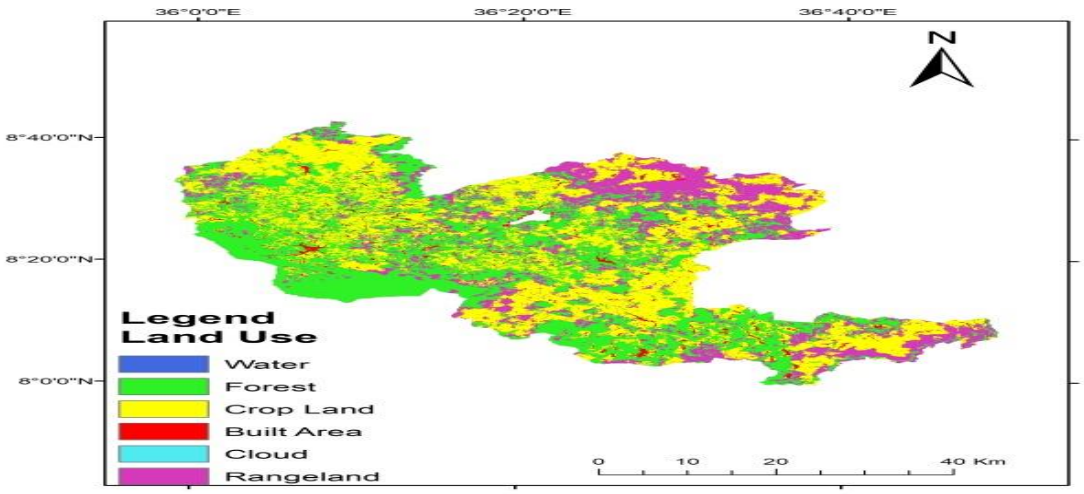
Land Use Land Cover Parameter Reclassification

Land use land cover types are an important factor that affects physical land suitability of tea cultivation. Tea can grow in forest land, shrubs lands, crop land, and grass land. According to (Chen et al., 2022) Tea plantation, Forest, Farmland lands are the optimal land use types for tea cultivations, whereas building land and water body are not suitable for tea cultivation. Existing tea-growing areas, crop lands, grass land, and forest lands are appropriate land use for tea and urban, rock, bare land, open water, wet lands, paddy, and road were not appropriate land use for tea cultivation (Jayasinghe et al., 2019).

The land use land cover of the study area was classified as forest, crops land, land (moderate to sparse cover of bushes, shrubs, and tufts of grass, savannas with very sparse grasses, trees or other plants) bare land, built area and water bodies' area (Table 7 and Figure 8). Current existing land use map of the basin was used to assess the condition of restricted land use for tea growing. Therefore, the existing land use classes were classified as "1" which possible and appropriate land use classes for tea such as existing tea-growing areas, crop land, tree cover and range land use, and "0" was where tea could not be grown (Built Area, bare land, water bodies, and seasonally flooded vegetation). The newly developed land use restriction map was overlaid with the rasterized suitability map. The results of land use land cover suitability analysis indicated that about 332094.5 ha which is the largest part of the current land use of the study area was suitable (97.64%) for tea cultivation. Meanwhile, the remaining 2.34% was not suitable for tea cultivation due to restricted land use condition that was not suitable of for tea growing.

Table 6. Suitability criteria and area coverage of LULC for Tea cultivation

Factor	LULC Type	Classification	Area (ha)	Area (%)
LULC	Forest, Cropland, Rangeland	Suitable	332094.5	97.64
	Built Area, bare lands, water bodies and wet land	Not suitable	7953.2	2.34
	Total		340047.7	100



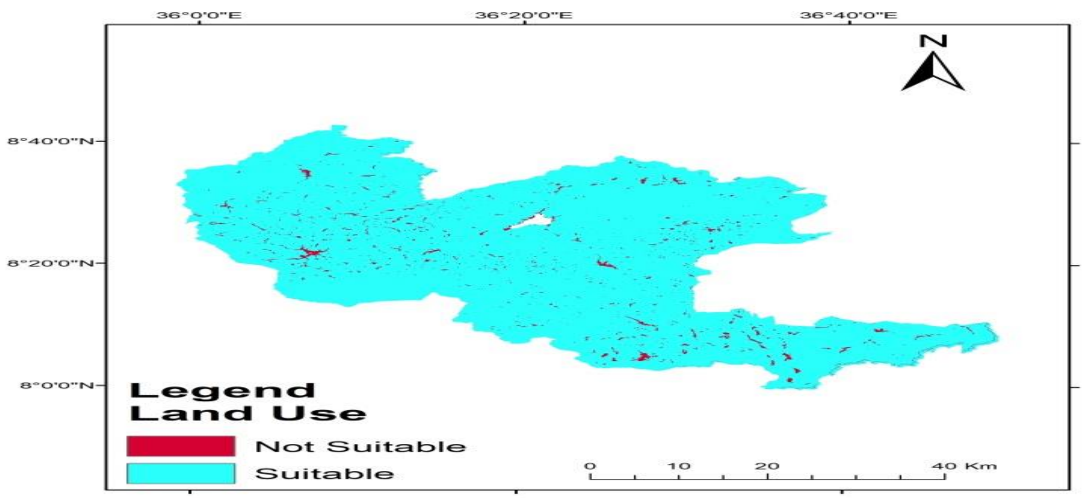


Figure 7. Land use land cover and land suitability map

Criteria Weights

In this study, the weights for selected parameters were derived using AHP model. Relative importance of factors that affect the growth of tea plants was assigned in pairwise comparison matrix. In the matrix above, diagonal values were assigned in comparison with the column parameters. The values of each parameter were given in accordance with the parameter effect on the growth and productivity of tea plants. Below diagonal values of each parameter are the reciprocal of the above diagonal. After assigning the relative importance values of the above diagonal and the reciprocal of the above diagonal matrix, normalization of each cell value was done (Table 8).

Table 7. Analytical Hierarchical Process Comparison Matrix

Criteria	pH	Temp	Rain	Slope	Elevation	Drainage	depth	texture	aspect	LULC
Soil pH	1.00	3.00	3.00	0.33	1.00	3.00	3.00	0.20	1.00	1.00
Temp	0.33	1.00	2.00	0.33	0.33	1.00	1.00	0.20	0.33	0.33
Rain	0.33	0.50	1.00	0.20	0.33	0.33	0.33	0.20	0.33	0.33
Slope	3.00	3.00	5.00	1.00	1.00	3.00	3.00	0.33	0.33	3.00
Elevation	1.00	3.00	3.00	1.00	1.00	3.00	3.00	0.33	1.00	1.00
Drainage	0.33	1.00	3.00	0.33	0.33	1.00	3.00	0.33	0.33	0.33
Depth	0.33	1.00	3.00	0.33	0.33	0.33	1.00	0.33	0.33	0.33
texture	5.00	5.00	5.00	3.00	3.00	3.00	3.00	1.00	3.00	3.00
Aspect	1.00	3.00	3.00	3.00	1.00	3.00	3.00	0.33	1.00	1.00
LULC	1.00	3.00	3.00	0.33	1.00	3.00	3.00	0.33	1.00	1.00
Sum	13.30	23.50	31.00	9.87	9.33	20.67	23.33	3.60	8.67	11.33

Normalization can be computed by dividing each cell value by the column total of each parameter. Normalization of the parameters values was performed to generate criteria weights for each parameter. Criteria of each parameter were obtained by summing up the row values of each cell. Consistency ratio of all parameters was computed to check whether the calculated value is correct or not correct. Values of consistency ratio exceeding 0.10 are indicative of inconsistent judgments; whereas values of 0.10 or less indicate a reasonable level of consistency in the pairwise comparison. In this case, the computed CR is 0.083 and this indicates a reasonable level of consistency in the matrix (Table 9).

According to the criteria weight, soil parameter is the paramount importance for tea plant growth performance, soil texture has the highest significance indicator value followed by rainfall, elevation, land use land cover, aspect and slope, indicating that these are the most important criteria for the land suitability assessment for tea in the study area, however the relatively lowest position was indicated by temperature, soil drainage class and soils depth for the land suitability assessment for tea in the area. Final criteria weights were achieved by calculating each criterion's weight by models as indicated in Table 10 and applied to the land-use suitability for tea crops. Soil texture (25.98), Slope (14.01%) Aspect (13.31%) and elevations (10.72%) was highly contributed to the land suitability evaluation than other criteria followed by land use land cover (9.85%), soil pH (9.53%). Soil drainage class (5.42%), soil depth (4.3%), Temperature (4.05%) and Rain fall (2.83%) had least impact influence on tea land suitability predictions based on the results of normalized matrix assessment on relative importance of climate, soil, and topography parameter.

Table 8. Analytical Hierarchical Process (AHP) analysis for the assessment of the relative importance of climate, soil, and topography parameters; normalized matrix results

Criteria	pH	Temp	Rain	Slope	Altitude	Drain	Depth	Texture	Aspect	LULC	Total	Weight
Soil pH	0.08	0.13	0.10	0.03	0.11	0.15	0.13	0.06	0.12	0.09	1.00	9.53
Temp	0.03	0.04	0.06	0.03	0.04	0.05	0.04	0.06	0.04	0.03	0.42	4.05
Rain	0.03	0.02	0.03	0.02	0.04	0.02	0.01	0.06	0.04	0.03	0.30	2.83
Slope	0.23	0.13	0.16	0.10	0.11	0.15	0.13	0.09	0.04	0.26	1.40	14.01
Altitude	0.08	0.13	0.10	0.10	0.11	0.15	0.13	0.09	0.12	0.09	1.10	10.72
Drain	0.03	0.04	0.10	0.03	0.04	0.05	0.13	0.09	0.04	0.03	0.58	5.42
Depth	0.03	0.04	0.10	0.03	0.04	0.02	0.04	0.09	0.04	0.03	0.46	4.30
Texture	0.38	0.21	0.16	0.30	0.32	0.15	0.13	0.28	0.35	0.26	2.54	25.98
Aspect	0.08	0.13	0.10	0.30	0.11	0.15	0.13	0.09	0.12	0.09	1.30	13.31
LULC	0.08	0.13	0.10	0.03	0.11	0.15	0.13	0.09	0.12	0.09	1.03	9.85

Eigenvalue (λmax) = 10.810, Consistency Index (CI) = 0.09, Consistency Ratio (CR) = 0.061

Land suitability for Tea

Land suitability for tea in the study area comprises highly suitable, suitable, less suitable and not suitable (Table 10 and Figure 8).The analysis of the final weighed results indicated that the of the study area had potential land for tea cultivation as the majority part of the land in the studies area (97%) is occupied by suitable class of suitability in which, about 319737.82ha (94.03%) highly suitable followed by 8527.81ha (2.51%) marginally suitable of land for tea cultivation in this area. From reaming land of studies area about 7953.18ha (2.34%) and 3826.63ha (1.13%) land was occupied with not Suitable and highly suitable respectively. Most of the suitable lands found in Chora district of the studies area. This is maybe due to optimum soil, climatic and topographic conditions for tea cultivation. Soil texture, Slope, Altitude, Aspect and Land use land cover were identified as the main limitation factors for tea productions. in the studies area. Altitude has the greatest positive value of relationship indicator, which means that it has a dominating, causal influence on the other criteria. According to the relationship indicators (Table 9), Altitude, Aspect, Land use and slope belong to the cause group, and have a significant influence over the criteria of temperatures, soil drainage, and depth, soil pH and soil texture. Altitude, in fact influences temperature, and present Land use land cover of the studies area.

Table 9. Land Suitability class and area coverage of the study area for tea cultivation

Suitability class	Area (ha)	Area (%)
Not Suitable	7953.18	2.34
Less Suitable	8527.81	2.51
Suitable	319737.82	94.03
Highly suitable	3826.63	1.13

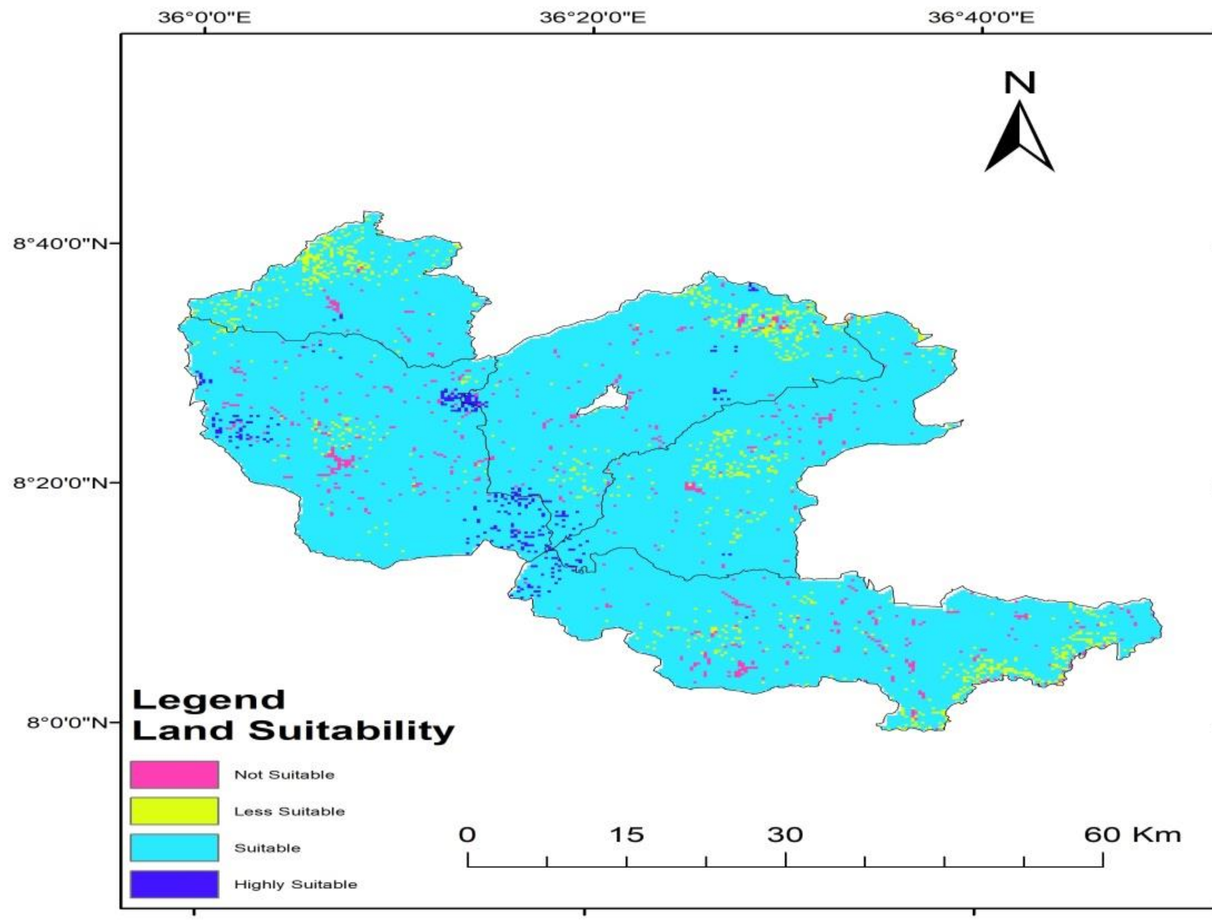


Figure 8. Final land suitability map for tea cultivation

Conclusion and Recommendation

Based on the findings of this study, it can be concluded that studies area has great potential for tea plants production especially well-distributed rainfall and the optimum mean temperature for tea plants production. From the generated land suitability map, results showed that 97.66% of the total area was rated suitable for tea production, of which 94.03 % was rated suitable, 1.13% was rated highly suitable and 2.51% was rated marginally suitable.

The findings further showed that only 2.34% of the area was not suitable for tea plant production that represents the land either currently not suitable or permanently not suitable. Soil texture, slope, elevation and aspect were the main limiting factors for growing tea in the studies area as identified in the land capability analysis. Therefore, identification of these limiting factors is necessary to disseminate of tea plantations through to avoid a sightless expansion of tea plantations in the area. Introducing tea plantations for investment at large scale or small farm were possible and economically profitable as that Studies area has great potential for tea plants production especially well-distributed rainfall and the optimum mean temperature for tea plants production. It is recommended that, the method used in this study be applied in future studies to map land suitability for tea plantations or other agricultural crops, with addition of other soil parameters that were not included in this study as such organic matter, CEC, exchangeable aluminum and exchangeable acidity factors.

The fact that this study was restricted to only one crop, it is recommended that future studies apply the analysis method used in this study to develop land suitability maps for other crops such as cereals. It is further recommended that field trials can be set up in the various suitability classes as identified in the study. Introducing tea plantations for investment at large scale or small farmers especially in the studies area as acid tolerance crops to increase income of poor farmers who are totally depend on small land for their daily life. Expansion of tea plantations in the area highly recommended as soil acidity were sever problem that limited crop productions for alternative income generation mechanism.

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4. Land Suitability Evaluation for Tea Cultivation using Geographic's Information System (GIS) and analytical hierarchical process (AHP) in Selected Districts of Ilu Abba Bora, Southwest Ethiopia

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Abstract

Tea is a crops economically important export commodity for Ethiopia that generates foreign currency when exporting its products. Predicting the physical land suitability of tea is vital to avoid a sightless expansion of tea plantations and significant to recognize the potential suitable area for tea to disseminate of tea plantations in the country Land suitability analysis is a basic premise for allocating specific land for specific purposes. The study integrate applications of Geographic Information System , Remote Sensing, and Analytical Hierarchical Process model to assign suitability weights to criteria that affect the tea plant's growth and produce a predictive suitability map for its cultivation. Topographic, Soils, climatic and land use land cover features were considered in the model as an important contributing factor for tea plant's growth. Each of the evaluations criteria layers were classified into four suitability class (not suitable, less suitable, suitable, and highly suitable) based on the revived literature and expert level judgment. The Analytical Hierarchical Process indicated that soils texture (22.23), Rain fall (13.43%) was highly contributed to the land suitability evaluation than other criteria followed by land use land cover (12.63%), Aspect (12.63%) elevations (11.65%). The least impact on the evaluation of land suitability for tea was soil pH (5.44%) drainage class (4.74%) and Temperature (4.65%), while Slope (9.13%) had an intermediate influence on tea land suitability predictions. Studies area has great potential for tea plants production. From the generated land suitability map, results showed that 94.5% of the total area was rated suitable for tea production, of which 1.66 % was rated highly suitable, 92.78% was rated suitable and 0.06% was rated marginally suitable. The findings further showed that only 5.54% of the area was not suitable for tea plant production. Soil Texture, rainfall, elevation and aspect were the main limiting factors for growing tea in the studies area as identified in the land capability analysis. Therefore, Expansion of tea plantations is recommended in the area were for investment at large scale or small farm level as soil acidity were sever problem that limited other crop productions for alternative income generation mechanism.

Keywords: Tea cultivation, Land suitability evaluation, GIS, analytical hierarchy process

Introduction

Tea (Camellia sinensis L.O. Kuntze) is a perennial evergreen shrub and a high-value added cash crop, and it is renowned for its nutritional, medicinal, antimicrobial, and anticancer properties worldwide (Feng et al., 2019 and Chen et al., 2022). Discovered about 2700 B.C, it is one of the oldest beverages in the world today and it is available for consumption in six main varieties, based on the oxidization and fermentation techniques applied (FAO, 2015 and Hajiboland, 2017). Tea is one of the most popular and lowest cost beverages in the world, and consumed by a wide range of age groups in all levels of society with more than three billion cups daily worldwide (Kidanu et al., 2020).

The tea crop has rather specific agro-climatic requirements that are only available in tropical and subtropical climates because it needs a hot, moist climate. Tea requires a well-distributed minimum rainfall ranging from 1200mm to 2200mm that is well distributed throughout the year, and temperatures' ranging from 13ºC to 30ºC is optimum (FAO, 2015, Hajiboland, 2017, Kariuki, et al., 2017 Gahlod et al., 2017 and Chen et al., 2022). Elevations, slope and aspect are the most critical topographic factors for tea growth and chemical compositions as they influence microclimate that control water availability and soils drainage conditions. The tea plant requires gentle slope, ranging 5-10 Degree or 13-25% slopes and elevations of 1500 to 2250m for optimum growth (Hajiboland, 2017, Gahlod et al., 2017, Kamunya et al., 2019 and Kariuki, et al., 2022). Tea plant requires soil having optimum soils drainage conditions and soil pH 4.5-5.6 for the most favorable for growth (Hajiboland, 2017 and Kariuki et al., 2022)

Soil texture like sandy is significantly limited tea plant growth due to low water retention, low resistance to soil erosion, and insufficient nutrient were as clay loam, loamy clay and sandy clay loam are moderate soil texture for tea cultivation (Gahlod et al., 2017 and DENGİZ et al., 2018). Tea was introduced to Ethiopia around 1928 by British missioners in Gore area of Gumaro which is the oldest tea farm in the southwest Ethiopia (Ahmed, 2022). Ethiopia has 6 million hectares of land suitable for tea production, particularly the western part of country: however, up to date, only 2660 ha of land have been devoted to tea plantations (Erge et al., 2021).

Tea planting at wush wush Plantation at altitudinal average 1900m above sea level, rainfall is 1820mm and the minimum and maximum temperature is 12 and 240c respectively. Gumaro tea plantation is located at an altitude of 1718m above sea level and rainfall of 2089mm. The minimum and maximum temperature is 12 and 240c respectively (Kidanu et al., 2020). Despite the importance of tea production in Ethiopia, there is lack of basic information on tea cultivation land suitability which is vital to avoid a sightless expansion of tea plantations and significant to recognize the potential suitable area for tea plantations to disseminate of tea plantations in the country. Generally executed by examining natural and human factors, such as climatic conditions, topography conditions, and soil physical-chemical properties in response to the crop requirements for growth and production up to the extent of land unit quality which matches the necessity of a specific land use that influences tea cultivation to evaluate the potential and

limitations of particular land use (Gahlod et al., 2017 and Chen et al., 2022). GIS and Analytic Hierarchy Process (AHP) modeling-based approach is important for Physical Land Suitability Evaluation analysis for agricultural production. It enables all factors affecting land suitability to be considered and weighted under one umbrella to resolve highly complex decision-making problems involving multiple factors in suitability analysis for agricultural production and that enable all factors affecting land suitability to be considered (Saaty, 2008 and Goepel, 2013). The objective of this study was to assess Physical Land Suitability Evaluation for tea production cultivation using GIS and analytical hierarchical process in Ilu Abba Bora Zone, Oromia Region, Southwest Ethiopia.

Materials and methods

Study Area

The Studies was conducted in five Districts of Ilu Abba Bora Zone, Oromia Region, Southwest Ethiopia. The selected districts covered about 528733.2 hectares of land. It includes Metu, Didu, Ale, Nono sele and Halu districts. The Studies area location were extent from West to East is 34°51’50” to 35°45’31” east and south to north is 7°28’35” to 8°31’5” north (Figure 1). The mean annual temperature of basin was ranged from 19.43 to 25.74°C and receives annual rainfall of 1353.83 to 2126.94mm.

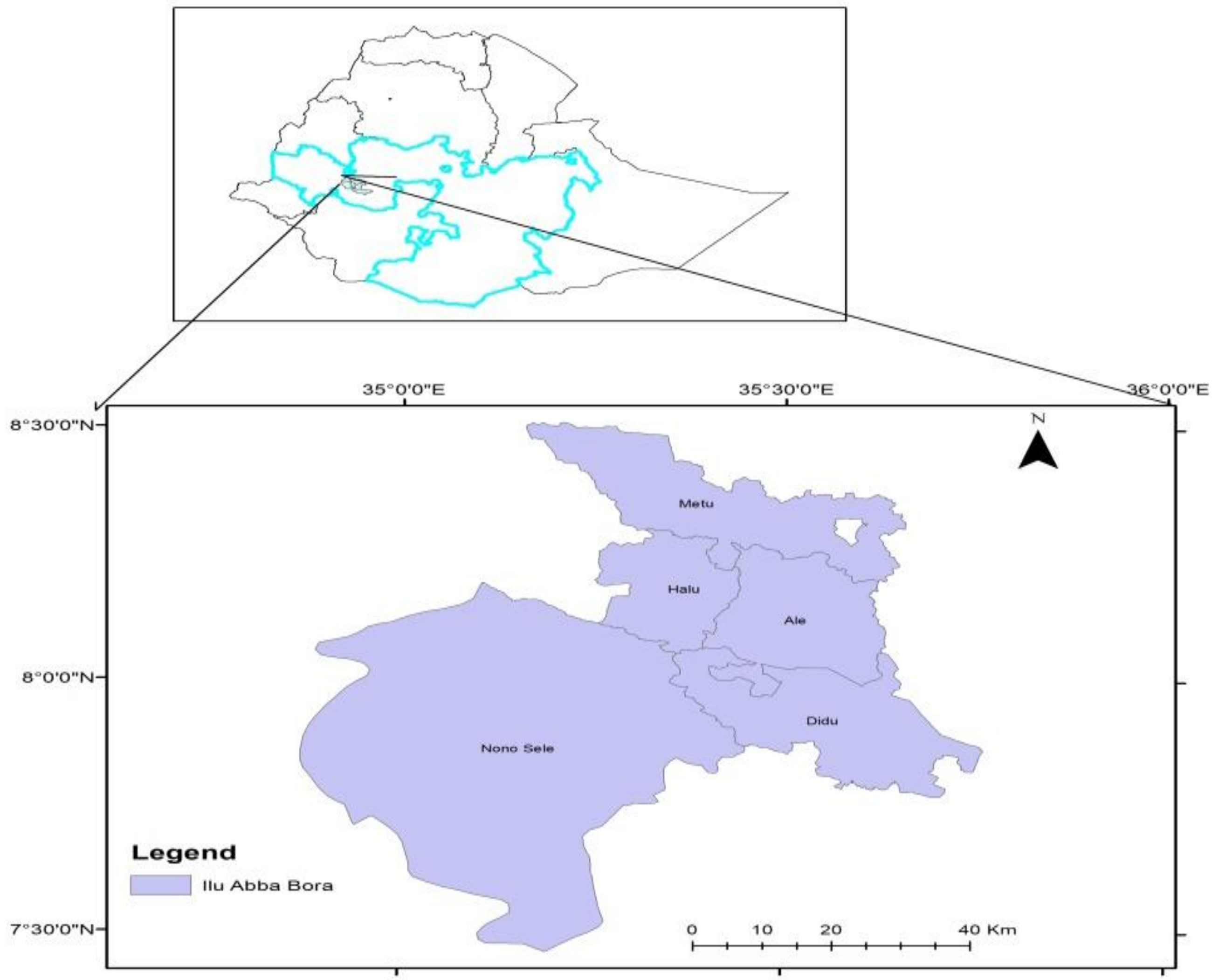


Figure 6. Map of study area

Data Source

To predict physical land suitability evaluation for tea cultivation using GIS and analytical hierarchical process in the Metu, Didu, Ale, Nono sele and Halu districts. Dataset was obtained from primary and secondary data sources. High resolution climate data of mean temperature and annual precipitation data used in this study were obtained from the World Climate Data with a spatial resolution of 30 s (~1 km2) and they represent the average monthly climate data of the year 2011-2020 were downloaded from the world climate website (www.worldclim.org) (Karra et al., 2021).

Digital evaluation models of the study area were used as sources of for topographic features (elevation, aspect, and slope), Soil data (soil texture and soil pH) was obtained from laboratory, Drainage and soil depth data was extracted from ISRIC Gird250m 2017.

Land use land cover of 2021 with 10m spatial resolution was obtained from ESRI 2021 (https:// www.esri.com) used to produce the final land suitability map for tea. All raster layers used in this study were projected into WGS_1984_UTM_Zone_37N projection system. Climate data used in this study were obtained from the World Climate Data with a spatial resolution of 30 s (~1 km2) and they represent the average monthly climate data of the year 2011-2020.

Data Setting

In this study, a tea cultivation site selection model was developed based on the spatial analysis of multi-criteria decision making analysis. The process modeling has been done with the application of both spatial data and expert level opinions of decision makers in the integration of data and relationships between criteria. GIS has good ability for managing, manipulating, and analysis of spatial data, while AHP model-based multi criteria decision analyses were used for preparing a methodology for assessing and ranking decisions for tea cultivation site selection model development. Setting all of the criteria and their interrelationships is a crucial decision for developing an accurate model for the identification of suitable sites. The methodology and steps of applying AHP MCDA model for tea cultivation suitable site selection are presented in Figure 2.

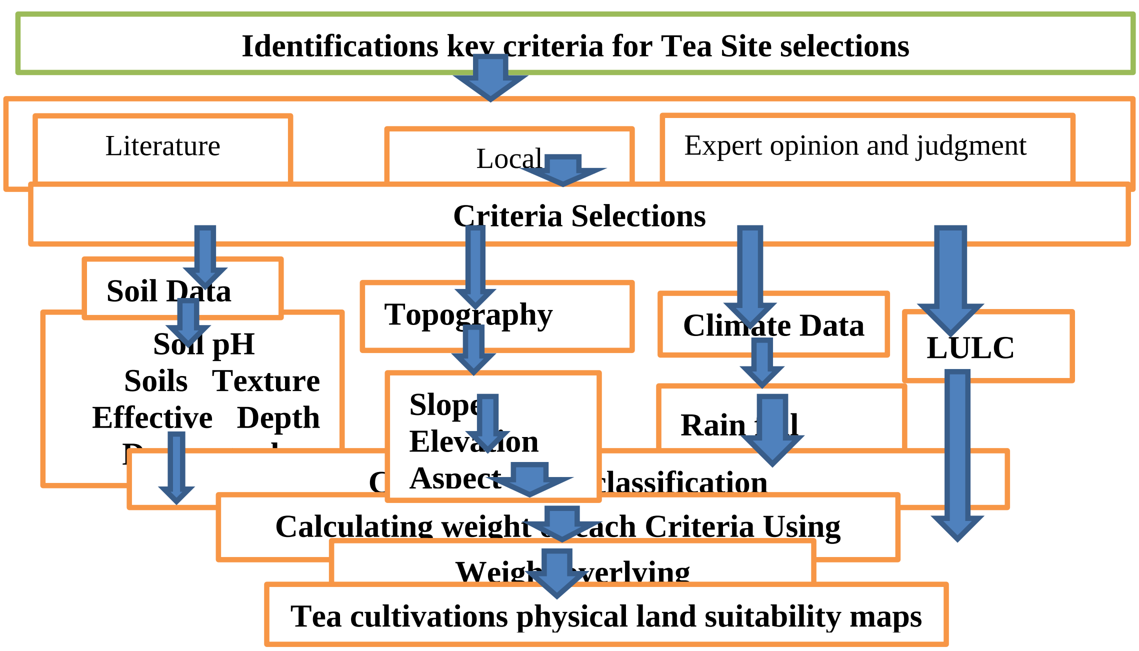


Figure 7: Flow chart of the methodology for the identification of tea cultivation.

Data Analysis

Methodology: AHP and GIS based agricultural land suitability analysis

The AHP is a mathematical method that may be applied to resolve highly complex decision-making problems involving multiple scenarios, criteria, and factors (Saaty 2000). The AHP is a powerful and flexible decision-making process to help people set priorities and make the best decision when both quantitative and qualitative aspects of decisions need to be considered (Weerakoon 2014). The AHP applies to the decision problem after it is structured hierarchically at different levels, each level consisting of a finite number of elements (Srdjevic 2005). Proposed in the 1970s by Thomas L. Saaty, it constructs a ratio scale associated with the priorities for the various items compared. In his initial formulation in the conventional AHP, Saaty proposed a four-step methodology comprising of modeling, valuation, prioritization, and synthesis. At the first stage, a hierarchy representing relevant aspects of the problem (criteria, sub-criteria, attributes, and decision alternatives) is constructed. The goal or mission of the decision-making problem is placed at the top of this hierarchy. Other relevant aspects (criteria, sub criteria, attributes, etc.) are placed in the remaining levels (Patil et al., 2012).

The second stage involves the comparison of pairs of criteria, pairs of sub-criteria (pairs of sub–sub-criteria, etc.), and pairs of alternatives. The AHP uses a fundamental 9-point scale measurement to express individual preferences or judgments (Saaty, 1980) creating a matrix of pairwise comparisons (Table 1).

Table 10. Scale of rating influence of factors 1 to 9 Scale (Saaty, 2005)

Intensity of Importance	Definition	Explanation
1	Equal importance of i and j	Two activities contribute equally to the objective.
3	Weak importance of i over j	Experience and judgment slightly favor one activity over another
5	Strong importance of i over j	Experience and judgment strongly favor one activity over another
7	Demonstrated importance of i over j	Its dominance demonstrated in practice.
9	Absolute importance of i over j	The evidence favoring one activity over another is of the highest possible order of affirmation.
2,4,6 and 8	Intermediate values the two adjacent Judgments	When compromise is needed
Reciprocals of above Non zero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

After all, pairwise comparison matrices are formed, the vector of weights, w = [w1, w2, w3…wn] is calculated based on Saaty's eigenvector method. Then, this eigenvector is normalized by Eq. 1 and then the weights are computed by Eq. 2. The elements of the normalized eigenvector are weighted with respect to the criteria or sub criteria and rated with respect to the alternatives (Bhushan and Rai 2004; Carrion et al., 2008).

$$\boldsymbol{aij = \frac{aij}{\sum_{i=1}^{n} aij}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

$$\boldsymbol{W\dot{i} = \left(\frac{1}{n}\right) \sum_{i=1}^{n} aij, (i, j = 1, 2, 3 \ldots . n)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Where i, j = 1, 2, 3….n.

The AHP also provides mathematical measures to determine the consistency of judgment matrix. Based on the properties of the matrix, a consistency ratio (CR) can be calculated. In a matrix, the largest eigenvalue (kmax) is always greater than or equal to the number of rows or columns (n). A consistency index (CI) that measures the consistency of pairwise comparisons can be written as (Saaty 1980).

$$\lambda\text{max} = \boldsymbol{\frac{1}{n} \sum_{i}^{n} = 1 \left[\frac{\sum_{j=1}^{n} aijwj}{wi}\right]} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Where CI is the consistency index (1), n is the number of elements being compared in the matrix, kmax is the largest or principal eigenvalue of the matrix. If this consistency index fails to reach a threshold level, then the answers to comparisons are re-examined. To ensure the consistency of the pairwise comparison matrix, the consistency judgment must be checked for the appropriate value of n by CR. The CR coefficients are calculated according to the methodology proposed by Saaty (1980). The CR coefficients should be less than 0.1, indicating the overall consistency of the pairwise comparison matrix (Chen et al., 2022). CR is defined as:

$$\text{CR} = \left(\frac{\text{CI}}{\text{RI}}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

Where RI: is the average of the resulting consistency index depending on the matrix. The RI values for different numbers of n are shown in Table 2. If the CR less than 0.10, it means that the pairwise comparison matrix has an acceptable consistency. Otherwise, If CR C 0.10 it means that pairwise consistency has inadequate consistency. In this case, the AHP may not yield meaningful results unless one re-examines the judgments and changes them as necessary to reduce the inconsistency below 0.10 (Saaty 1980 and Chen et al., 2022). In this study, the resulting CR for the pairwise comparison matrix was 0.061 for tea land suitability. These values indicate that the comparisons of land characteristics were perfectly consistent. Finally, the rating of each alternative is multiplied by the weights of the criteria and aggregated to get local ratings with respect to each criterion.

Table 2. Random index (RI) table

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

Source: Saaty (1980)

Selection of evaluation criteria and AHP application

For evaluating agricultural land suitability, ten criteria including soil Data (Soil pH, soil texture, drainage class, and soil depth), topographic factors (slope, altitude and aspect) and climatic factors (temperature and rainfall). Were selected based on relevant literature review (Jayathilaka et al, 2012, Gahlod et al., 2017, Jayasinghe et al, 2018, Kumar et al., 2019 and Chen et al., 2022) and local expert interviews. These evaluation criteria were classified into four main groups (soil, topography, climate and Land use) in context of how they affect tea land suitability in studies area.

Results and discussions

Reclassification Evaluation criteria for Tea Land suitability classification

The spatial land suitability of tea cultivation was obtained after the analysis of selected evaluation criteria such as soil Data (Soil pH, soil texture, drainage class, and soil depth), topographic factors (slope, altitude and aspect) and climatic factors (temperature and rainfall). Identified evaluation criteria layers were converted into raster data format based on the value of the required attributed column to form each thematic layer and reclassified according to literatures and expert level judgments (Table 3). Reclassification was used to simplify the interpretation of raster datasets by changing a single input value into a new output value. By using reclassified layers, which results in a generalization and simplification of the original dataset, the input layers were categorized based on the same ranking scheme that can be used to compare and rank the least and most suitable sites. Soil-site characteristics and Climatic /land quality criteria was reclassified based on (Gahlod et al., 2017 and Chen et al., 2022)

Table 11. Suitability criteria and class for production of tea cultivations

Parameters	Highly suitable	Moderately Suitable	Marginally suitable	Not suitable
Soil pH (H2O)	4.5-5	5.1-6 /4- 4.4	6.1-6.5/<4	>6.5/>3.5
Soil texture	Loam, Loamy sand, Sandy, Sandy loam	Clay loam, Sandy clay, Silty clay, Sandy clay loam	Clay	Clay heavy
Soil Depth	>150	100-150	100-50	<50
Drainage	Excessive to moderate	Imperfect	Poor	Very poor
Elevation (m)	< 2000	2000-2500	>2,500	
Slope (percent)	< 13	13–25	25–55	>55
Aspect	[South, southeast, southwest]	[East, west, northeast, northwest]	[North]	-
Temperature (°C)	18-25	26-28 /15-17	29-30/13-14	>30/<13
Rainfall (mm)	1800-2,000	1600-1,800	1000-1600	<1000
LULC	Tea plantation/ Forest	Cropland	Farmland	Building area/water bod

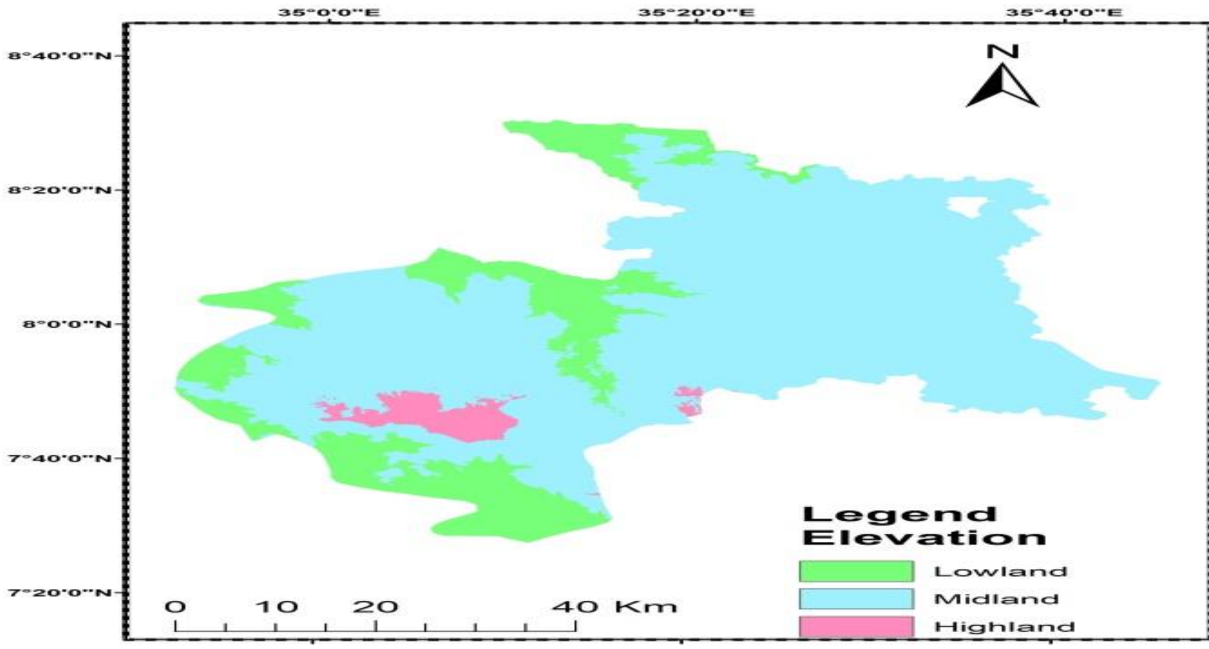
Reclassification of Topographic Characteristics of the Study Area

The unclassified elevation of the area ranges from 625 to 2605 m a.s.l distributed to lowland 102030.23ha (19.3%), midland 411208.43ha (77.77%) and 15491.89 ha (2.93 %) of the area was of highland altitude zone (Figure 3). The reclassified elevation map shows that about 79.25 and 20.6% of area has highly suitable and suitable altitude for growth tea plant. This indicated that the elevation influence tea plant growth in study the area. Elevation is one topographic feature that affects the growth, yield, and quality of tea crop performance through affecting water distribution and pedogenic process that influence soil properties in different landscape positions (Yaghmaeian et al., 2020). As elevation increases, the growth rates of tea crops especially shoot decreases that contribute towards slower growth at high altitudes. Yield and quality of black tea, particularly theaflavin and its fractions, aroma composition and water extract were positively affected by elevation which increased as elevation resulted in higher levels (Hossain et al., 2021 and Muthumani et al., 2013)

High elevations leads to higher concentrations of volatile compounds that include analgesic, antianxiety, antibacterial, anticancer, antidepressant, antifungal, anti-inflammatory, antioxidant, anti-stress, and cardio protective as compared with Low elevations. In addition, teas grown in high elevations were sweeter, floral, honey-like compounds than tea growing in low elevation (Robbat et al., 2018).

Tea is planted on elevated land slopes at 1,900-2,500 m, in addition, it is adaptive in a well-drained land at 1550 and 1800 m Rwanda (Ingabire, 2020).The unclassified slope of study the area from 0 to 169.48% that characterized by Very steep sloping (2.03%) Steep sloping (13.39%)

moderately steep sloping (33.97%), strongly sloping (31.51%), sloping to gently sloping slope (17.67%) and 1.44% of the area was very gently sloping slope.



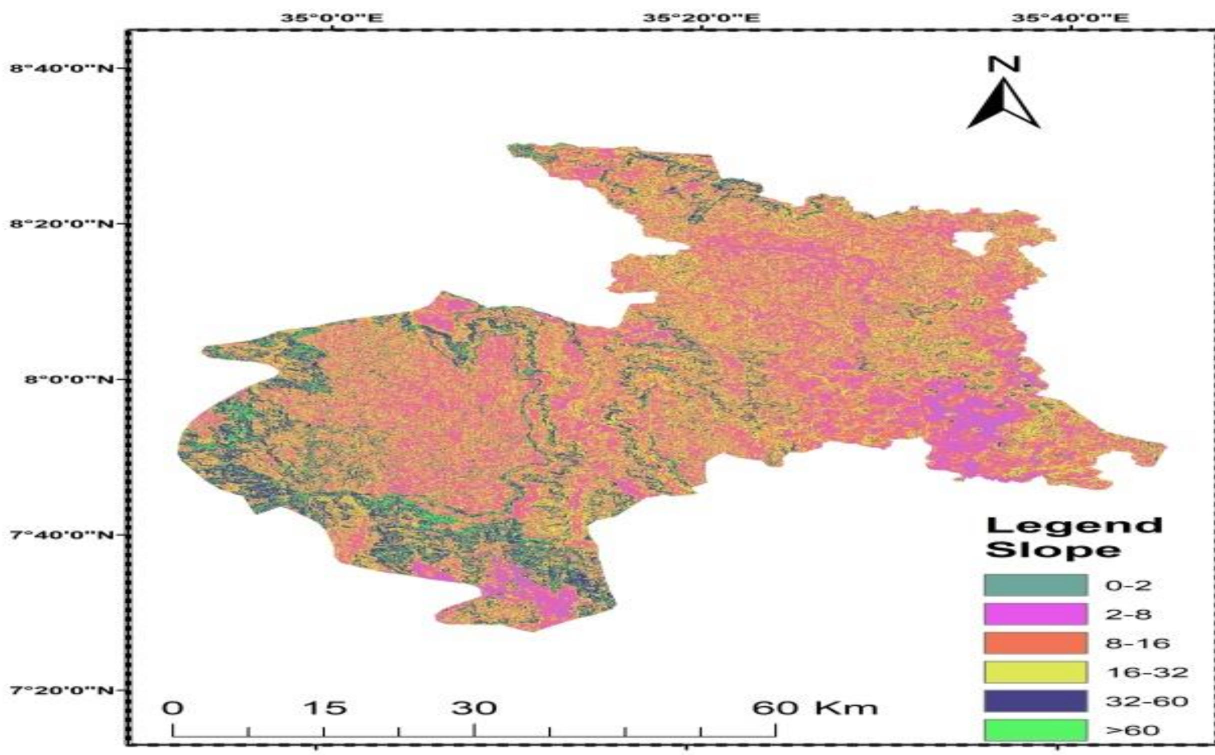


Figure 8. Elevation and slope the study area

The reclassified slope map shows that about 30.66 and 35.86 % of study the area has highly suitable and suitable slope for growth tea plant respectively (Table 4 and Figure 4). However 22.3% and 11.18 that represent less suitable and not suitable respectively affect tea plant growth significantly in study area.

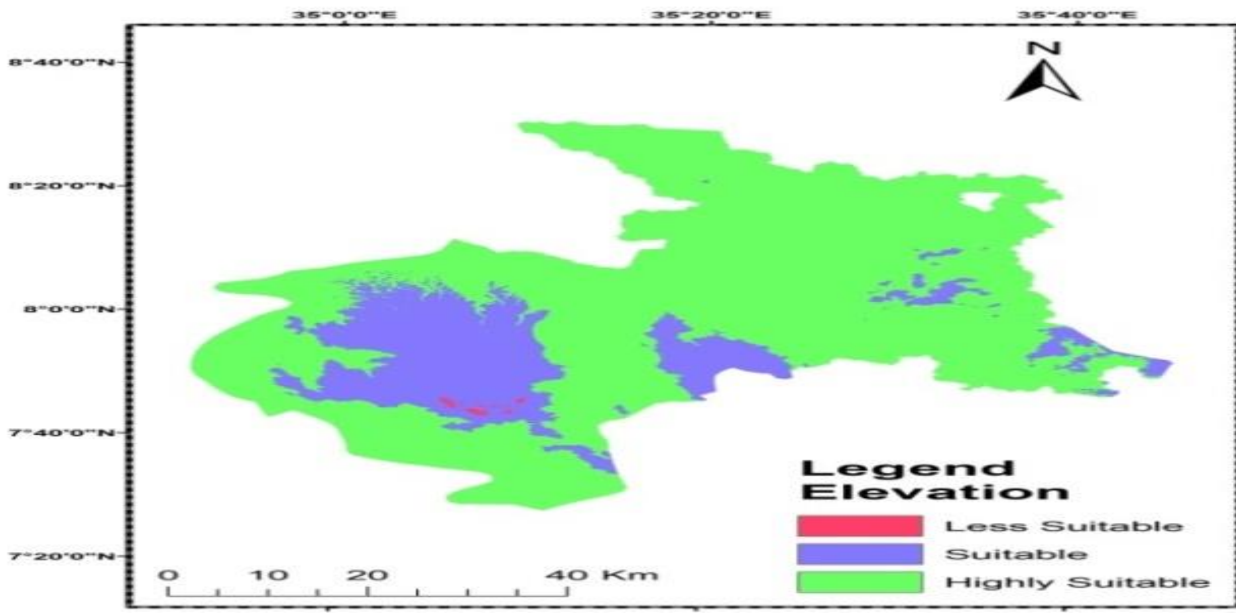
Effect of slope tea cultivation; slope affected growth and yield performance indirectly had significant effect on pedogenic process which highly affects solum thickness, thickness of the epipedons, saturated soil moisture, clay content, total N, calcium carbonate content, and exchangeable Mg.

Generally, slope affects tea cultivation through affecting physical, chemical, and morphological properties of the soil such as nutrient movement in landscape position and drainage condition of the soil which had significant on tea cultivation (Khormali et al., 2007).The slope aspect is one topographic feature affecting the growth, yield and quality of tea through affecting microclimate due to the difference in surface runoff and risk of soil erosion as well as solar radiation difference received on different aspects (Khormali et al., 2007). Aspects influence the growth, yield, and quality of tea through affecting the hydrological cycle of landform and the rate of soil forming processes, particular affecting the infiltration rate and evapotranspiration by changing the microclimate of the specific area rapid evapotranspiration on southern aspect, and high rate of soil forming processes in the north facing slopes which results in a thicker solum with higher organic matter and denser vegetation were observed due doe to slopes aspects difference (Khormali et al., 2007).

The reclassified aspects results show that about 35.56 and 52.4%, of the study the area highly suitable and suitable aspects for growth tea plant respectively. However the remaining 12.04% aspects of the area faced to North, has significant affect tea plant growth in the study the area (Table 4). Aspects are also an important indicator of land suitability as it influences drainage and soil erosion activity in specific areas.

Table 12. Suitability criteria and area coverage of elevation, slope and aspect for tea cultivation

Factors	Classification	Area (ha)	Area (%)
Elevation (m.a.s.l)	Highly suitable	419017	79.25
	Suitable	108893.30	20.60
	Less suitable	822.83	0.16
Slope (%)	Highly suitable	162102.30	30.66
	Suitable	189594.50	35.86
	Less suitable	117890.80	22.30
	Not suitable	59108.57	11.18
Aspects	Highly suitable	188004.90	35.56
	Suitable	277029.20	52.40
	Less suitable	63652.04	12.04



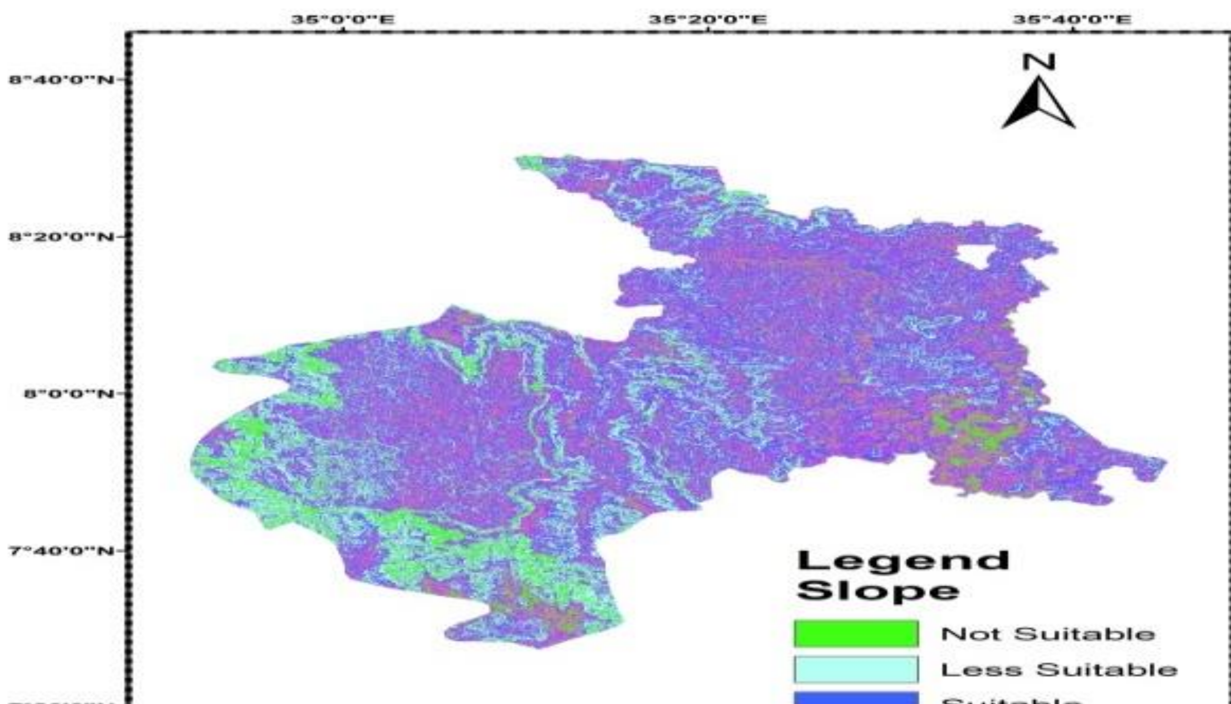
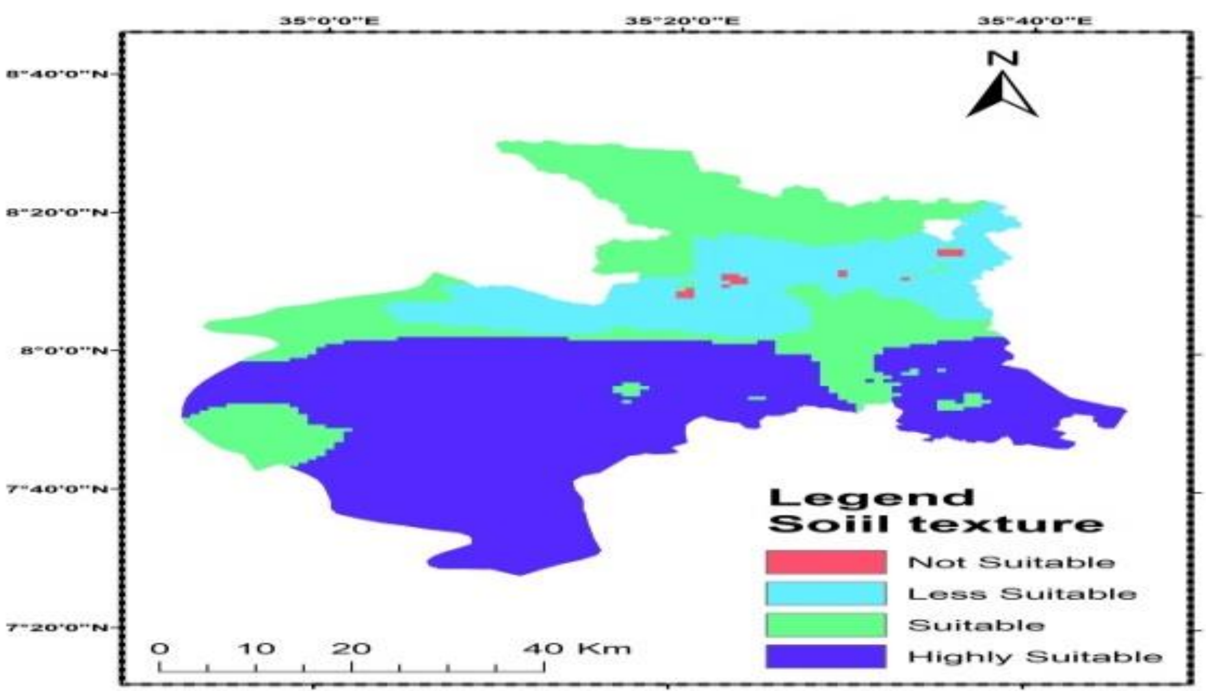


Figure 9. Elevation and slope suitability maps

Soil Factors Reclassification

The unclassified Soil pH of Studies area ranges from 4.0 to 5.32 and the reclassified Soil pH map shows that about 55.96 and 44.04% of Studies area has highly suitable and suitable Soil pH for tea plant growth (Table 5 and Figure 4). This indicated that soil pH is the most important factors affect tea plant growth in Studies area. Generally, tea plants require acid soils with soil pH range 4.5-5.5 for growing better (Jayathilaka et al., 2012 and Gahlod, et al., 2017).The unclassified soil texture of the Studies area ranges from medium texture class to Heavy texture class and the reclassified soil texture map shows that about 41.36 and 40.27% of Studies area had highly suitable and suitable soil texture class for growth tea plant where as 18.01% area were occupied by marginally suitable class of suitability (Table 5 and Figure 5). This indicated that the soil texture had significant effect on tea plant growth in the studies area. Soil texture such as loam, sand, loamy, sandy clay loam, and clay loam are highly suitable for tea production, whereas clay, silty clay, and silty clay loam are considered as Moderately Suitable for tea cultivation (Gahlod et al., 2017 and DENGİZ et al., 2018).



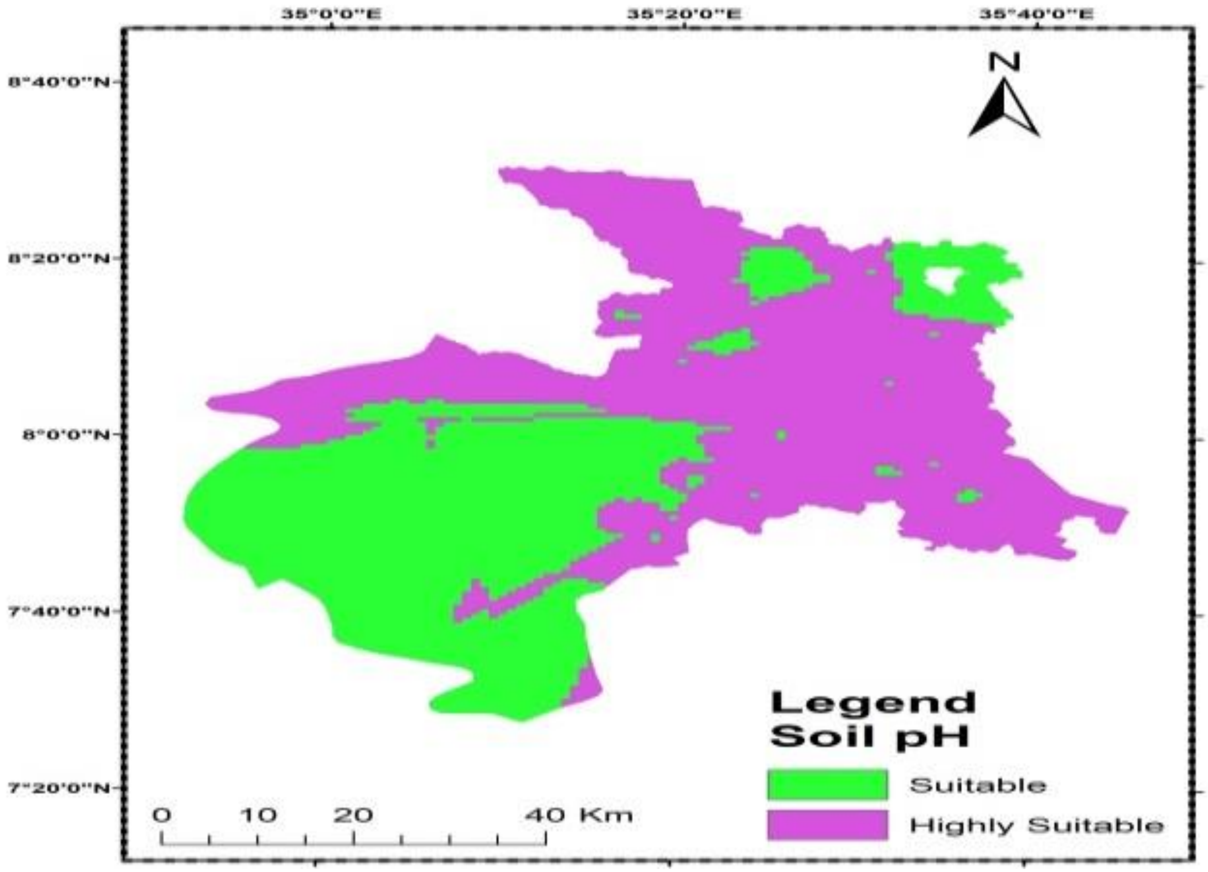
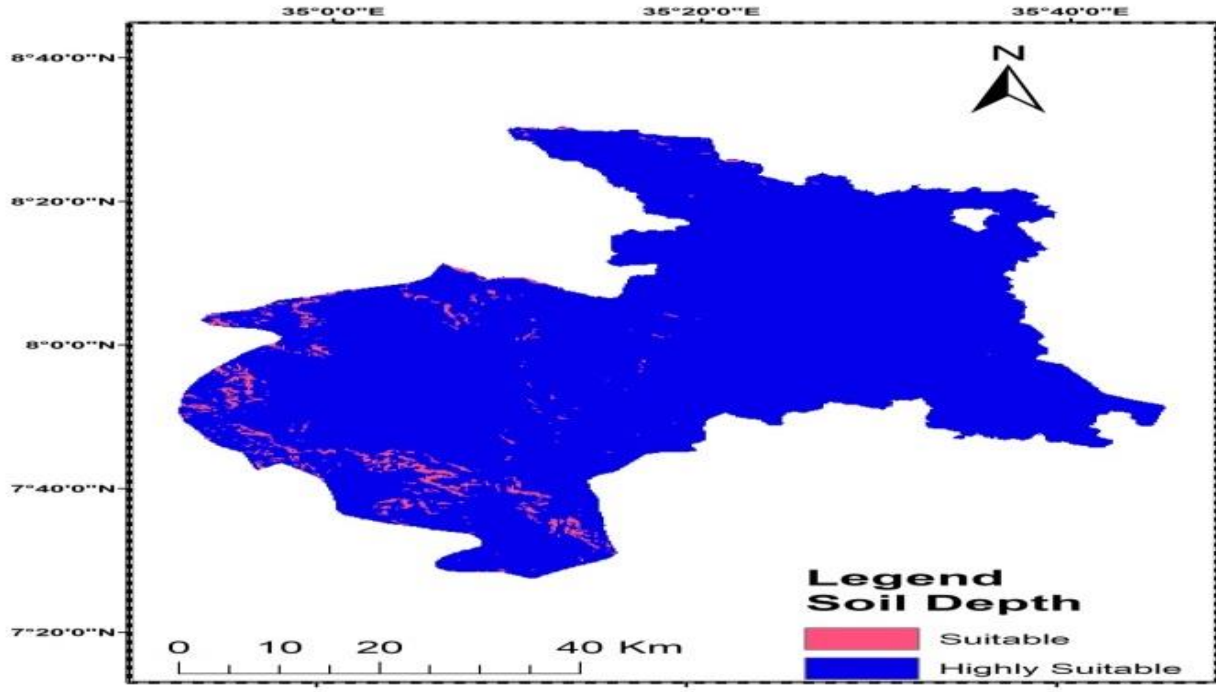


Figure 10: Soil Texture and pH suitability Map

The unclassified drainage class of the studies area ranges from well drainage class to poorly drained class and the reclassified Drainage class map shows that about 80.94 and 14.84% of the studies area has highly suitable and suitable Drainage class for growth tea plant (Table 5 and Figure 6). This indicated that the drainage class limits tea plant growth in the studies area significantly. However poorly drained drainage class occupied only 4.23% of the studies area. Tea is grown in well-drained soil drainage class, deep and well-aerated soil with more than 2% organic matter is the optimum soil condition soil for tea growing (Gahlod et al., 2017).

The unclassified soil depths of the study area ranges from very deep to deep depths of less than 107 cm and the reclassified drainage class map shows that about 97.88 and 2.22% of the studies area has highly suitable and suitable soil depths for growth tea plant (Table 5 and Figure 6). This indicated that the soil depth does not limit tea plant growth in the study area significantly. Soil depths of less than 50 cm, soil gravel of more than 50% in top 50 cm of the soil layer and a rockiness of 20% negatively affect tea growth. Tea cultivations do not tolerate prolonged flooding or poorly drained clay soils. This tree grows in a variety of soil types and conditions from fine drained sandy loam soils to heavier clay loam soils. Well-drained to moderately drained soils, deep and well-aerated soil were recommended as optimum soil conditions for tea growth (Hajiboland, 2017 and DENGİZ et al., 2018).



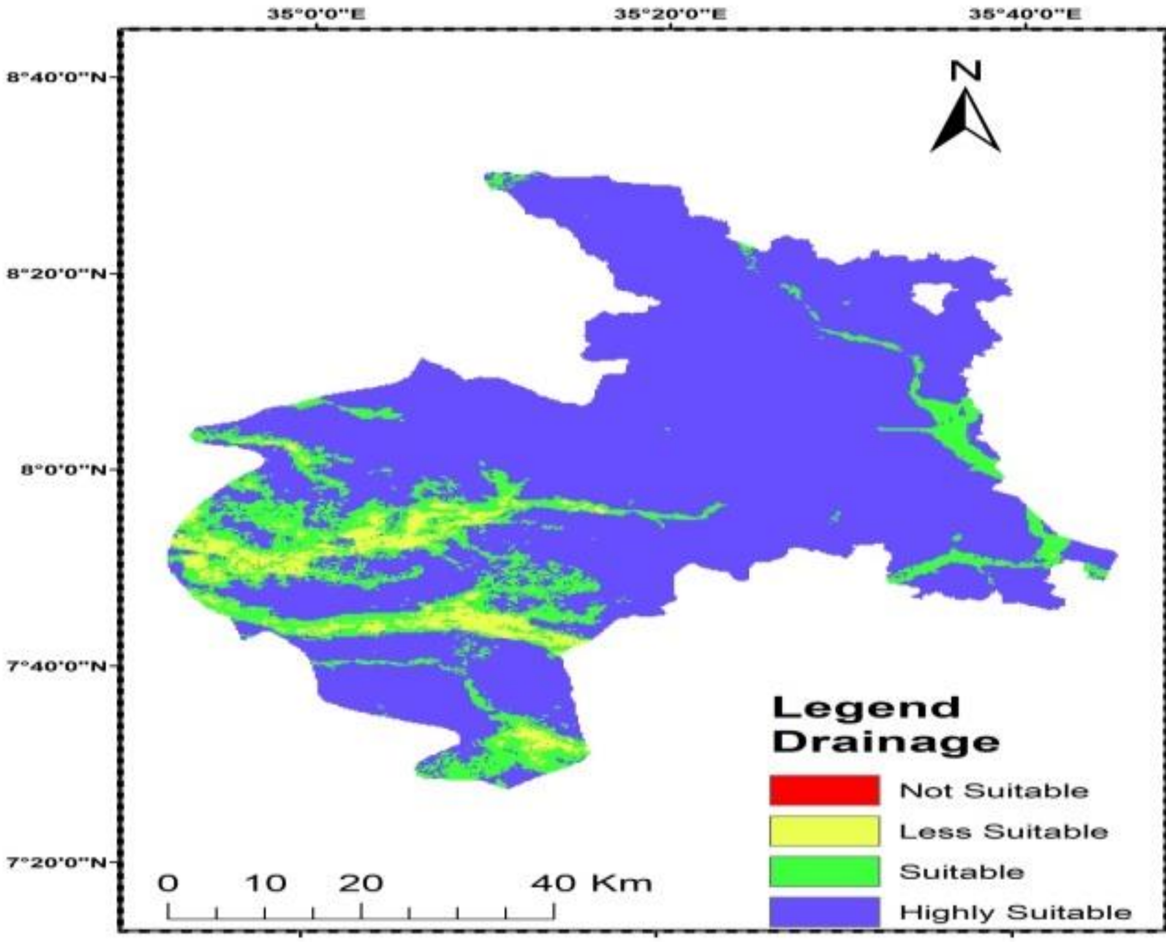


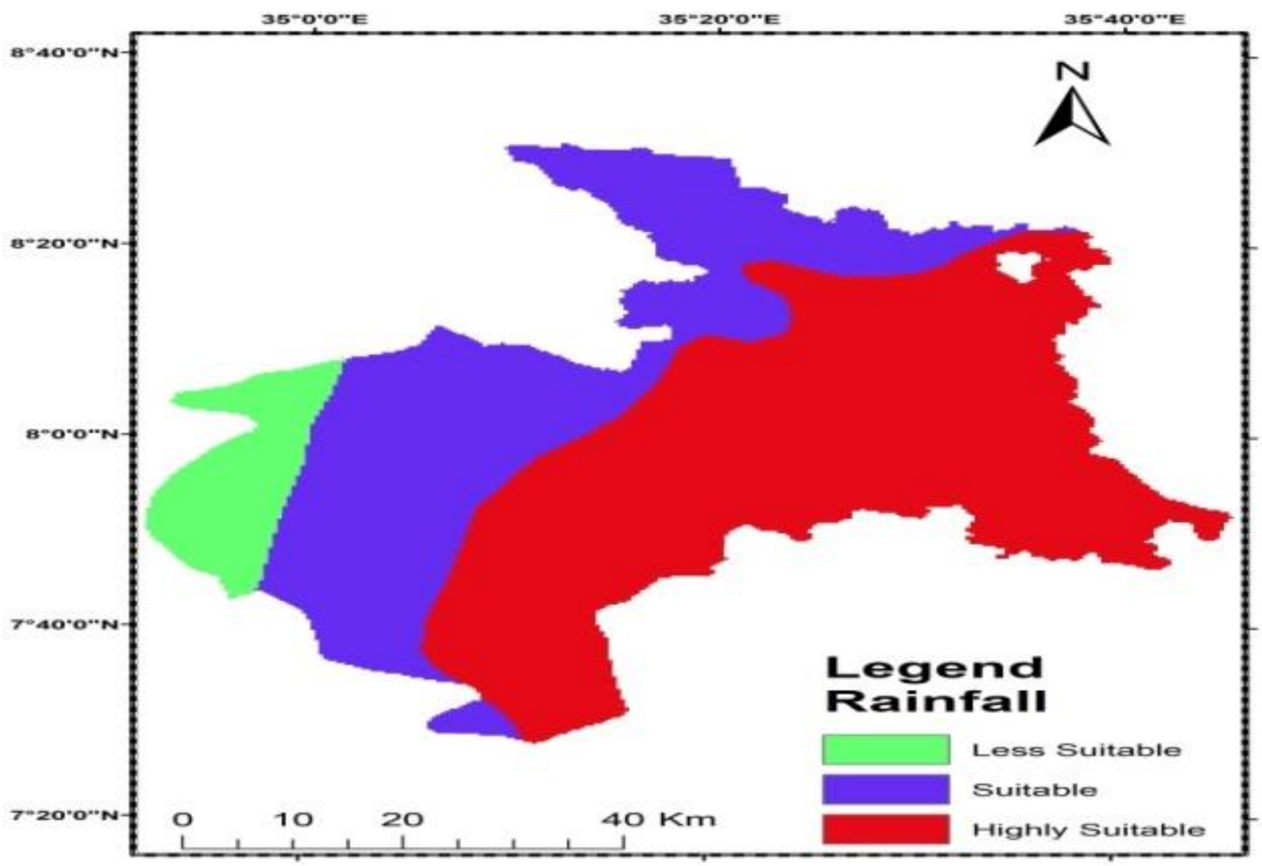
Figure 11. Soil Drainage class and Depth Suitability map

Table 13. Suitability criteria and coverage of soil pH, Depth, Texture and Drainage for tea cultivation

Factors	Classification	Area (ha)	Area (%)
Soil pH	Highly suitable	295880.5873	55.96091
	Suitable	232846.67	44.04
Soil Depth	Highly suitable	517448.6617	97.87898
	Suitable	11208.82	2.12
Soil Texture	Highly suitable	218691.02	41.36
	Suitable	212919.85	40.27
	Less suitable	95202.73	18.01
	Not suitable	1913.94	0.36
Drainage	Highly suitable	427775.4	80.94
	Suitable	78438.28	14.84
	Less suitable	22357.72	4.23
	Not suitable	8.56	0.00

Climatic Parameters Reclassification

The unclassified annual rainfall of the basin ranges from 1353.8 to 2126.95 mm pear year and the reclassified annual rainfall map shows that 55.71 and 36.1% of the studies area has highly suitable and suitable annual rainfall class for growth tea plant of the studies area (Table 6 and Figure 7). However, less suitable annual rainfall class occupied only 7.78% of the studies area.; This indicated that the annual rainfall limit tea plant growth in the studies area as the studies area receive highly suitable annual rainfall for tea plant growth. The unclassified mean temperature of the area ranges from 19.67 to 25.68°C and the reclassified mean temperature map shows that about 100% of the area has highly suitable mean temperature for tea plant growth (Table 6 and Figure 7). This indicated that the mean temperature does not limit tea plant growth in studies area as receive highly Suitable mean temperature for tea growth.



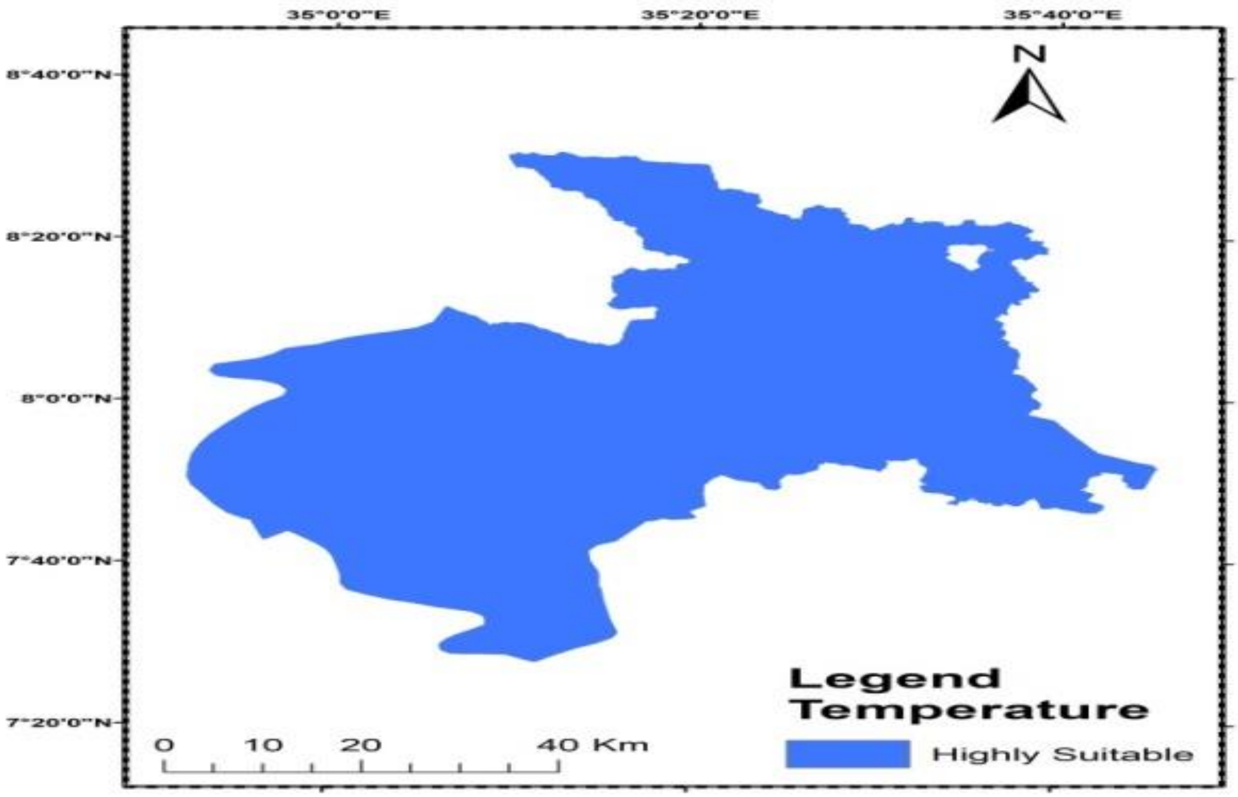


Figure 12: Rainfall and temperature suitability map

Its specific requirements are: temperatures ranging from 13-30oC, minimum annual precipitation of 1250 mm (FAO, 2015). Tea plant requires well-distributed rainfall and the optimum mean temperature in the range of 18 to 30 0C that receive an annual rainfall of at least 1200 mm per year (Hajiboland, 2017 and Kariuki et al., 2022).The tea plant requires a minimum rainfall of 1200mmper year, but 2500-3000mmper years are considered optimum (Hajiboland, 2017 and Jayasinghe et al., 2019)

Table 14. Suitability criteria and area coverage of Rainfall and Temperature for Tea cultivation

Factors	Classification	Area (ha)	Area (%)
Annual rainfall (mm)	Highly suitable	294574.90	55.71
	Suitable	192999.70	36.50
	Less suitable	41151.55	7.78
Mean annual temperature (°C)	Highly suitable	528726.20	100

Land Use/Land Cover Parameter Reclassification

Land use types are an important factor that affects physical land suitability of tea cultivation. Tea can grow in forest land, shrubs lands, crop land, and grass land. According to (Chen et al.,2022), Tea plantation, forest, farmland lands are the optimal land use types for tea cultivations, whereas building land and water body are not suitable for tea cultivation. Existing tea-growing areas, crop lands, grass land, and forest lands are appropriate land use for tea and urban, rock, bare land, open water, wet lands, paddy, and road were not appropriate land use for tea cultivation (Jayasinghe et al., 2019).

The land use land cover of the study area was classified as forest, crops land, range land, Built Area and water bodies' area (Table 7 and Figure 8). Current existing land use map of the basin was used to assess the condition of restricted land use for tea growing. Therefore, the existing land use classes were classified as "1" which possible and appropriate land use classes for tea such as existing tea-growing areas, crop land, tree cover and range land use, and "0" was where tea could not be grown (Built Area, bare land, water bodies, and seasonally flooded vegetation). The newly developed land use restriction map was overlaid with the rasterized suitability map. The results of land use land cover suitability analysis indicated that about 526387.4ha which is the largest part of the current land use of the study area was suitable (99.56%) for tea cultivation. Meanwhile, the remaining 0.44% was not suitable for tea cultivation due to restricted land use condition that was not suitable of for tea growing.

Table 15. Suitability criteria and area coverage of LULC for Tea cultivation

Factor	LULC Type	Classification	Area (ha)	Area (%)
LULC	Forest, Cropland, Rangeland	Suitable	526387.4	99.56
	Built Area, bare lands, water bodies and wet land	Not suitable	2335.38	0.44

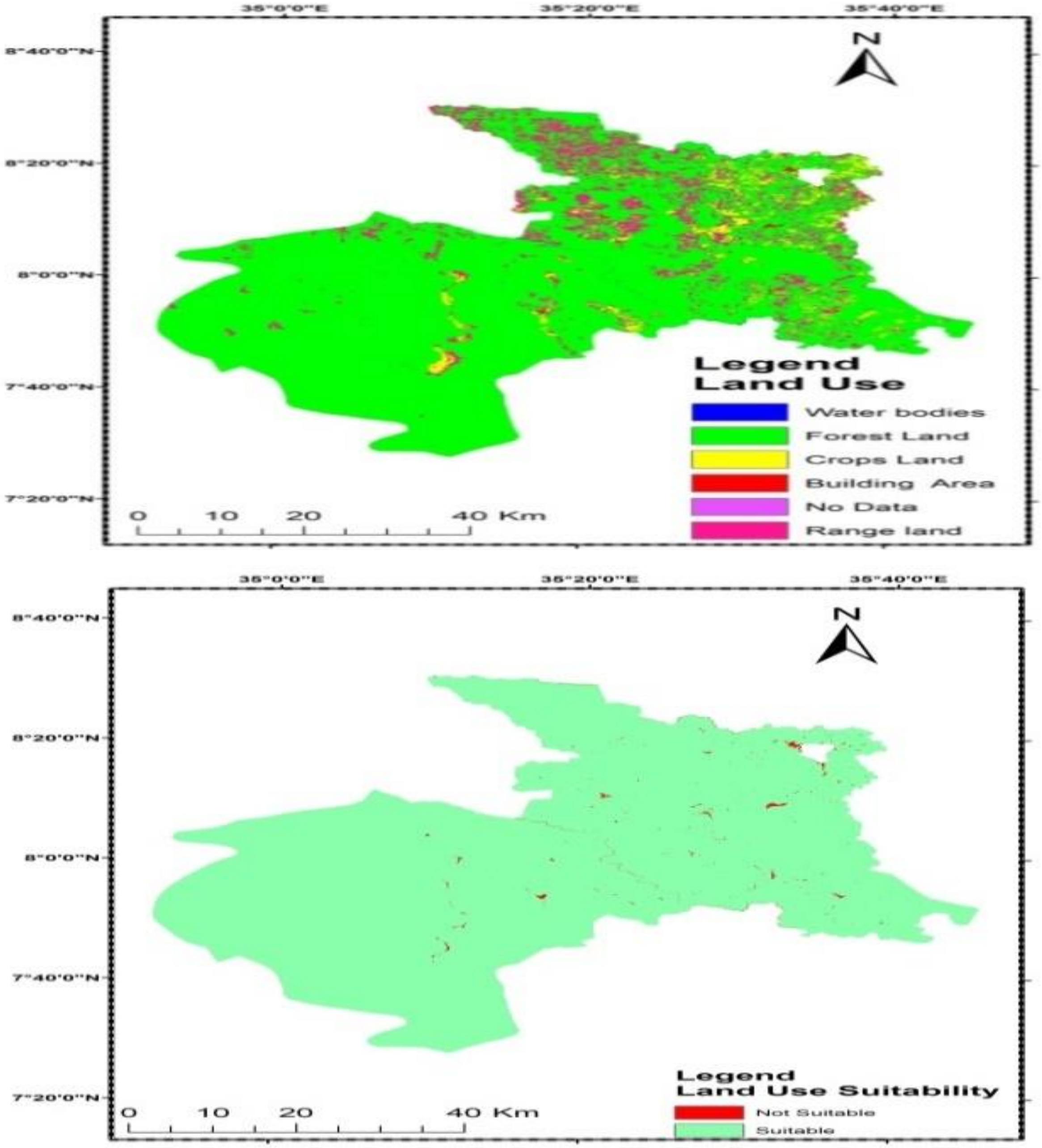


Figure 7: Land use, land cover, and Land suitability map

Criteria Weights

In this study, the weights for selected parameters/factors were derived using AHP model. Relative importance of factors that affect the growth of tea plants was assigned in pairwise comparison matrix. In the matrix above, diagonal values were assigned in comparison with the column parameters. The values of each parameter were given in accordance with the parameter effect on the growth and productivity of tea plants. Below diagonal values of each parameter are the reciprocal of the above diagonal. After assigning the relative importance values of the above diagonal and the reciprocal of the above diagonal matrix, normalization of each cell value was done (Table 8).

Table 16. Analytical Hierarchical Process Comparison Matrix

Criteria	pH	Tem	Rain	Slope	Altitude	Drainage	Depth	Texture	Aspect	LULC
Soil pH	1.00	1.00	0.33	0.33	1.00	1.00	3.00	0.33	0.33	0.33
Temp	1.00	1.00	1.00	0.33	0.33	1.00	1.00	0.20	0.33	0.33
Rain	3.00	1.00	1.00	5.00	1.00	3.00	3.00	0.33	1.00	1.00
Slope	3.00	3.00	0.20	1.00	0.33	3.00	3.00	1.00	0.33	0.33
Altitude	1.00	3.00	1.00	3.00	1.00	3.00	3.00	0.33	1.00	1.00
Drainage	1.00	1.00	0.33	0.33	0.33	1.00	3.00	0.33	0.33	0.33
Depth	0.33	1.00	0.33	0.33	0.33	0.33	1.00	0.33	0.33	0.33
Texture	3.00	5.00	3.00	1.00	3.00	3.00	3.00	1.00	3.00	3.00
Aspect	3.00	3.00	1.00	3.00	1.00	3.00	3.00	0.33	1.00	1.00
LULC	3.00	3.00	1.00	3.00	1.00	3.00	3.00	0.33	1.00	1.00
Sum	19.30	22.00	9.19	17.32	9.32	21.33	26.00	4.51	8.65	8.65

Normalization can be computed by dividing each cell value by the column total of each parameter. Normalization of the parameters values was performed to generate criteria weights for each parameter. Criteria of each parameter were obtained by summing up the row values of each cell. Consistency ratio of all parameters was computed to check whether the calculated value is correct or not correct. Values of consistency ratio exceeding 0.10 are indicative of inconsistent judgments; whereas values of 0.10 or less indicate a reasonable level of consistency in the pairwise comparison. In this case, the computed CR is 0.083 and this indicates a reasonable level of consistency in the matrix (Table 9).

According to the criteria weight, soil parameter is the paramount importance for tea plant growth performance, soil texture has the highest significance indicator value followed by Rainfall, elevation, land use land cover, aspect and slope, indicating that these are the most important criteria for the land suitability assessment for tea in the study area, however the relatively lowest position was indicated by Temperature, soil drainage class and soils depth for the land suitability assessment for tea in the area. Final criteria weights were achieved by calculating each criterion's weight by models as indicated in Table 10 and applied to the land-use suitability for tea crops. Soils texture (22.23) and Rain fall (13.43%) were highly contributed to the land suitability evaluation than other criteria followed by land use land cover (12.63%), Aspect (12.63%) elevations (11.65%).

The least impact on the evaluation of land suitability for tea was soil pH (5.44%) drainage class (4.74%) and Temperature (4.65%), while slope (9.13%) had an intermediate influence on tea land suitability predictions based on the results of normalized matrix assessment on relative importance of climate, soil, and topography parameters.

Table 17. Analytical Hierarchical Process (AHP) analysis for the assessment of the relative importance of climate, soil, and topography parameters; normalized matrix results

Criteria	pH	Temp	Rain	Slope	Altitude	Drain	Depth	Texture	Aspect	LU	Total	Weight
Soil pH	0.05	0.05	0.04	0.02	0.11	0.05	0.12	0.07	0.04	0.04	0.59	5.44
Temp	0.05	0.05	0.11	0.02	0.04	0.05	0.04	0.04	0.04	0.04	0.48	4.65
Rain	0.16	0.05	0.11	0.29	0.11	0.14	0.12	0.07	0.12	0.12	1.29	13.43
Slope	0.16	0.14	0.02	0.06	0.04	0.14	0.12	0.22	0.04	0.04	0.98	9.13
Altitude	0.05	0.14	0.11	0.17	0.11	0.14	0.12	0.07	0.12	0.12	1.15	11.65
Drain	0.05	0.05	0.04	0.02	0.04	0.05	0.12	0.07	0.04	0.04	0.52	4.74
Depth	0.02	0.05	0.04	0.02	0.04	0.02	0.04	0.07	0.04	0.04	0.38	3.49
Texture	0.16	0.23	0.33	0.06	0.32	0.14	0.12	0.22	0.35	0.35	2.28	22.23
Aspect	0.16	0.14	0.11	0.17	0.11	0.14	0.12	0.07	0.12	0.12	1.26	12.63
LU	0.16	0.14	0.11	0.17	0.11	0.14	0.12	0.07	0.12	0.12	1.26	12.63

Eigenvalue (λmax) = 11.093, Consistency Index (CI) = 0.12, Consistency Ratio (CR) = 0.082

Land suitable for Tea

Land Suitability for tea in the study area comprises highly suitable, suitable, less suitable and not suitable (Table 10 and Figure 8).The analysis of the final weighed results indicated that study area had potential land for tea cultivation as the majority part of the land in the study area (99.2%) is occupied by suitable class of suitability in which, about 363390.30ha (68.73%) suitable followed by 161109.92ha (30.47%) highly suitable of land for tea cultivation in this area.

The rest of study area land 1720.50 ha (0.33) and 2500.77 ha (0.47) occupied with less suitable and not suitable respectively. Most of the suitable lands found in Southeast part of the study area this is maybe due to optimum soil conditions; to optimum rainfall, appropriate slope aspect and to optimum elevations. Land not suitable for tea mostly consecrated north parts of the study area particularly in Metu and Ale districts, which indicated that soils, Climate and topographic factors particularly soil textures, rainfall, Land use and elevation were significantly affect tea cultivation in this area. Soil texture, annual rainfall, altitude, aspect and land use land cover were identified in the study area as the main limitation factors for tea productions. Altitude has the greatest positive value of relationship indicator, which means that it has a dominating, causal influence on the other criteria. According to the relationship indicators (Table 9) annual rainfall, altitude, aspect, land use land cover and slope belong to the cause group, and have a significant influence over the criteria of temperatures, soil drainage, and depth, soil pH and soil texture. Altitude, in fact influences temperature, and present land use land cover of the study area.

Table 18. Land Suitability class and area coverage of the study area for tea cultivation

Suitability class	Area (ha)	Area (%)
Highly suitable	161109.92	30.47
Suitable	363390.30	68.73
Less suitable	1720.50	0.33
Not suitable	2500.77	0.47

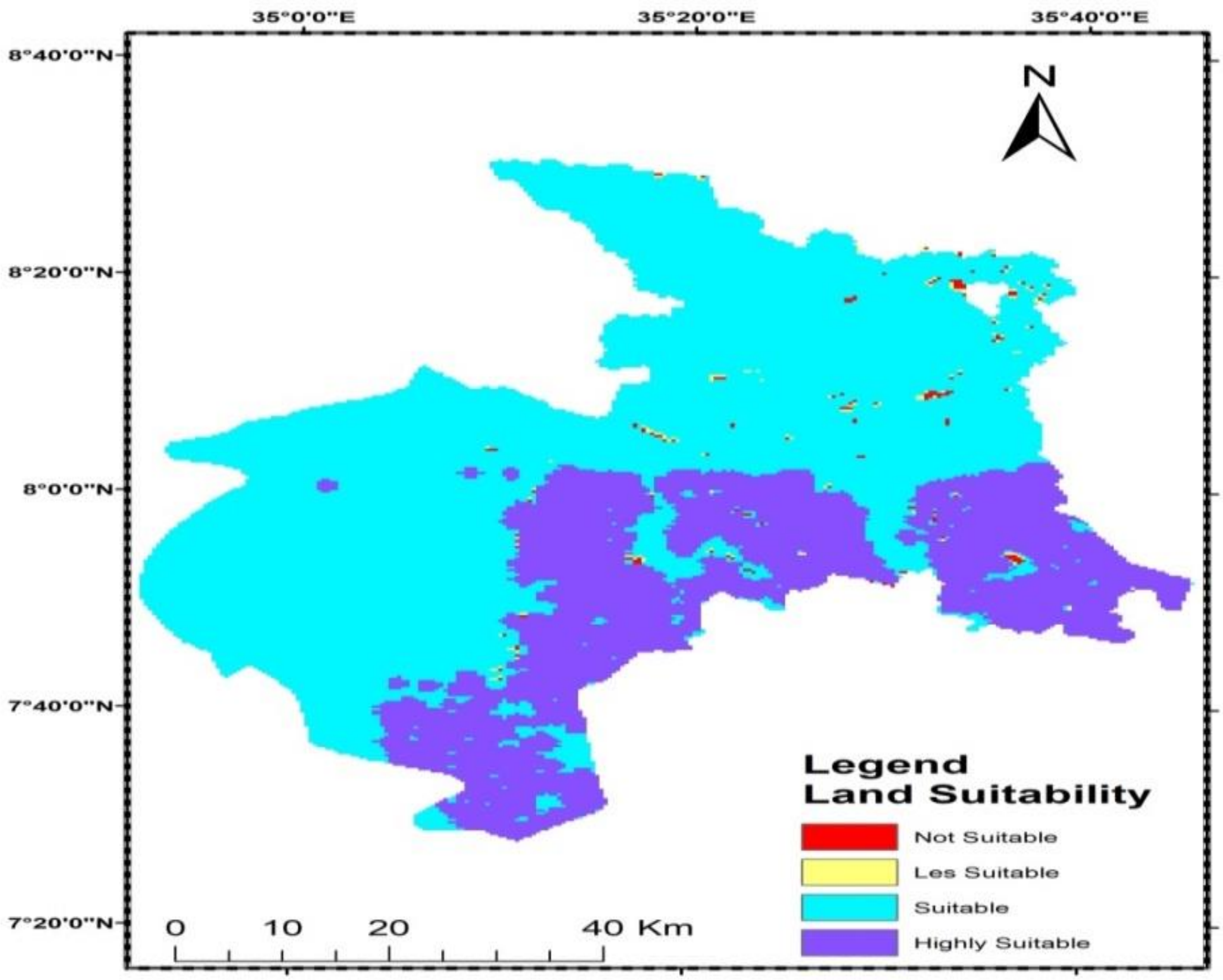


Figure 8: Final Land suitability map for tea cultivation

Conclusion and recommendation

Based on GIS and Analytic Hierarchy Process (AHP) modeling-based approach decision making for sustainable tea production in the study area and offers an opportunity to increase tea production planning by providing basic required information for farmers and agricultural planners. Introducing tea plantations for investment at large scale or small farm were possible and economically profitable as that studies area has great potential for tea plants production especially well-distributed rainfall and the optimum mean temperature for tea plants production.

The fact that this study was restricted to only one crop, it is recommended that future studies apply the analysis method used in this study to develop land suitability maps for other horticultural crops. It is further recommended that field trials can be set up in the various suitability classes as identified in the study.

Appropriate land use management is recommended by modifying the current land-use pattern according to its suitability by introducing alternative income generation mechanism could help the poor farmers who are totally depend on fragmented small land for their daily life.

Introducing tea plantations for investment at large scale or small farmers especially in the Studies area as acid tolerance crops to increase income of poor farmers who are totally depend on small land for their daily life. Expansion of tea plantations in the area highly recommended as soil acidity were sever problem that limited crop productions for alternative income generation mechanism.

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5. Land Suitability Evaluation for Tea Cultivation using Geographic's Information System (GIS) and analytical hierarchical process (AHP) in Selected Districts of Jima Zone, Southwest Ethiopia

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Abstract

Predicting the physical land suitability of tea is vital to avoid a sightless expansion of tea plantations and significant to recognize the potential suitable area for tea to disseminate of tea plantations in the country Land suitability analysis is a basic premise for allocating specific land for specific purposes. The study integrates applications of geographic information system, remote sensing, and analytical hierarchical process model to assign suitability weights to criteria that affect the tea plant's growth and produce a predictive suitability map for its cultivation. Topographic, Soils, climatic and land use land cover features were considered in the model as an important contributing factor for tea plant's growth. Each of the evaluations criteria layers were classified into four suitability class (not suitable, less suitable, suitable, and highly suitable) based on the revived literature and expert level judgment. The Analytical Hierarchical Process indicated that Soils texture (22.23), rainfall (13.43%) was highly contributed to the land suitability evaluation than other criteria followed by land use land cover (12.63%), Aspect (12.63%) elevations (11.65%). The least impact on the evaluation of land suitability for tea was soil pH (5.44%) drainage class (4.74%) and Temperature (4.65%), while Slope (9.13%) had an intermediate influence on tea land suitability predictions. Studies area has great potential for tea plants production. From the generated land suitability map, results showed that 94.5% of the total area was rated suitable for tea production, of which 1.66 % was rated highly suitable, 92.78% was rated suitable and 0.06% was rated marginally suitable. The findings further showed that only 5.54% of the area was not suitable for tea plant production. Soil Texture, rainfall, Elevation and aspect were the main limiting factors for growing tea in the studies area as identified in the land capability analysis. Therefore, Expansion of tea plantations is recommended in the area were for investment at large scale or small farm level as soil acidity were sever problem that limited other crop productions for alternative income generation mechanism.

Keywords: Tea cultivation, Land suitability evaluation, GIS, analytical hierarchy process

Introduction

Tea (Camellia sinensis L.O. Kuntze) is a perennial evergreen shrub and a high-value added cash crop, and it is renowned for its nutritional, medicinal, antimicrobial, and anticancer properties worldwide (Chen et al., 2022 and Feng et al., 2019). Discovered about 2700 B.C, it is one of the oldest beverages in the world today and it is available for consumption in six main varieties, based on the oxidization and fermentation techniques applied (Hajiboland, 2017 and FAO, 2015). Tea is one of the most popular and lowest cost beverages in the world, and consumed by a wide range of age groups in all levels of society with more than three billion cups daily worldwide (Kidanu et al., 2020).

The tea crop has rather specific agro-climatic requirements that are only available in tropical and subtropical climates because it needs a hot, moist climate. Tea requires a well-distributed minimum rainfall ranging from 1200mm to 2200mm that is well distributed throughout the year, and temperatures' ranging from 13ºC to 30ºC is optimum (Chen et al., 2022, Hajiboland, 2017, Kariuki, et al., 2017 Gahlod et al., 2017 and FAO, 2015). Elevations, slope and aspect are the most critical topographic factors for tea growth and chemical compositions as they influence microclimate that control water availability and soils drainage conditions. The tea plant requires gentle slope, ranging 5-10 Degree or 13-25% slopes and elevations of 1500 to 2250m for optimum growth (Hajiboland, 2017, Kariuki, et al., 2022 Gahlod et al., 2017 and Kamunya et al., 2019). Tea plant requires soil having optimum soils drainage conditions and Soil pH 4.5-5.6 for the most favorable for growth (Hajiboland, 2017 and Kariuki et al., 2022)

Soil texture like sandy is significantly limited tea plant growth due to low water retention, low resistance to soil erosion, and insufficient nutrient were as clay loam, loamy clay and sandy clay loam are moderate soil texture for tea cultivation (Gahlod et al., 2017 and DENGİZ et al., 2018). Tea was introduced to Ethiopia around 1928 by British missioners in Gore area of Gumaro which is the oldest tea farm in the southwest Ethiopia (Ahmed, 2022). Ethiopia has 6 million hectares of land suitable for tea production, particularly the western part of country: however, up to date, only 2660 ha of land have been devoted to tea plantations (Erge et al., 2021).

Tea planting at wush wush Plantation at altitudinal average 1900m above sea level, rainfall is 1820mm and the minimum and maximum temperature is 12 and 240c respectively. Gumaro tea plantation is located at an altitude of 1718m above sea level and rainfall of 2089mm. The minimum and maximum temperature is 12 and 240c respectively (Kidanu et al., 2020). Despite the importance of tea production in Ethiopia, there is lack of basic information on tea cultivation land suitability which is vital to avoid a sightless expansion of tea plantations and significant to recognize the potential suitable area for tea plantations to disseminate of tea plantations in the country. Generally executed by examining natural and human factors, such as climatic conditions, topography conditions, and soil physical-chemical properties in response to the crop requirements for growth and production up to the extent of land unit quality which matches the necessity of a specific land use that influences tea cultivation to evaluate the potential and

limitations of particular land use (Gahlod et al., 2017 and Chen et al., 2022). GIS and Analytic Hierarchy Process (AHP) modeling-based approach is important for Physical Land Suitability Evaluation analysis for agricultural production. It enables all factors affecting land suitability to be considered and weighted under one umbrella to resolve highly complex decision-making problems involving multiple factors in suitability analysis for agricultural production and that enable all factors affecting land suitability to be considered (Saaty, 2008 and Goepel, 2013). The objective of this study was to assess Physical Land Suitability Evaluation for tea production cultivation using GIS and analytical hierarchical process in Jimma Zone, Oromia Region, Southwest Ethiopia.

Materials and methods

Study area

The Studies was conducted in five districts of Jimma Zone, Oromia Region, Southwest Ethiopia. The selected districts covered about 441430.74 hectares of land. It includes: Gomma, Gera, Manna, Seka Chakorsa and Shebe Sombo districts. The Studies area location were extent from West to East is 35.909° to 36.879° east and south to north is 7.335° to 8.061° north (Figure 1). The mean annual temperature of basin was ranged from 17.20 to 18.97°C and receives annual rainfall of 1309 to 1845mm.

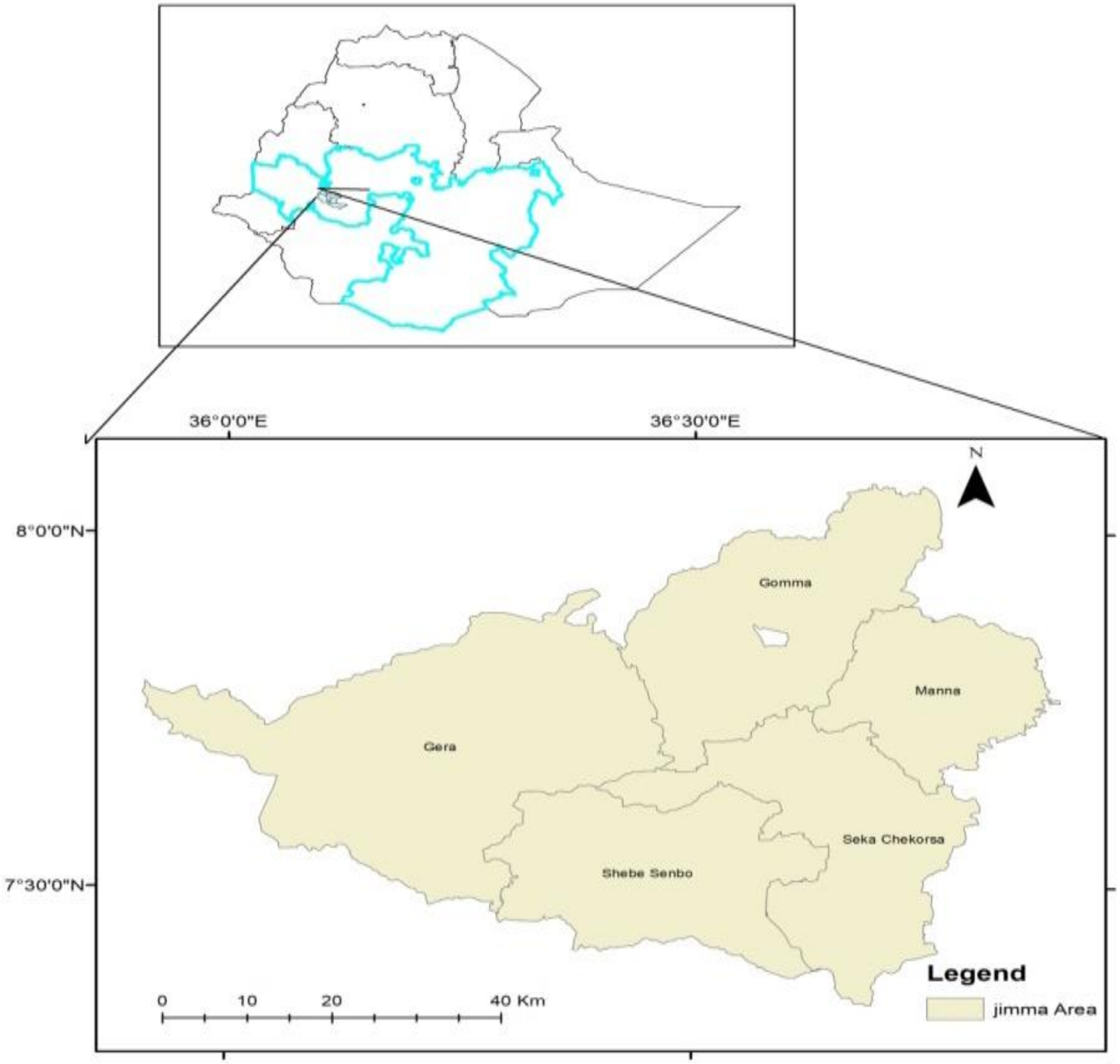


Figure 13: Study Area

Data Source

To predict physical land suitability evaluation for tea cultivation using GIS and analytical hierarchical process in the Gomma, Gera, Manna, Seka Chakorsa and Shebe Sombo districts. Dataset was obtained from primary and secondary data sources. High resolution climate data of mean temperature and annual precipitation data used in this study were obtained from the World Climate Data with a spatial resolution of 30 s (~1 km2) and they represent the average monthly climate data of the year 2011-2020 were downloaded from the world climate website (www.worldclim.org) (Karra et al., 2021).

Digital evaluation models of the study area were used as sources of for topographic features (Elevation, aspect, and Slope), Soil data (soil texture and soil pH) was obtained from laboratory, Drainage and soil depth data was extracted from ISRIC Gird250m 2017. Land use and land cover of 2021 with 10m spatial resolution was obtained from ESRI 2021 (https://www.esri.com) used to produce the final land suitability map for tea. All raster layers used in this study were projected into WGS_1984_UTM_Zone_37N projection system. Climate data used in this study were obtained from the World Climate Data with a spatial resolution of 30 s (~1 km2) and they represent the average monthly climate data of the year 2011-2020.

Data Setting

In this study, a tea cultivation site selection model was developed based on the spatial analysis of multi-criteria decision making analysis. The process modeling has been done with the application of both spatial data and expert level opinions of decision makers in the integration of data and relationships between criteria. GIS has good ability for managing, manipulating, and analysis of spatial data, while AHP model-based multi criteria decision analyses were used for preparing a methodology for assessing and ranking decisions for tea cultivation site selection model development. Setting all of the criteria and their interrelationships is a crucial decision for developing an accurate model for the identification of suitable sites. The methodology and steps of applying AHP MCDA model for tea cultivation suitable site selection are presented in figure 2.

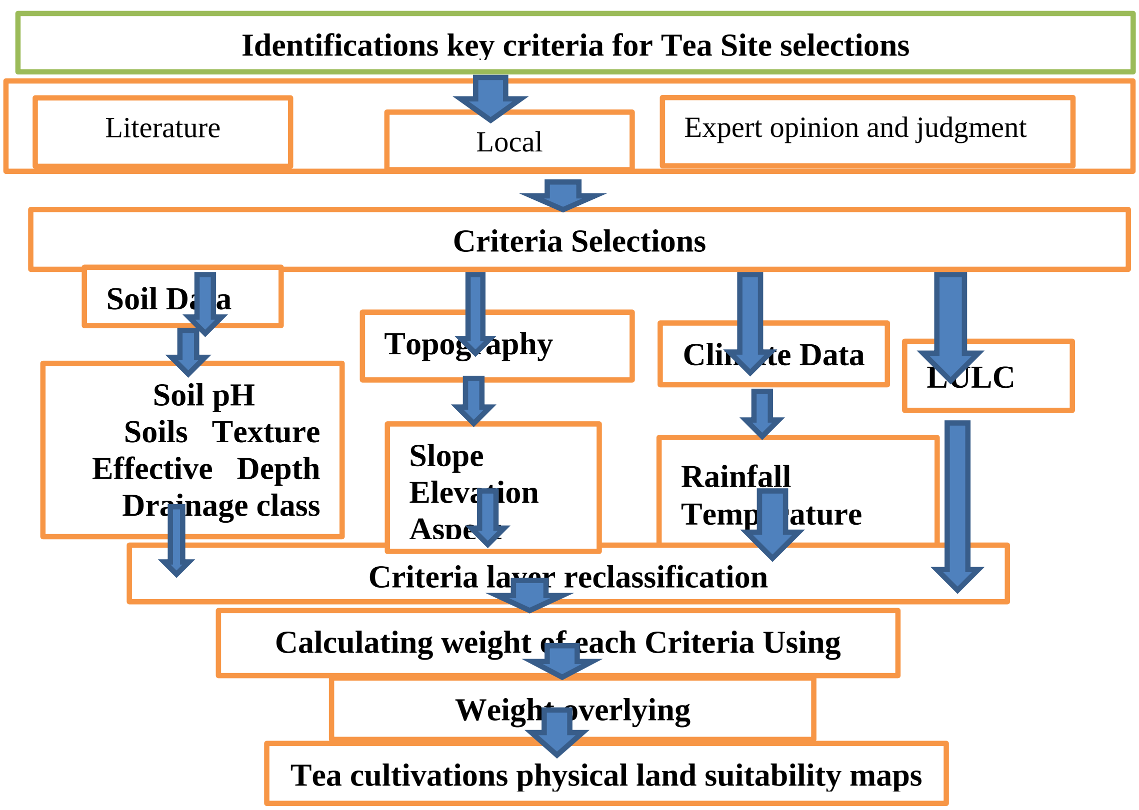


Figure 14: Flow chart of the methodology for the identification of tea cultivation.

Data Analysis

Methodology: AHP and GIS based agricultural land suitability analysis

The AHP is a mathematical method that may be applied to resolve highly complex decision-making problems involving multiple scenarios, criteria, and factors (Saaty 2000). The AHP is a powerful and flexible decision-making process to help people set priorities and make the best decision when both quantitative and qualitative aspects of decisions need to be considered (Weerakoon 2014). The AHP applies to the decision problem after it is structured hierarchically at different levels, each level consisting of a finite number of elements (Srdjevic 2005). Proposed in the 1970s by Thomas L. Saaty, it constructs a ratio scale associated with the priorities for the various items compared. In his initial formulation in the conventional AHP, Saaty proposed a four-step methodology comprising of modeling, valuation, prioritization, and synthesis. At the first stage, a hierarchy representing relevant aspects of the problem (criteria, sub-criteria, attributes, and decision alternatives) is constructed. The goal or mission of the decision-making problem is placed at the top of this hierarchy. Other relevant aspects (criteria, sub criteria, attributes, etc.) are placed in the remaining levels (Patil et al., 2012).

The second stage involves the comparison of pairs of criteria, pairs of sub-criteria (pairs of sub–sub-criteria, etc.) and pairs of alternatives. The AHP uses a fundamental 9-point scale measurement to express individual preferences or judgments (Saaty, 1980) creating a matrix of pairwise comparisons (Table 1).

Table 19. Scale of rating influence of factors 1 to 9 Scale (Saaty, 2005)

Intensity of Importance	Definition	Explanation
1	Equal importance of i and j	Two activities contribute equally to the objective.
3	Weak importance of i over j	Experience and judgment slightly favor one activity over another
5	Strong importance of i over j	Experience and judgment strongly favor one activity over another
7	Demonstrated importance of i over j	Its dominance demonstrated in practice.
9	Absolute importance of i over j	The evidence favoring one activity over another is of the highest possible order of affirmation.
2,4,6 and 8	Intermediate values the two adjacent Judgments	When compromise is needed
Reciprocals of above Non zero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

After all pairwise comparison matrices are formed, the vector of weights, w = [w1, w2, w3…wn] is calculated based on Saaty's eigenvector method. Then, this eigenvector is normalized by Eq. 1 and then the weights are computed by Eq. 2. The elements of the normalized eigenvector are weighted with respect to the criteria or sub criteria and rated with respect to the alternatives (Bhushan and Rai 2004; Carrion et al., 2008).

$$\boldsymbol{aij = \frac{aij}{\sum_{i=1}^{n} aij}} \text{…………………} (1)$$

$$\boldsymbol{W\dot{i} = \left(\frac{1}{n}\right)\sum_{i=1}^{n} aij, (i, j = 1, 2, 3 \ldots . n)} \text{…………………} (2)$$

Where i, j = 1, 2, 3….n.

The AHP also provides mathematical measures to determine the consistency of judgment matrix. Based on the properties of the matrix, a consistency ratio (CR) can be calculated. In a matrix, the largest eigenvalue (kmax) is always greater than or equal to the number of rows or columns (n). A consistency index (CI) that measures the consistency of pairwise comparisons can be written as (Saaty 1980).

$$\lambda\text{max}=\boldsymbol{\frac{1}{n}\sum{}^{n}_{i} = 1 \left[\frac{\sum_{j=1}^{n} aijwj}{wi}\right]} \text{………………………………………} (3)$$

Where CI is the consistency index (1), n is the number of elements being compared in the matrix, kmax is the largest or principal eigenvalue of the matrix. If this consistency index fails to reach a threshold level, then the answers to comparisons are re-examined. To ensure the consistency of the pairwise comparison matrix, the consistency judgment must be checked for the appropriate value of n by CR. The CR coefficients are calculated according to the methodology proposed by Saaty (1980). The CR coefficients should be less than 0.1, indicating the overall consistency of the pairwise comparison matrix (Chen et al., 2022). CR is defined as:

$$\boldsymbol{CR = \left(\frac{CI}{RI}\right)} \text{…………………………} (4)$$

Where RI: is the average of the resulting consistency index depending on the matrix. The RI values for different numbers of n are shown in Table 2. If the CR less than 0.10, it means that the pairwise comparison matrix has an acceptable consistency. Otherwise, If CR C 0.10 it means that pairwise consistency has inadequate consistency. In this case, the AHP may not yield meaningful results unless one re-examines the judgments and changes them as necessary to reduce the inconsistency below 0.10 (Saaty 1980 and Chen et al., 2022). In this study, the resulting CR for the pairwise comparison matrix was 0.061 for tea land suitability. These values indicate that the comparisons of land characteristics were perfectly consistent. Finally, the rating of each alternative is multiplied by the weights of the criteria and aggregated to get local ratings with respect to each criterion.

Table 2. Random index (RI) table

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

Source: Saaty, (1980)

Selection of evaluation criteria and AHP application

For evaluating agricultural land suitability, ten criteria including soil Data (Soil pH, soil texture, drainage class, and soil depth), topographic factors (slope, altitude and aspect) and climatic factors (temperature and rainfall). Were selected based on relevant literature review (Jayathilaka et al, 2012, Gahlod et al., 2017, Jayasinghe et al, 2018, Kumar et al., 2019 and Chen et al., 2022) and local expert interviews. These evaluation criteria were classified into four main groups (soil, topography, climate and Land use) in context of how they affect tea land suitability in studies area.

Results and Discussions

Reclassification Evaluation criteria for Tea Land suitability classification

The spatial land suitability of tea cultivation was obtained after the analysis of selected evaluation criteria such as soil data (soil pH, soil texture, drainage class, and soil depth), topographic factors (slope, altitude and aspect) and climatic factors (temperature and rainfall). Identified evaluation criteria layers were converted into raster data format based on the value of the required attributed column to form each thematic layer and reclassified according to literatures and expert level judgments (Table:3). Reclassification was used to simplify the interpretation of raster datasets by changing a single input value into a new output value. By using reclassified layers, which results in a generalization and simplification of the original dataset, the input layers were categorized based on the same ranking scheme that can be used to compare and rank the least and most suitable sites. Soil-site characteristics and Climatic /land quality criteria was reclassified based on (Chen et al., 2022 and Gahlod et al., 2017).

Table 20. Suitability criteria and class for production of tea cultivations

Parameters	Highly suitable	Moderately Suitable	Marginally suitable	Not suitable
Soil pH (H2O)	4.5-5	5.1-6 /4- 4.4	6.1-6.5/<4	>6.5/>3.5
Soil texture	Loam, Loamy sand, Sandy, Sandy loam	Clay loam, Sandy clay, Silty clay, Sandy clay loam	Clay	Clay heavy
Soil Depth	>150	100-150	100-50	<50
Drainage	Excessive to moderate	Imperfect	Poor	Very poor
Elevation (m)	< 2000	2000-2500	>2,500	
Slope (percent)	< 13	13–25	25–55	>55
Aspect	[South, southeast, southwest]	[East, west, northeast, northwest]	[North]	-
Temperature (°C)	18-25	26-28 /15-17	29-30/13-14	>30/<13
Rainfall (mm)	1800-2,000	1600-1,800	1000-1600	<1000
LULC	Tea plantation/ Forest	Cropland	Farmland	Building area/water body

Reclassification of Topographic Characteristics of the Study Area

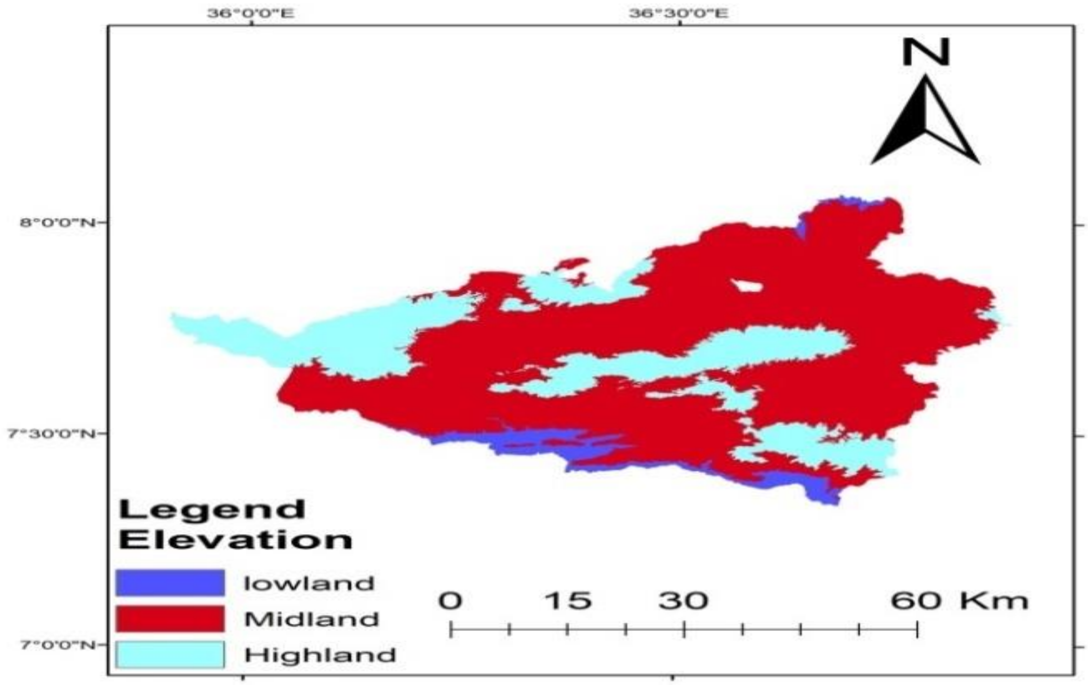
The unclassified Elevation of the area ranges from 1,158 to 3,094 m a.s.l distributed to lowland (1158-1500 m) 4.94%, midland (1500-2300m) 70.31 and 24.75 % of the area was of highland (Figure 3). The reclassified Elevation map shows that about 44.55 and 46.38% of area has highly suitable and suitable altitude for growth tea plant. This indicated that the elevation influence tea plant growth in study the area.

Elevation is one topographic feature that affects the growth, yield, and quality of tea crop performance through affecting water distribution and pedogenic process that influence soil properties in different landscape positions (Yaghmaeian et al., 2020). As elevation increases, the growth rates of tea crops especially shoot decreases that contribute towards slower growth at high altitudes. Yield and quality of black tea, particularly theaflavin and its fractions, aroma composition and water extract were positively affected by elevation which increased as elevation resulted in higher levels (Hossain et al., 2021 and Muthumani et al., 2013).

High elevations leads to higher concentrations of volatile compounds that include analgesic, antianxiety, antibacterial, anticancer, antidepressant, antifungal, anti-inflammatory, antioxidant, anti-stress, and cardio protective as compared with low elevations. In addition, teas grown in high elevations were sweeter, floral, honey-like compounds than tea growing in low elevation (Robbat et al., 2018).

Tea is planted on elevated land slopes at 1,900-2,500 m in addition; it is adaptive in a well-drained land at 1550 and 1800 m Rwanda (Ingabire, 2020). The unclassified slope of study the area from 0 to 284.4% that characterized by Very steep sloping (1.83%) Steep sloping (11.3%)

moderately steep sloping (37.33%), strongly sloping (31.75%), sloping to gently sloping slope (16.3%) and 1.38% of the area was very gently sloping slope (Figure 3).



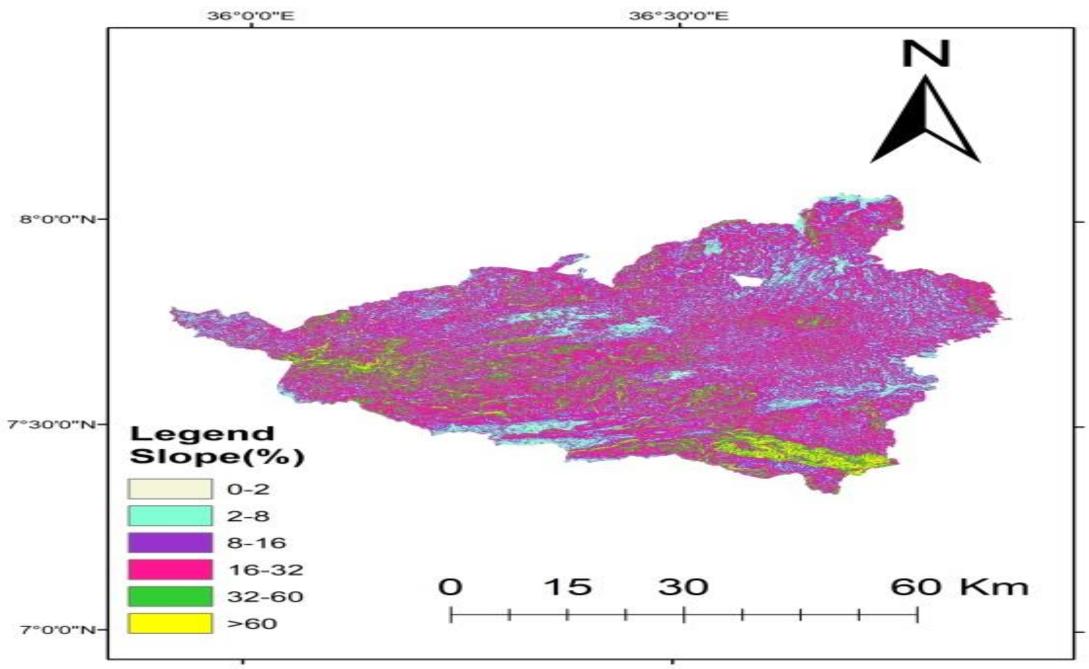


Figure 15. Elevation and Slope the study area

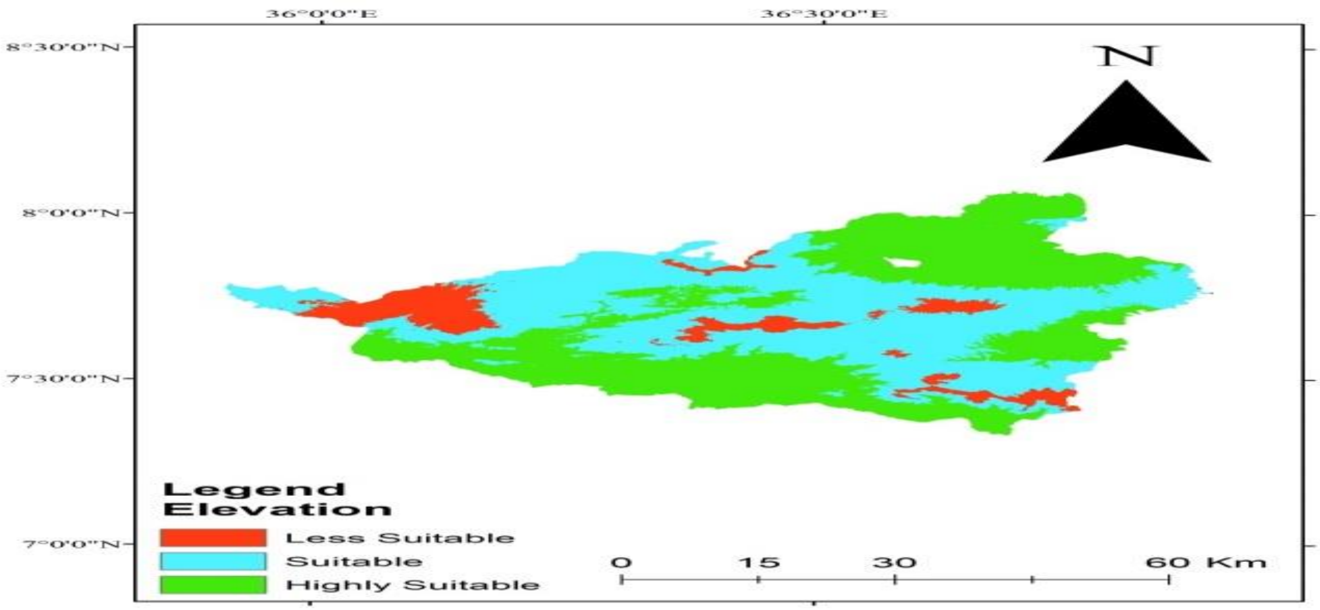
The reclassified slope map shows that about 29.58 and 39.11 % of study the area has highly suitable and suitable slope for growth tea plant respectively (Table 4 and Figure 4). However 21.14% and 10.17 that represent less suitable and not suitable respectively affect tea plant growth significantly in study area.

Slope affected growth and yield performance indirectly had significant effect on pedogenic process which highly affects solum thickness, thickness of the epipedons, saturated soil moisture, clay content, total N, calcium carbonate content, and exchangeable Mg. Generally, slope affects tea cultivation through affecting physical, chemical, and morphological properties of the soil such as nutrient movement in landscape position and drainage condition of the soil which had significant on tea cultivation (Khormali et al., 2007). The slope aspect is one topographic feature affecting the growth, yield and quality of tea through affecting microclimate due to the difference in surface runoff and risk of soil erosion as well as solar radiation difference received on different aspects (Khormali et al., 2007). Aspects influence the growth, yield, and quality of tea through affecting the hydrological cycle of landform and the rate of soil forming processes, particular affecting the infiltration rate and evapotranspiration by changing the microclimate of the specific area rapid evapotranspiration on southern aspect, and high rate of soil forming processes in the north facing slopes which results in a thicker solum with higher organic matter and denser vegetation were observed due doe to slopes aspects difference (Khormali et al., 2007).

The reclassified aspects results show that about 36.99 and 50.84%, of the study the area highly suitable and suitable aspects for growth tea plant respectively. However the remaining 12.17% aspects of the area faced to North, has significant affect tea plant growth in the study the area (Table 4). Aspects are also an important indicator of land suitability as it influences drainage and soil erosion activity in specific areas.

Table 21. Suitability criteria and area coverage of elevation, slope and aspect for tea cultivation

Factors	Reclassified	Classification	Area (ha)	Area (%)
Elevation (m.a.s.l)	< 2000	Highly suitable	196671.70	44.55
	2000-2500	Suitable	204718.60	46.38
	2500-3094	Less suitable	40039.67	9.07
Slope (%)	5< 13	Highly suitable	130571.60	29.58
	13– 25	Suitable	172620.20	39.11
	25 – 55	Less suitable	93331.58	21.14
	>55	Not suitable	44879.28	10.17
Aspects	[South, southeast, southwest]	Highly suitable	163259.60	36.99
	[East, west, northeast, northwest]	Suitable	224417.7	50.84
	[North]	Less suitable	53721.02	12.07



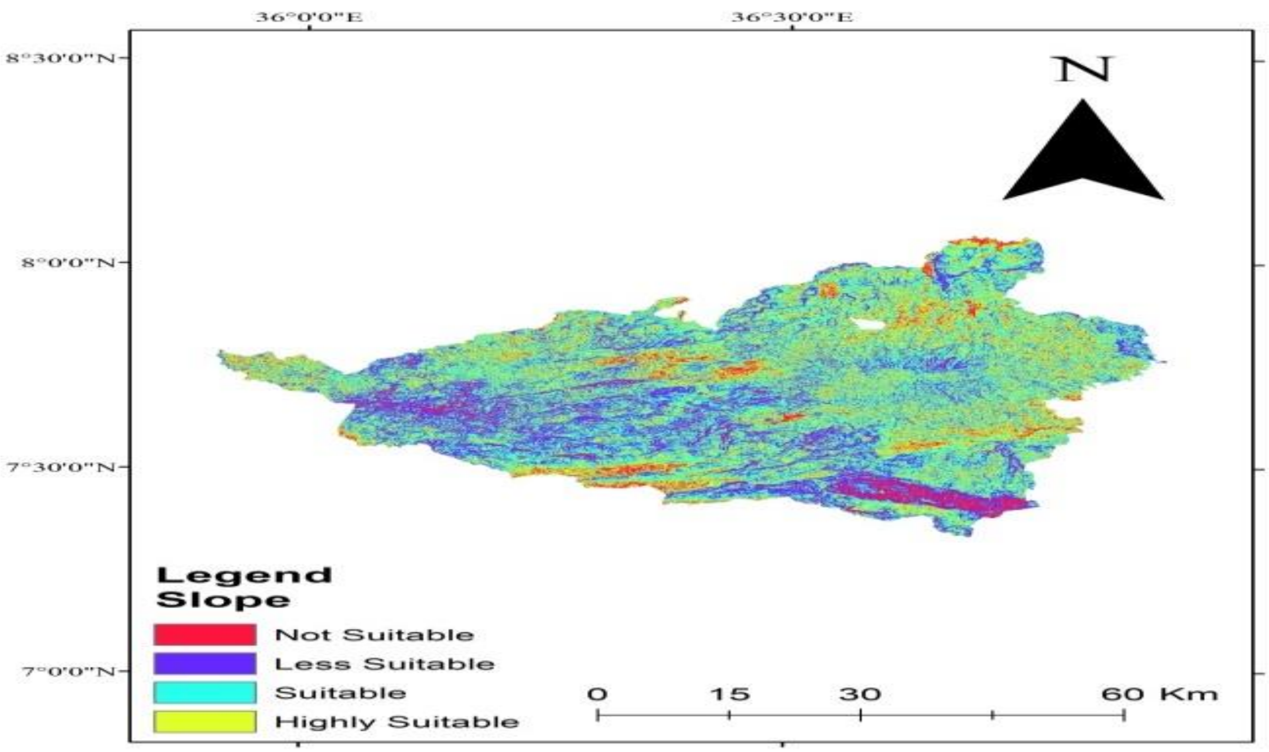
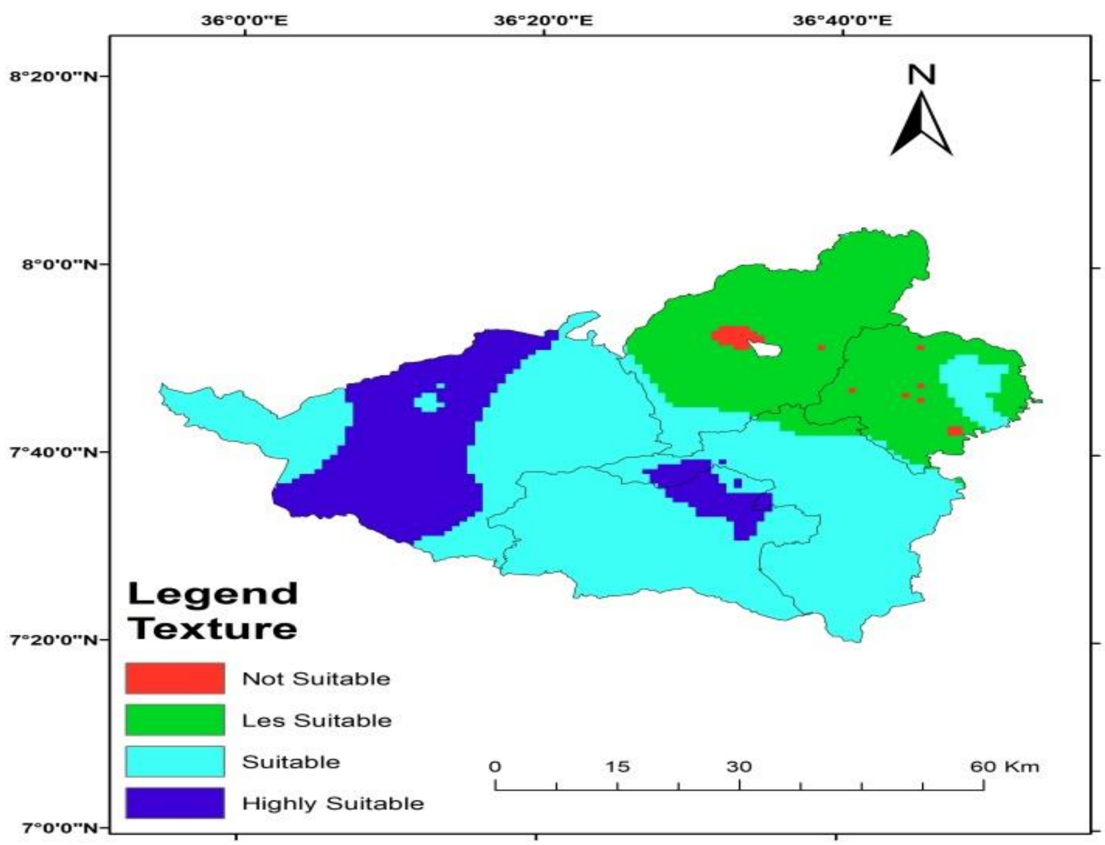


Figure 16.Elevation and Slope Suitability Maps

Soil Factors Reclassification

The unclassified soil pH of Studies area ranges from 4.1 to 5.7 and the reclassified soil pH map shows that about 88.9 and 11.1% of studies area has highly suitable and suitable soil pH for tea plant growth (Table 5 and Figure 4). This indicated that Soil pH is the most important factors affect tea plant growth in Studies area. Generally, tea plants require acid soils with soil pH range 4.5-5.5 for growing better (Gahlod, et al., 2017 and Jayathilaka et al., 2012). The unclassified Soil texture of the studies area ranges from medium texture class to Heavy texture class and the reclassified soil texture map shows that about 17.71 and 54.61% of studies area has highly suitable and suitable soil texture class for growth tea plant where as the remaining 27.01% and 0.62% occupied by less suitable and not suitable class of suitability that limit tea plant growth (Table 5 and Figure 5). This indicated that the soil texture had significant effect on tea plant growth in the studies area. Soil texture such as loam, sand, loamy, sandy clay loam, and clay loam are highly suitable for tea production, whereas clay, silty clay, and silty clay loam are considered as Moderately Suitable for tea cultivation (Gahlod et al., 2017 and DENGİZ et al., 2018).



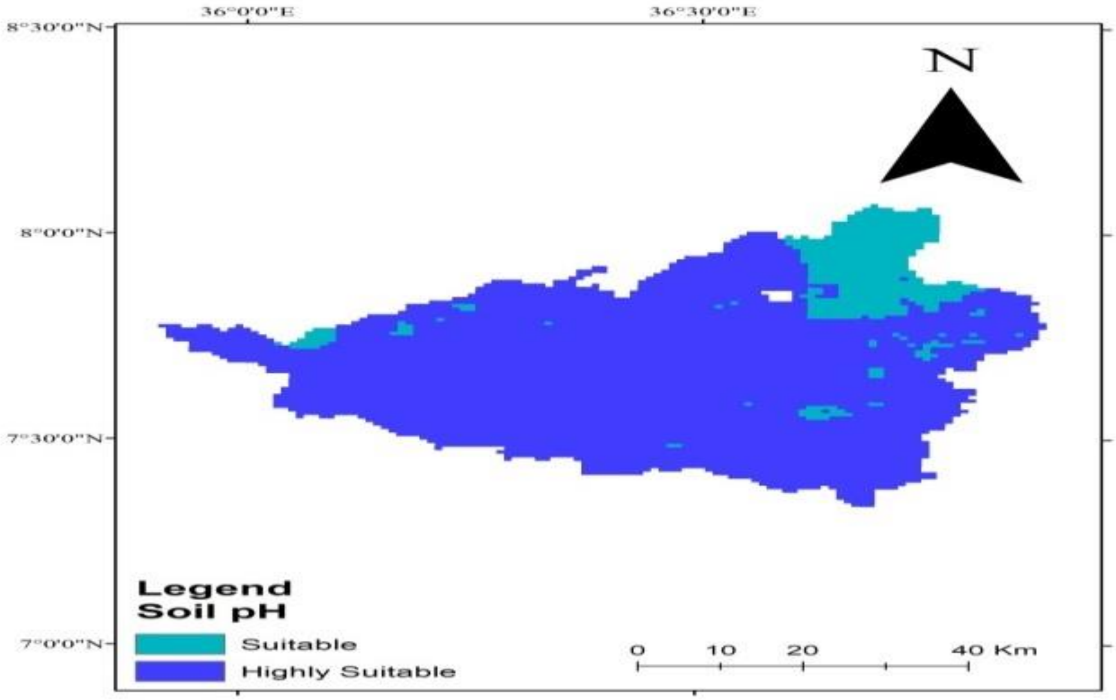


Figure 17. Soil texture and pH suitability map

The unclassified drainage class of the studies area ranges from well drainage class to poorly drained class and the reclassified drainage class map shows that about 94.29 and 5.45% of the studies area has highly suitable and suitable drainage class for growth tea plant (Table 5 and Figure 6). This indicated that the drainage classes limit tea plant growth in the studies area significantly. However poorly drained drainage class occupied only 0.62% of the studies area. Tea is grown in well-drained soil drainage class, deep and well-aerated soil with more than 2% organic matter is the optimum soil condition soil for tea growing (Gahlod et al., 2017).

The unclassified Soil depths of the study area ranges from very deep to deep depths of less than 120 cm and the reclassified drainage class map shows that about 99.39 and 0.61% of the studies area has highly suitable and suitable soil depths for growth tea plant (Table 5 and Figure 6); This indicated that the soil depths does not limit tea plant growth in the study area significantly. Soil depths of less than 50 cm, soil gravel of more than 50% in top 50 cm of the soil layer and a rockiness of 20% negatively affect tea growth. Tea cultivations do not tolerate prolonged flooding or poorly drained clay soils. This tree grows in a variety of soil types and conditions from fine drained sandy loam soils to heavier clay loam soils. Well-drained to moderately drained soils, deep and well-aerated soil were recommended as optimum soil conditions for tea growth (Hajiboland, 2017 and DENGİZ et al., 2018).

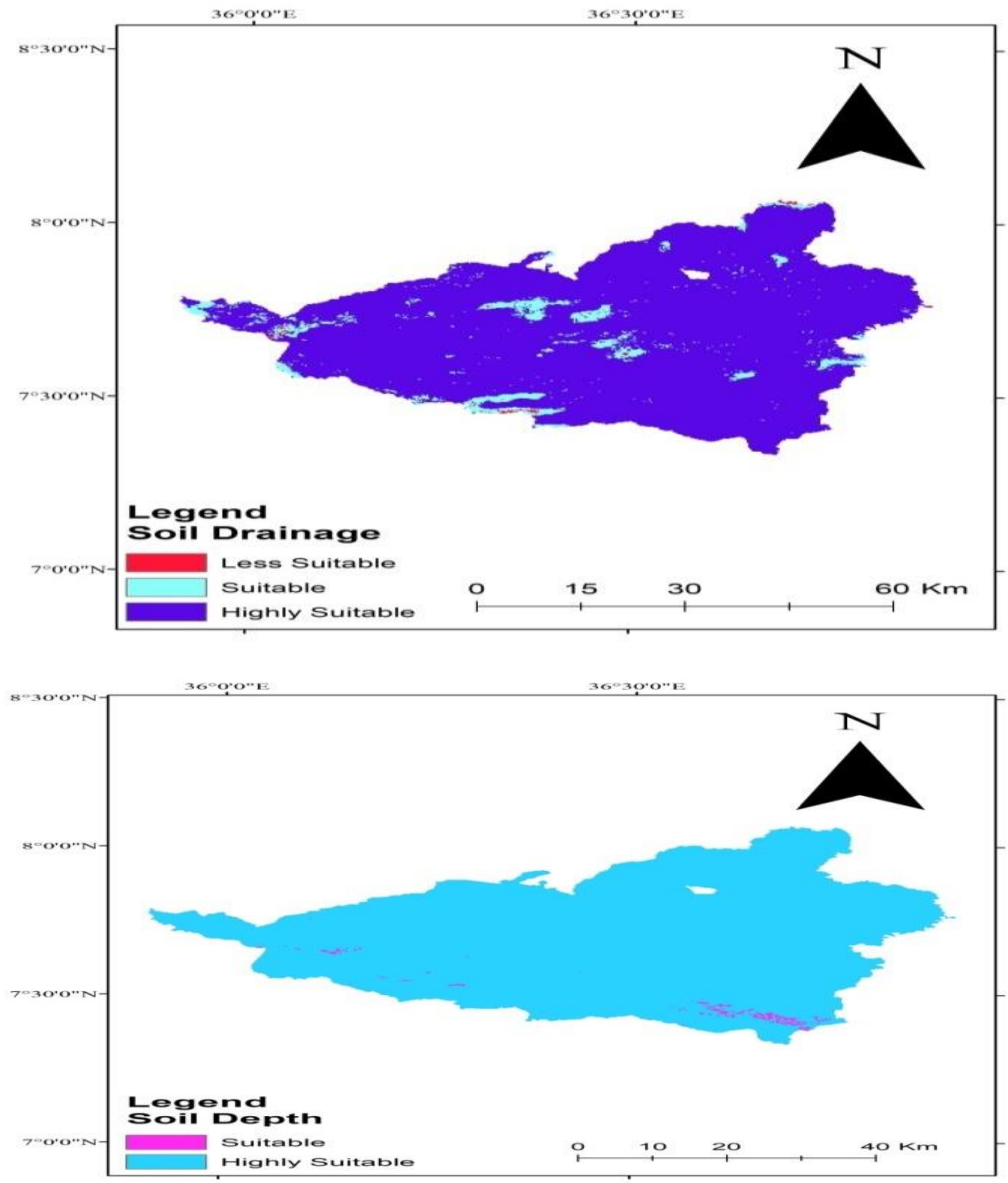


Figure 18. Soil Drainage class and Depth Suitability map

Table 22. Suitability criteria and coverage of Soil pH, Depth, Texture and Drainage for tea cultivation

Factors	Reclassified	Classification	Area (ha)	Area (%)
Soil pH	4.5-5.0	Highly suitable	392603.4	88.9
	5.1-6 /4- 4.4	Suitable	49016.95	11.1
Soil Depth	>150	Highly suitable	438826	99.39
	150– 100	Suitable	2682	0.61
Soil Texture	scl, l, cl, sl	Highly suitable	77721.05	17.61
	c, sicl, sic	Suitable	241518.3	54.71
	Heavy Clay	Less suitable	119251.1	27.01
	Heavy Clay	Not suitable	2941.18	0.67
Drainage	Well drained	Highly suitable	416016.1	94.29
	Moderately drained	Suitable	21045.74	5.45
	Excessively and Imperfectly	Less suitable	1169.2	0.62

Climatic Parameters Reclassification

The unclassified annual rainfall of the basin ranges from 1449.92 to 19635.51 mm pear year and the reclassified annual rainfall map shows that about 7.26 and 51.54% of the studies area has highly suitable and suitable annual rainfall for growth tea plant (Table 6 and Figure 7). This indicated that the annual rainfall significantly limit tea plant growth in the studies area as 41.72% of the studies area receive less Suitable annual rainfall tea plant growth. The unclassified mean temperature of the study area ranges from 17.20 to 18.97°C and the reclassified mean temperature map shows about 53.14% and 46.86% of Studies area has highly suitable and suitable mean temperature for tea plant growth (Table 6 and Figure 7). This indicated that mean temperature of the study area is optimum for tea plant growth. The most important climatic factors for tea are temperature and rainfall, as tea growth and productivity are mainly controlled by water availability and temperature.

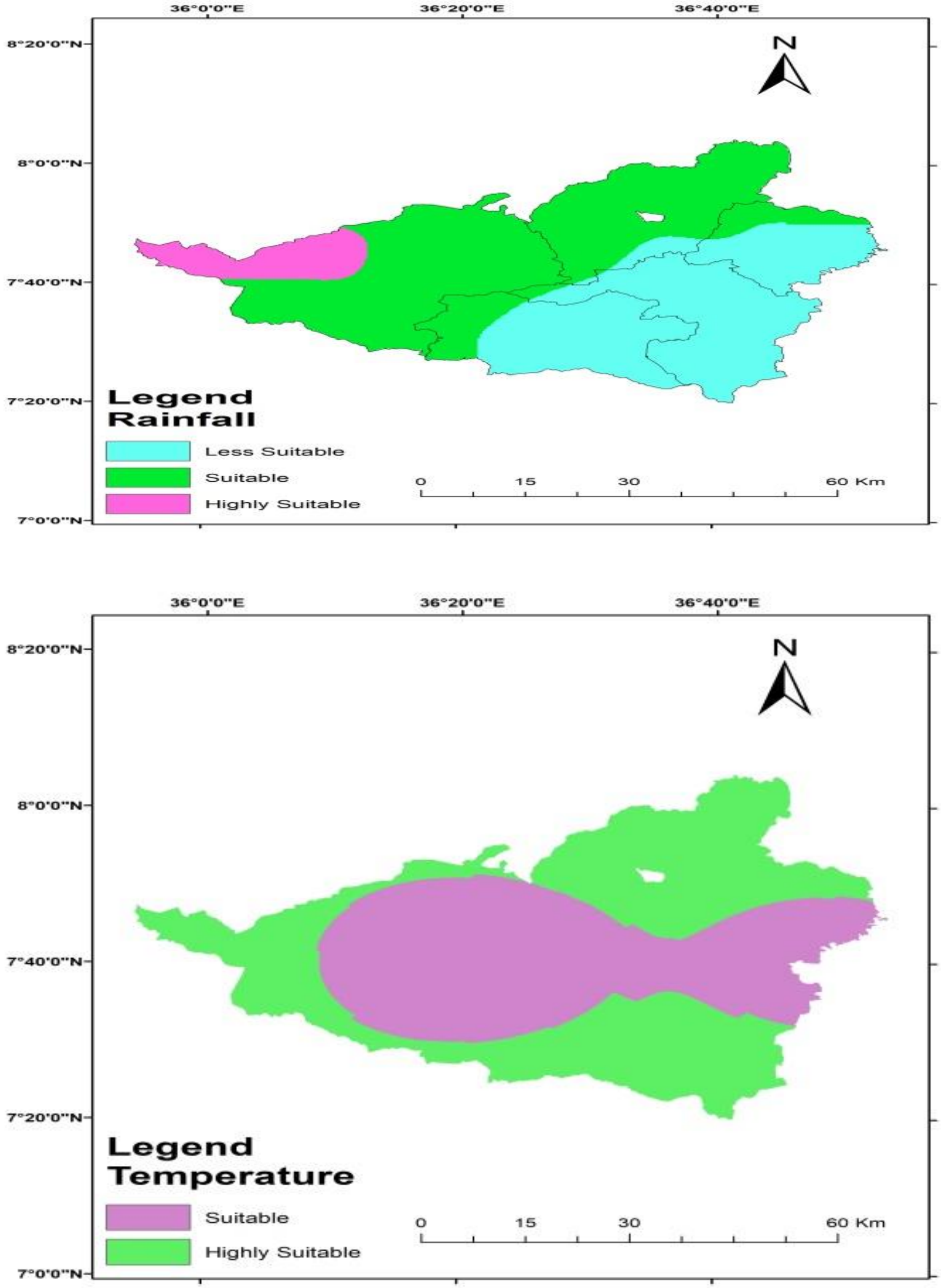


Figure 19: Rainfall and Temperature suitability map

Its specific requirements are: temperatures ranging from 13-30oC, minimum annual precipitation of 1250 mm (FAO, 2015). Tea plant requires well-distributed rainfall and the optimum mean temperature in the range of 18 to 30 0C that receive an annual rainfall of at least 1200 mm per year (Hajiboland, 2017 and Kariuki et al., 2022).The tea plant requires a minimum rainfall of 1200mmper year, but 2500-3000mmper years are considered optimum (Hajiboland, 2017 and Jayasinghe et al., 2019).

Table 23. Suitability criteria and area coverage of Rainfall and Temperature for Tea cultivation

Factors	Reclassified	Classification	Area (ha)	Area (%)
annual rainfall (mm)	1800-2,000	Highly suitable	32058.01	7.26
	1600-1800	Suitable	2274422.00	51.54
	1000-1600	Less suitable	181798.72	41.20
Mean annual temperature (°C)	18-25°C	Highly suitable	234562.20	53.14
	<18°C	Suitable	206842.80	46.86

Land Use Land Cover Parameter Reclassification

Land use types are an important factor that affects physical land suitability of tea cultivation. Tea can grow in forest land, shrubs lands, crop land, and grass land. According to (Chen et al., 2022), Tea plantation, forest, farmland lands are the optimal land use types for tea cultivations, whereas building land and water body are not suitable for tea cultivation. Existing tea-growing areas, crop lands, grass land, and forest lands are appropriate land use for tea and urban, rock, bare land, open water, wet lands, paddy, and road were not appropriate land use for tea cultivation (Jayasinghe et al., 2019).

The land use land cover of the study area was classified as forest, crops land, land (moderate to sparse cover of bushes, shrubs, and tufts of grass, savannas with very sparse grasses, trees or other plants), bare land, Built Area and water bodies' area (Table 7and Figure 8). Current existing land use map of the basin was used to assess the condition of restricted land use for tea growing. Therefore, the existing land use classes were classified as "1" which possible and appropriate land use classes for tea such as existing tea-growing areas, crop land, tree cover and range land use, and "0" was where tea could not be grown (Built Area, bare land, water bodies, and seasonally flooded vegetation). The newly developed land use restriction map was overlaid with the rasterized suitability map. The results of land use land cover suitability analysis indicated that about 412700 ha which is the largest part of the current land use of the study area was suitable (93.49%) for tea cultivation. Meanwhile, the remaining 6.51% was not suitable for tea cultivation due to restricted land use condition that was not suitable of for tea growing.

Table 24. Suitability criteria and area coverage of LULC for Tea cultivation

Factor	LULC Type	Classification	Area (ha)	Area (%)
LULC	Forest, Cropland, Rangeland	Suitable	412700	93.49
	Built Area, bare lands, water bodies and wet land	Not suitable	28731.21	6.51
	Total		441431.21	100

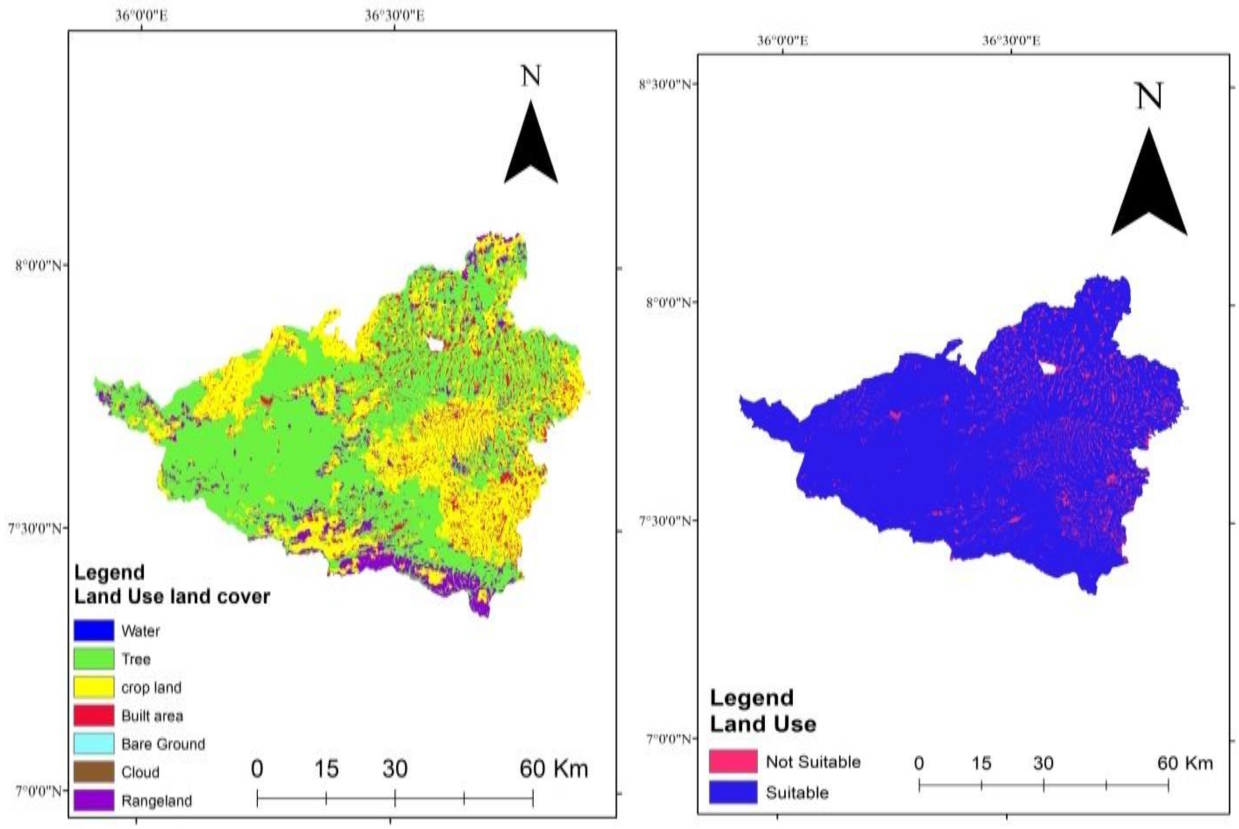


Figure 7: Land use, land cover, and Land suitability map

Criteria Weights

In this study, the weights for selected parameters/factors were derived using AHP model. Relative importance of factors that affect the growth of tea plants was assigned in pairwise comparison matrix. In the matrix above, diagonal values were assigned in comparison with the column parameters. The values of each parameter were given in accordance with the parameter effect on the growth and productivity of tea plants. Below diagonal values of each parameter are the reciprocal of the above diagonal. After assigning the relative importance values of the above diagonal and the reciprocal of the above diagonal matrix, normalization of each cell value was done (Table 8).

Table 25. Analytical Hierarchical Process Comparison Matrix

Criteria	pH	Tem	Rain	Slope	Altitude	Drainage	Depth	Texture	Aspect	LULC
Soil pH	1.00	1.00	0.33	0.33	1.00	1.00	3.00	0.33	0.33	0.33
Temp	1.00	1.00	1.00	0.33	0.33	1.00	1.00	0.20	0.33	0.33
Rain	3.00	1.00	1.00	5.00	1.00	3.00	3.00	0.33	1.00	1.00
Slope	3.00	3.00	0.20	1.00	0.33	3.00	3.00	1.00	0.33	0.33
Altitude	1.00	3.00	1.00	3.00	1.00	3.00	3.00	0.33	1.00	1.00
Drainage	1.00	1.00	0.33	0.33	0.33	1.00	3.00	0.33	0.33	0.33
Depth	0.33	1.00	0.33	0.33	0.33	0.33	1.00	0.33	0.33	0.33
Texture	3.00	5.00	3.00	1.00	3.00	3.00	3.00	1.00	3.00	3.00
Aspect	3.00	3.00	1.00	3.00	1.00	3.00	3.00	0.33	1.00	1.00
LULC	3.00	3.00	1.00	3.00	1.00	3.00	3.00	0.33	1.00	1.00
Sum	19.30	22.00	9.19	17.32	9.32	21.33	26.00	4.51	8.65	8.65

Normalization can be computed by dividing each cell value by the column total of each parameter. Normalization of the parameters values was performed to generate criteria weights for each parameter. Criteria of each parameter were obtained by summing up the row values of each cell. Consistency ratio of all parameters was computed to check whether the calculated value is correct or not correct. Values of consistency ratio exceeding 0.10 are indicative of inconsistent judgments; whereas values of 0.10 or less indicate a reasonable level of consistency in the pairwise comparison. In this case, the computed CR is 0.083 and this indicates a reasonable level of consistency in the matrix (Table 9).

According to the criteria weight, soil parameter is the paramount importance for tea plant growth performance, soil texture has the highest significance indicator value followed by rainfall, elevation, land use land cover, aspect and slope, indicating that these are the most important criteria for the land suitability assessment for tea in the study area, however the relatively lowest position was indicated by Temperature, soil drainage class and soils depth for the land suitability assessment for tea in the area. Final criteria weights were achieved by calculating each criterion’s weight by models as indicated in Table 10 and applied to the land-use suitability for tea crops. Soils texture (22.23), rainfall (13.43%) was highly contributed to the land suitability evaluation than other criteria followed by land use land cover (12.63%), Aspect (12.63%) elevations (11.65%).

The least impact on the evaluation of land suitability for tea was soil pH (5.44%) drainage class (4.74%) and temperature (4.65%), while Slope (9.13%) had an intermediate influence on tea land suitability predictions based on the results of normalized matrix assessment on relative importance of climate, soil, and topography parameters.

Table 26. Analytical Hierarchical Process (AHP) analysis for the assessment of the relative importance of climate, soil, and topography parameters; normalized matrix results

Criteria	pH	Temp	Rain	Slope	Altitude	Drain	Depth	Texture	Aspect	LU	Total	Weight
Soil pH	0.05	0.05	0.04	0.02	0.11	0.05	0.12	0.07	0.04	0.04	0.59	5.44
Temp	0.05	0.05	0.11	0.02	0.04	0.05	0.04	0.04	0.04	0.04	0.48	4.65
Rain	0.16	0.05	0.11	0.29	0.11	0.14	0.12	0.07	0.12	0.12	1.29	13.43
Slope	0.16	0.14	0.02	0.06	0.04	0.14	0.12	0.22	0.04	0.04	0.98	9.13
Altitude	0.05	0.14	0.11	0.17	0.11	0.14	0.12	0.07	0.12	0.12	1.15	11.65
Drain	0.05	0.05	0.04	0.02	0.04	0.05	0.12	0.07	0.04	0.04	0.52	4.74
Depth	0.02	0.05	0.04	0.02	0.04	0.02	0.04	0.07	0.04	0.04	0.38	3.49
Texture	0.16	0.23	0.33	0.06	0.32	0.14	0.12	0.22	0.35	0.35	2.28	22.23
Aspect	0.16	0.14	0.11	0.17	0.11	0.14	0.12	0.07	0.12	0.12	1.26	12.63
LU	0.16	0.14	0.11	0.17	0.11	0.14	0.12	0.07	0.12	0.12	1.26	12.63

Eigenvalue (λmax) = 11.093, Consistency Index (CI) = 0.12, Consistency Ratio (CR) = 0.082

Land suitablity for tea

Land Suitability for tea in the study area comprises highly suitable, suitable, less suitable and not suitable (Table 10 and Figure 8).The analysis of the final weighed results indicated that the of the study area had potential land for tea cultivation as the majority part of the land in the study area (94.44%) is occupied by suitable class of suitability in which, about 409574.45ha (92.78%) suitable followed by 7317.247ha (1.66%) highly suitable of land for tea cultivation in this area. The rest land of study area 270.48(0.06) and 24269.44h (5.55) occupied with less Suitable and not suitable respectively. Most of the suitable lands found in South part of the study area.

This is maybe due to optimum soil conditions; to optimum rainfall, appropriate slope Aspect and to optimum elevations. The highest proportion of not suitable area for tea cultivation was found in East and North part of study area, however less suitable land for tea cultivation land in this area which is 0.06% of the area land cover study area remains from the area covered by suitable class of suitability. Land not suitable for tea mostly consecrated north parts of the study area particularly in Manna ,Gomma and Seka chekorsa districts, which indicated that Soils, Climate and topographic factors particularly soil textures, rainfall, Land use and elevation were significantly affect tea cultivation in this area. Soil texture, annual rainfall, Altitude, Aspect and Land use land cover were identified in the study area as the main limitation factors for tea productions.

Altitude has the greatest positive value of relationship indicator, which means that it has a dominating, causal influence on the other criteria. According to the relationship indicators (Table 9), annual rainfall, Altitude, Aspect, Land use land cover and slope belong to the cause group, and have a significant influence over the criteria of temperatures, soil drainage, and depth, soil pH and soil texture. Altitude, in fact influences temperature, and present Land use land cover of the study area.

Table 27. Land Suitability class and area coverage of the study area for tea cultivation

Suitability class	Area (ha)	Area (%)
Not Suitable	24269.44	5.50
Less Suitable	270.48	0.06
Suitable	409574.45	92.78
Highly suitable	7317.24	1.66

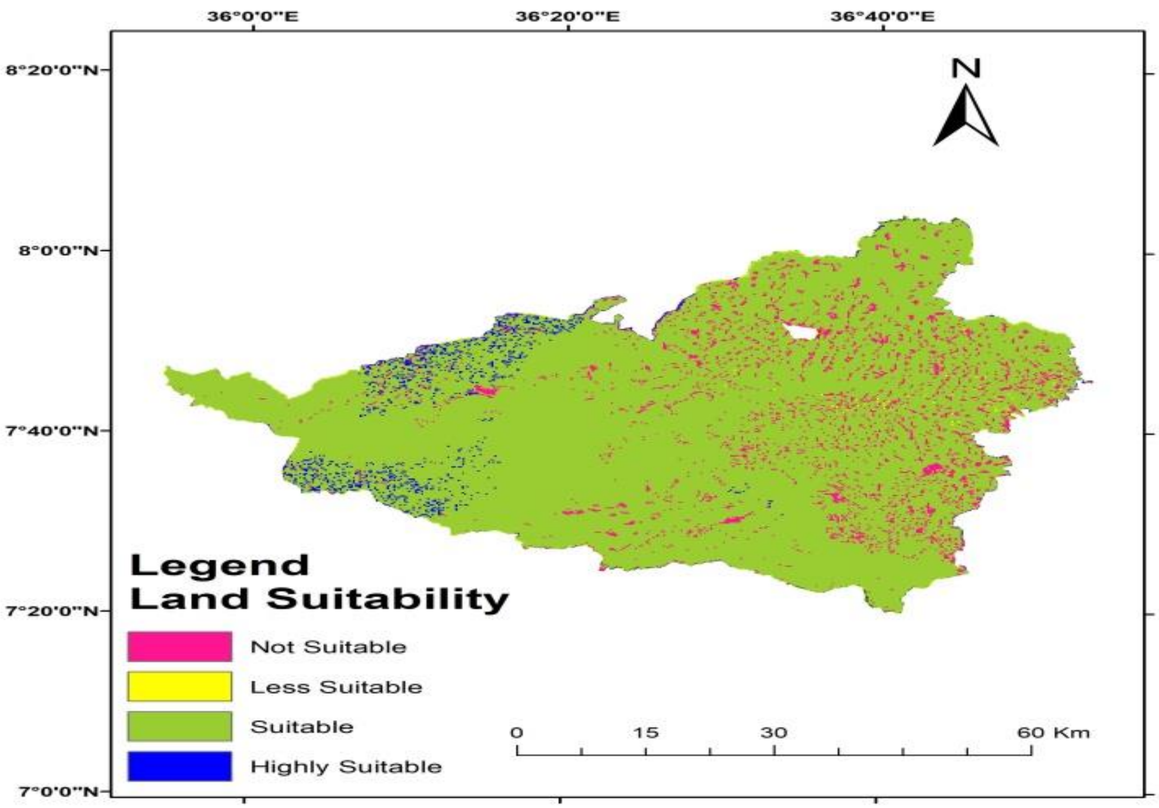


Figure 8: Final Land suitability map for tea cultivation

Conclusion and Recommendation

Based on GIS and Analytic Hierarchy Process (AHP) modeling-based approach decision making for sustainable tea production in the study area and offers an opportunity to increase tea production planning by providing basic required information for farmers and agricultural planners. Therefore, the resulting tea production land suitability map (1) provide better understanding tea production and facilitates a better understanding of alternative agricultural land use suitability patterns for future development, thus can be used for decision-making in agricultural development of the study area and (2) suggesting tea productions activities to the areas that have good physical and environmental conditions for tea productions, thus achieving maximum tea productions efficiency in the study area..

Therefore, identification of these limiting factors is necessary to disseminate of tea plantations through to avoid a sightless expansion of tea plantations in the area. Introducing tea plantations for investment at large scale or small farm were possible and economically profitable as that Studies area has great potential for tea plants production especially well-distributed rainfall and the optimum mean temperature for tea plants production.

The fact that this study was restricted to only one crop, it is recommended that future studies apply the analysis method used in this study to develop land suitability maps for other horticultural crops. It is further recommended that field trials can be set up in the various suitability classes as identified in the study. Appropriate land use management is recommended by modifying the current land-use pattern according to its suitability by introducing alternative income generation mechanism could help the poor farmers who are totally depend on fragmented small land for their daily life. Introducing tea plantations for investment at large scale or small farmers especially in the Studies area as acid tolerance crops to increase income of poor farmers who are totally depend on small land for their daily life. Expansion of tea plantations in the area highly recommended as soil acidity were sever problem that limited crop productions for alternative income generation mechanism.

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6. Current status of major Coffee (Coffea arabica L.) Diseases in Buno Bedele and Ilu Aba Bora, South Western Oromia, Ethiopia

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Abstract

In Ethiopia, coffee is the most important crop in the economy of the country which has used as a source of foreign income and also millions of the people relying on coffee production for their livelihood. However, its production and productivity has been decreasing due to major biotic factors, such as diseases, insect pests and weeds. Especially coffee diseases have been very important to limit the yield and quality of coffee in the study areas. Therefore, to overcome these problems, there is need to assess major diseases which are highly result in coffee yield loose at growing areas. This assessment was conducted at Buno Bedele and Ilu Aba Bora, a zone which includes six districts kindly Gachi, Chora, Didesa, Ale, Halu and Yayo. The result of this study revealed that three coffee diseases were occurred at the study areas. From these diseases CBD was more severe at all districts by 61.6% of Incidence followed by CLR (59.1%) incidences. CWD was also observed at all districts by 32.9% mean intensity. Generally, from the results the production and productivity of coffee in the study area was threatened by these major diseases. Therefore, these major diseases should be get considerations in surveyed areas to practiced and design an appropriate management options for its management.

Keywords: Coffea arabica L., CBD, CLR, CWD, Incidence, Severit

Introduction

Coffee is an important export crop and a major foreign exchange earner for Ethiopia. According to Petit et al. (2007) coffee is a backbone of Ethiopian fiscal underlying 41% of foreign exchange, Supporting more than 1million farming household, fascinating 25% employment opportunity and 10% of government income. It is the most important and valuable commodity in Ethiopia and in the world supporting the economic growth and providing job opportunity to millions of people. Ethiopia is the leading producer in Africa, and the 5th in the world, following Brazil, Vietnam, Colombia and Indonesia and produces premium quality coffee (USDA, 2021). Ethiopia the 10th coffee exporter with 4.79 percent share of the world total (Bellachew, 2015). If we consider Arabica coffee alone, Ethiopia is the 3rd largest producer after Brazil and Colombia (USDA, 2021). In Ethiopia, coffee has being contributes to the Lion's share in its national economy being the leading source of foreign exchange earnings. Besides, the livelihood of a quarter of the Ethiopian population depends directly or indirectly on the different processes of production and marketing along the coffee value chain (Girma et al., 2008)

In Ethiopia, the overall land area devoted to coffee production due to new plantings is increasing and estimated to be 662,000 hectares, of which 496,000 hectares are estimated to be productive. The average annual production is amounting to about 350,000 t and productivity of about 0.71 t/ha (Alemayehu et al., 2008). Here, coffee is produced under four broad production systems, i.e. forest coffee (8-10%), semiforest coffee (30-35%), cottage or garden coffee (50-57%) and modern coffee plantations (5%).

However, its production and productivity is mainly constrained with many factors, among biotic factors like diseases, insect pests and weeds are the major one. Despite the largest share in production and economic contribution, C. arabica is threatened by several coffee diseases which remain among the major constraints to reduced production and productivity in many parts of Ethiopia. About fourteen fungal diseases and one bacterial disease have been reported to attack the crop (Eshetu et al., 2000). Amongst coffee berry disease (CBD) caused by Colletotrichum kahawae, coffee wilt disease (CWD) caused by Gibberella xylarioides and coffee leaf rust (CLR) caused by Hemileia vastatrix are the three major economically important biotic coffee production constraints in the country (Eshetu et al., 2000). Although the rest were found minor importance under current situation, a few diseases like coffee thread blight and bacterial blight of coffee have been identified potential threat for Arabica coffee (Belachew, 2015). Since coffee is perennial crop that remains on the field through the year for many years and allows some pests to maintain an endless succession of generations

(Arega, 2009).

South western part of Oromia including Buno Bedele and Ilu Aba Bora Zones are potential area in coffee production. In these areas like another Ethiopian coffee growing areas coffee production has been threatened by different factors, mainly biotic factors (diseases, insect pests and weeds). Yet there has been lack of information related to geographical occurrence, distribution and status of coffee diseases in these areas. So, Assessment of coffee plant diseases is important to design proper management strategies. Thus, assessment is an essential work in terms of obtaining baseline information about major diseases of coffee in one study area for designing sound management options. The activity was initiated with the objective to assess prevalence, incidence and severity of coffee diseases at Buno Bedele and Ilu Aba Bora coffee growing areas.

Materials and Methods

Description of study areas

The survey of major coffee diseases was undertaken in major coffee producing areas of Buno Bedele zone, namely Chora, Gachi and Didesa and major producing areas of Ilu Aba Bora zones, namely Ale, Halu and Yayo districts. These districts were purposively selected for their coffee production and disease prevalence. Geographical information was recorded by using GPS at the point of farm assessed (Table 1 & Figure 1).

Table 28. Weather conditions of assessed districts of Buno Bedele and Ilu Aba Bora zones during 2021

Districts	Altitude (masl)	Latitude N	Longitude E	Rainfall (mm)	Min. temp (oC)	Max. temp (oC)
Ale	1648-2377	8o02’0.00”	35o39’59.99”	1982	14	19
Chora	1470-2516	8o19’60.00”	36o14’60.00”	1350	9	31
Didesa	1428-2512	8o04’60.00”	36o39’59.99”	1800	13	28
Gachi	1363-2553	8o19’60.00”	36o39’59.99”	1100	13	18
Halu	1370-1917	8o08’51.26”	35o20’27.74”	1450	18	24
Yayo	1304-2587	8o20’35.09’’	35o48’58.83’’	2300	7	32

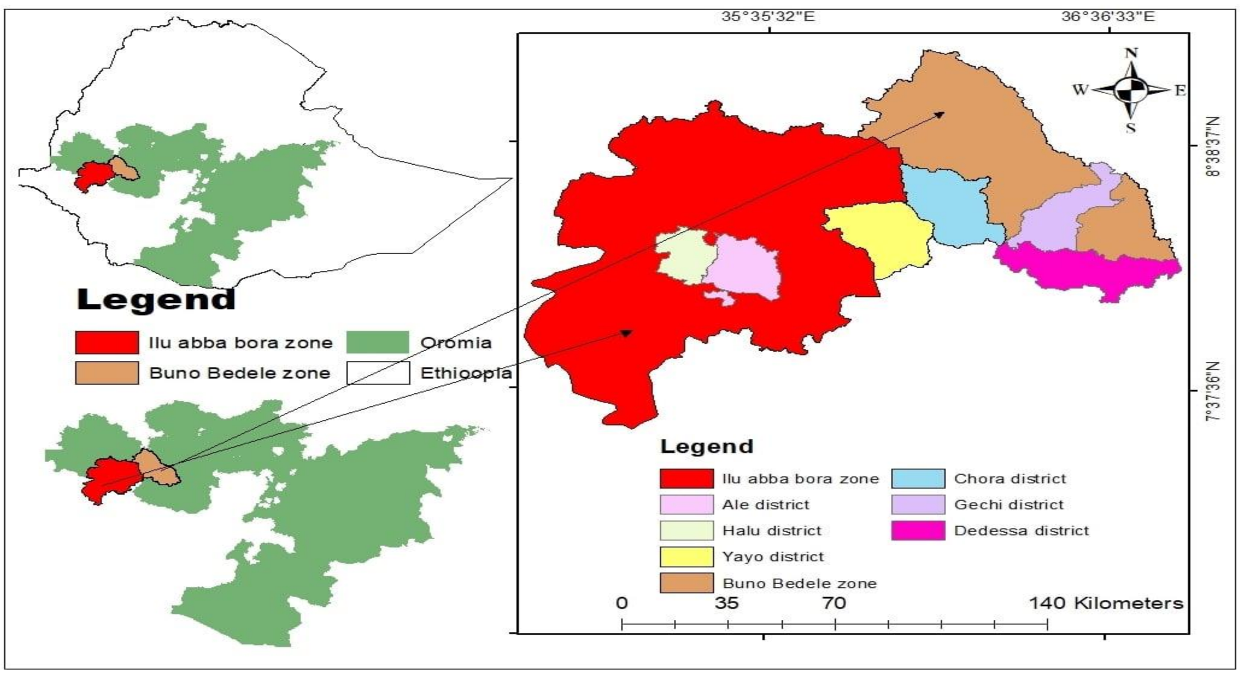

Figure 20. Map of the study area

Methods of coffee Disease Assessment

Each district was categorized into highland, midland and lowland agro ecologies. From each agro ecology 5 farmer's farms were sampled in interval of 3-5 km. Ninety farms were assessed for the diseases and other required data was collected. At each farm a questionnaire was administered and the owner was asked about the age tree, type of coffee cultivar/landraces and the diseases history. The farms also were diagnosed for agronomic practices applied, weed control methods, shade tree condition (shaded or un-shaded) and factors which contribute in occurrence and distribution of diseases. Major disease assessment methods like prevalence, incidence and severity were used during field assessment. Generally, the collected coffee disease data was measured and summarized according to the following formula.

Disease Incidence: The numbers of infected and healthy trees were counted. Then, Incidences of the diseases were calculated:

$$\text{Disease Incidence (\%)} = \frac{Total\ infected\ tree}{Total\ assessed\ tree} X100$$

Disease Severity: each tree classified into three strata of branches (top, middle and bottom). From each stratum two branches were selected to record disease severity. Then, disease damaged and healthy berries/ other tissues were counted and calculated as follows:

$$\text{Disease severity (\%)} = \frac{Total\ infected\ berries/leaves}{Total\ counted\ berries/leaves} X100$$

Disease Prevalence: The infected farms were recorded. The prevalence was calculated

$$\text{Disease prevalence (\%)} = \frac{Total\ infected\ farm/field}{Total\ surveyed\ farm/field} X100$$

Data analysis

Collected data was entered into computer using Excel Spread Data Sheet and analyzed by using SPSS computer software.

Results and Discussion

The Prevalence of Coffee Disease at Buno Bedele and Ilu Aba Bora Zones

The result of this study was revealed that three major coffee diseases occurred at the study areas. The prevalence of CBD showed that highest prevalence (93.30%) recorded from Didesa district followed (86.70%) recorded from Ale, Chora, Gachi and Halu districts. The lowest prevalence (73.30%) CBD recorded from Yayo district. The highest CLR (100%) prevalence recorded at Yayo district and the lowest (73.30%) CLR prevalence was recorded at Didesa district. The highest (73.30%) of CWD prevalence recorded from Yayo and Chora districts, the lowest

(46.70%) CWD prevalence was recorded from Halu district. This result shows more farms of Buno Bedele and Ilu Aba Bora zones occurred by CLR and CBD diseases followed by CWD disease (Figure 2).

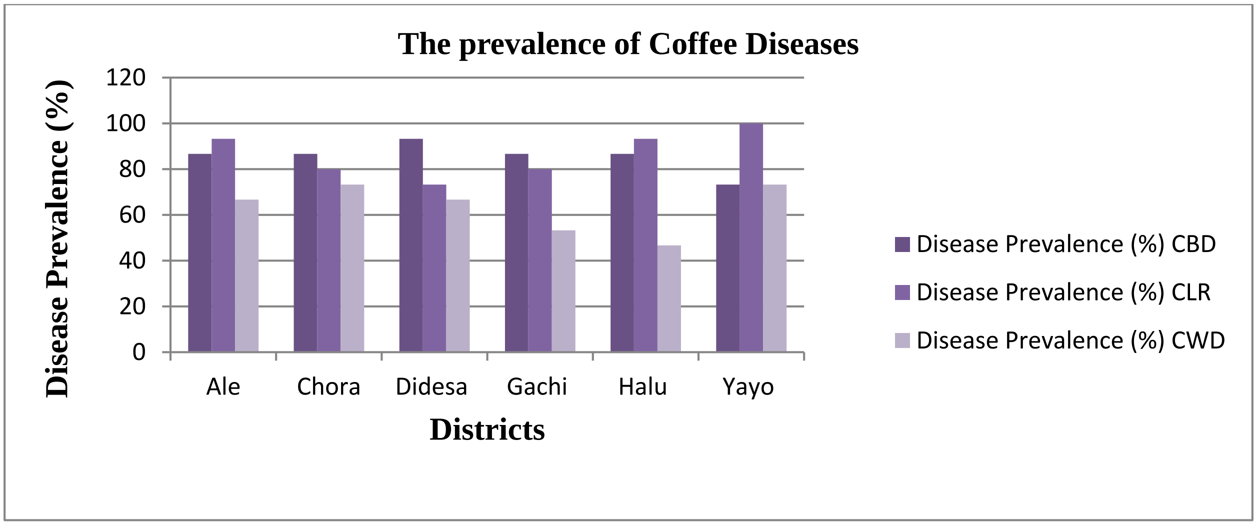

Figure 21. The prevalence status of coffee diseases at the study areas

The Incidence and Severity of Coffee Disease at Buno Bedele and Ilu Aba Bora Zones

The highest (61.6%) mean of CBD incidence was recorded at all districts followed by (59.1%) mean of CLR incidences at surveyed districts. CWD was also observed at all districts and recorded with mean intensity 32.9% (Table 2). The range of CBD was 22.5-89 followed by 31-82 range of CLR Incidences.

The highest (55.0%) severity of CBD was recorded from Gachi district followed by (54.4%) from Chora district. The lowest (44.7%) of CBD severity was recorded from Yayo district. The result of CLR severity was recorded at all districts, the highest (60%) was recorded from Yayo, whereas, the lowest (41.2) recorded from Ale district.

Table 29. Status Incidence and Severity of coffee diseases at Buno Bedele and Ilu Aba Bora zones

District	Disease Incidence			Severity (%)	
	CBD	CLR	CWD	CBD	CLR
Chora	68.5	62.5	34.3	54.4	51.1
Didesa	66.0	53.3	29.3	52.3	44.4
Gachi	69.4	52.6	34.3	55.0	43.4
Ale	62.0	56.0	36.7	46.9	41.2
Halu	52.7	62.3	30.7	45.1	52.7
Yayo	50.9	68.3	32.3	44.7	60.0
Mean	61.6	59.1	32.9	49.7	48.8
Range	22.5-89	31-82	13-47.5	18-74	26-77

Where: CBD: Coffee Berry Disease, CLR: Coffee Leaf Rust, and CWD: Coffee Wilt Disease

The status of Incidence and Severity of Coffee Diseases across Different Agro ecology

The highest (52.0%) CBD mean incidence was recorded at the highland of Gachi district and followed by Ale district (50.0%). The lowest (6.0%) CBD mean incidence was recorded at the lowland of Yayo district. The highest (50%) mean incidence of CLR was recorded at the lowland of Yayo district and followed by lowlands of Chora, Halu and Didesa districts by mean of 36%. The lowest (14.0%) was recorded from the midlands of Halu, Didesa and highland of Chora district (Table 3). This result was similar with earlier study (Abdi, 2020) which revealed the incidence and severity of CBD was very high at higher altitudes. This shows that CBD favors high rainfall, high altitude and humidity areas than lowland areas, where as CLR favors at lowland agro ecology. Similarly, Bayetta (2001) explained high CBD occurrence related with high humidity with high altitude around Gera. This might be at higher elevations low night temperatures followed with low day temperatures was found which make the pathogen in passive for a longer period and slower epidemic while in lower elevation it hastens rust development since high temperature make suitable condition for pathogen. At lower altitudes, CLR may benefit from higher temperatures (Lamouroux et al., 1995). The highest (50%) CWD incidence recorded from lowland of Chora followed by 30% followed by midland of Yayo district. The lowest (16%) incidence was recorded from highland of Gachi district. This shows that with extended dry seasons predicted in future climatic scenarios that CWD could have a more severe impact (CABI, 2021).

Table 30. Status of major coffee disease incidence under different coffee Agro-ecology during 2021

Districts	Incidence (%) of Disease per agro ecology								
	CBD			CLR			CWD		
	Highland	Midland	Lowland	Highland	Midland	Lowland	Highland	Midland	Lowland
Gachi	52.0	36.0	20.0	30.0	24.0	30.0	16.0	27.5	30.0
Chora	42.0	26.0	22.0	14.0	20.0	36.0	28.0	28.0	50.0
Didesa	44.0	42.0	24.0	20.0	14.0	36.0	22.0	38.0	24.0
Ale	50.0	32.0	24.0	20.0	14.0	30.0	24.0	20.0	28.0
Halu	40.0	18.0	12.0	18.0	24.0	36.0	24.0	18.0	28.0
Yayo	18.0	14.0	6.0	24.0	30.0	50.0	24.0	30.0	24.0
Mean	41.0	28.0	18.0	21.0	21.0	36.3	23.0	26.9	30.6
S.d.	12.1	10.7	7.3	5.4	6.2	7.3	3.9	7.2	9.7

Where: CBD: Coffee Berry Disease, CLR: Coffee Leaf Rust, and CWD: Coffee Wilt Disease

The highest severity of CBD was recorded from the highland of Ale district by 38.6% then followed by highland of Gachi district with 33.8%, whereas, the lowest (5.2%) was recorded from lowland of Yayo district. The highest severity of CLR (47.6%) was also recorded at the lowland of Yayo district followed by 29.4% of lowland of Halu district, whereas the lowest (10.6%) was recorded from midland of Ale district (Figure 3). This result shows coffee grown in lower altitudes is more predisposed to the CLR and suffers more attacks (Ritschel, 2005).

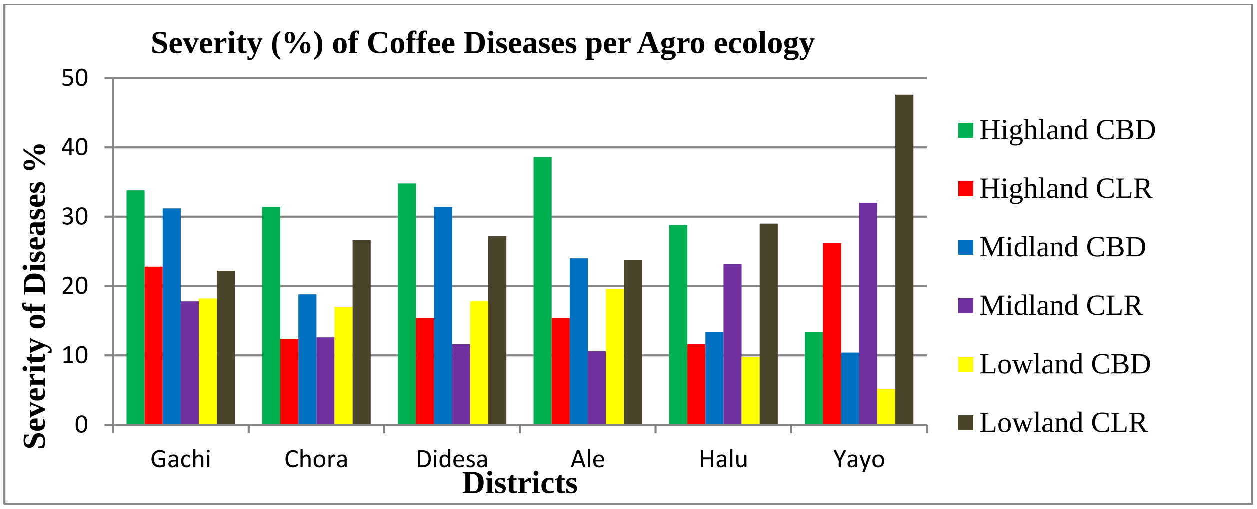

Figure 22. Status of Coffee Disease Severity under different Agro ecology

The Effect of Shade Condition on the Status of Coffee Diseases in surveyed areas

The result showed that the lowest severity (12.4%) CLR was recorded from shaded coffee farms than un shaded farms, whereas the highest severity (22%) was recorded from un shaded farms (Figure 4). This shows in low shade level or un shaded condition efficient light penetration under such conditions make high temperature which in turn increases disease intensity of CLR diseases. Additionally, there might be the presence of optimum microclimate conducive for pathogen occurrence and distribution (Ano. et al., 2021). This result agrees with the previous reported of Mohamedsani and Hika, (2017) which revealed that the incidence of CLR was lower under shade condition but higher under un shaded farms.

In other wise this study results showed that the highest mean incidence (36%) and severity (27%) of CBD was recorded from coffee farms covered with shade tree. This might be due to the most favorable shade for the fungus was that provided by fruit trees or forest species and an absence of pruning also acted in favor of the fungus. Due to that the wetter period, the more intense were the epidemics. CBD development depends on climatic factors such as rainfall, temperature, and relative humidity (Guyot et al., 2001). Rainfall is the main agent of Colletotrichum spp. conidium dispersal (Mouen Bedimo et al., 2006). Most of Coffee growing areas in Buno Bedele and Ilu Aba Bora are under forest and more shaded which not regulated as Coffee needed. Therefore, CBD was critical disease at study area. This result agrees with the work of Avelino et al. (2007) who reported that reducing losses caused by the disease through the use of shade plants is an original prospect for reducing CBD impact, because the incidence of fungal diseases is often greater under shade. This result also, dis agrees with (Mouen Bedimo et al., 2008) who reported shade could limit rain intensity and subsequently, reduced splash dispersal of Colletotrichum kahawae. CWD also recorded from the study areas highest incidence

(20%) from un shaded coffee areas and lowest incidence (14%) was from shaded condition. This result shows Coffee wilt disease was found in all assessed forest coffee areas suffering considerably in coffee tree losses. This result agrees with Damelash, (2018) who reported the mean incidence (16.9%) was recorded previously from Yayo forest.

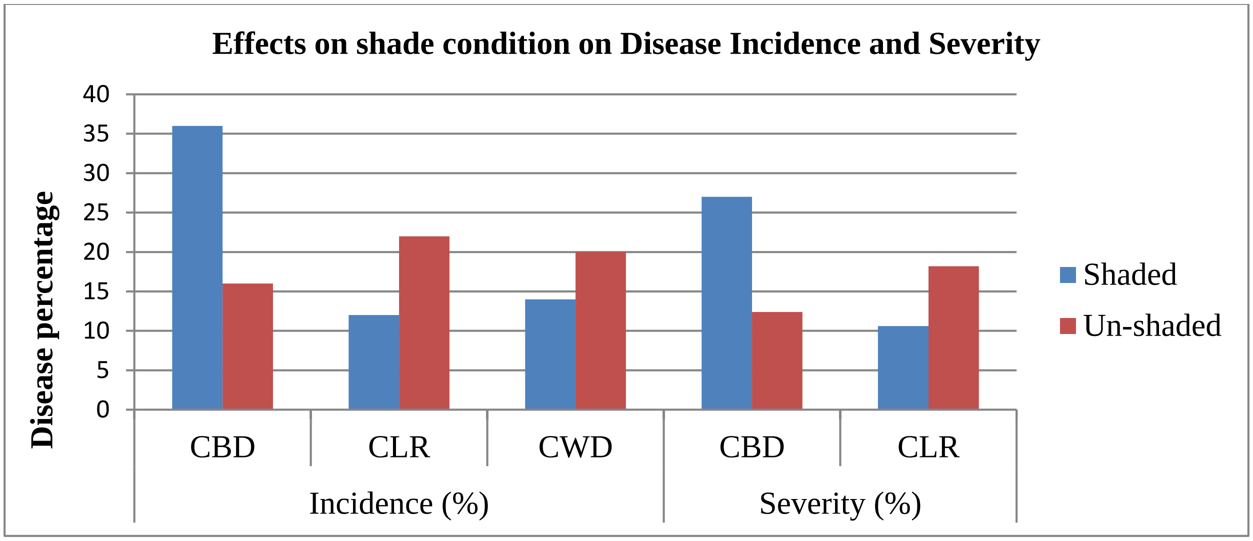

Figure 23. Effects of Shaded and un shaded condition on coffee disease Incidence and Severity

The Effect of Agronomic Practices on the Status of Coffee Diseases in surveyed areas

The result revealed that hoeing practice reduced the incidence of CBD (14%) than slashing and intercropping practice, whereas incidence of CLR (12%) reduced by slashing practice (Table 6). According to the current study different agronomic practices were had effects on severity and incidence of the diseases. The incidence and severity of disease under intercropping practice was very high. This might be due to crops are serve as source of harbor for disease. The lowest incidence diseases were 2.3%, 1.6% and 1.4% recorded by CBD, CLR, and CWD, respectively under pruned coffee plants. This result agrees with Mouen Bedimo et al. (2007) and Joseph (2012) observed that high level management including:- pruning, mulching, appropriate fertilizer application and good weed control contribute to masking the adverse effect of CLR and CBD epidemic on Arabica and Robusta coffee. These good management practices increase plant vigor, making them more tolerant to disease attack (Joseph, 2012). This indicates that in areas of good management practices the intensity of rust was low as compare to poor management practices.

Table 31. Status of Disease under coffee agronomic practice

Agronomic Practice	Incidence			Severity (%)	
	CBD	CLR	CWD	CBD	CLR
Slashing	16.0	12.0	24.0	20.0	14.6
Hoeing	14.0	16.0	14.0	15.4	17.8
Pruning	2.3	1.6	1.4	0.8	0.4
Intercropping	20.0	22.0	22.0	27.0	27.2
Mean	16.6	16.6	20.0	20.8	19.8

Where: CBD: Coffee Berry Disease, CLR: Coffee Leaf Rust, and CWD: Coffee Wilt Disease

The result in the Figure 4 showed that, different agronomic practices had different effects on the types of coffee diseases. Slashing decreased Incidence of CLR (12%) followed CBD (16%) and CWD (24%). Pruning method also decreased the Incidence of CWD (1.4%) followed CLR (1.6%) and CBD (2.3%). From this results Pruning practice was very important to decrease the Incidence of Coffee diseases. However, Intercropping was no significant between different diseases of coffee at the study areas. Cultural agronomic practices (pruning and stumping) that bring about wounding in coffee trees should be done with efficiently disinfected tools to avoid coffee wilt disease (Asmamaw, 2019).

Conclusion and Recommendation

Major Coffee diseases occurred across all study areas. CBD, CLR and CWD were very important disease in all selected districts of both zones. The status of all coffee diseases were varied based on the management practices, agro ecologies and shade conditions in all study areas. Coffee leaf rust and Coffee berry disease were highly increased in the study areas. Generally, high rainfall, high humidity or wetness, and relatively low temperatures that persist for long periods favor CBD development and the disease is invariably severe at higher altitudes where these conditions generally prevail. CWD is the leading disease of coffee, after CBD and CLR in Ethiopia and the most distractive coffee production threat without any solution till now. The soil-borne nature of the pathogen and perennial character of coffee have made management of the disease difficult through the conventional control approach of ‘uproot and burn infected trees at the spot.

Additionally,practicing proper coffee agronomic recommendation, consulting professionals and i mplementation were the knowledge gaps identified among the surveyed farmers in the study area. Further studies should be conducted on the seasonal variation and abundance of major disease assessment on the newly emerging and potentially important disease and the ecological influence on the distribution of disease, the economic threshold level and management practices. As well as the effective integrated disease management strategies should be developed for the study areas.

Generally, adequate training for farmers, extension workers and district's experts on how to manage major disease ought to be given.

Acknowledgements

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7. Survey of major Coffee (Coffea arabica L.) Insect Pests in Buno Bedele and Ilu Aba Bora, Southwestern Oromia, Ethiopia

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Abstract

Coffee (Coffea arabica L.) is the most important and valuable agricultural commodity and beverage cultivated and marketed throughout the world. However, its production and productivity has been decreasing due to major insect pests. Therefore, to overcome these problems, there is need to assess major insect pest infestations and damage level in coffee yields at growing areas. This assessment conducted at Buno Bedele and Ilu Aba Bora zones districts including such like Gachi, Chora, Didesa, Ale, Halu and Yayo. The result of this study revealed that Survey on major coffee insect pests; maximum mean (30.75%) number of Antestia bug was recorded at Ale followed by Didesa (30.5%). Similarly, Blotch leaf minor was also observed in all districts. From the survey result the average infestation of coffee blotch leaf miner at Yayo, Chora, Halu, Gachi, Didesa, Ale was 64.9, 64.5, 61.6, 55.5, 55.0 and 51.8% were recorded respectively. Survey result showed White stem borer (WSB) insect pest was recorded only at Gachi district with 3.1% infestation rate .Generally from the results the production and productivity of coffee in the study area was threatened by insect pests, particularly by anthestia bug and blotch leaf minor. Thus, further study is needed in order to design sound coffee insect pests control methods for the study areas.

Keywords: Coffea arabica L., Antestia bug, Coffee blotch leaf miner, Infestation, Damage level

Introduction

Coffee (Coffea arabica L.) is the most important and valuable agricultural commodity and beverage cultivated and marketed throughout the world and worth up to US $ 14 billion annually for producing country. More than 50 developing countries are earning 25% of their foreign exchange from coffee, (Belay et al., 2016). In Ethiopia Coffee is the largest export crop and the backbone for the country's economy. Ethiopia is the largest producer of coffee in Africa and is the fifth largest coffee producer in the world next to Brazil, Vietnam, Colombia and Indonesia, contributing about 4.2 percent of total world coffee production (USDA, 2022).

This high value crop constrained by many biotic and biotic factors. One of the most common biotic factors is insect pests. Insect pests are among the number of factors considered to limit coffee production both in quality and in quantity (Million and Bayissa, 1986). The crop is prone to a number of diseases and insect pests that attack fruits, leaves, stems and roots and reduce the yield and marketability (Aebissa, 2012). Coffee insect pests are estimated to cause losses of about 13%, but in Africa the yield losses can be higher up to 96%. In different coffee plantations, there are four major economically important insect pests such as, white stem borer (Anthores leuconatus), antestia bug (Antestiopsis spp.), coffee berry borer (CBB), Hypothenemus hampei and coffee leaf miner (CLM) Leucoptera meyricki. Other coffee insect pests have low economic damage (Aebissa, 2012; Nahayol and Bayisenge, 2012). Over 47 species of insect pests are recorded on coffee (Million and Bayissa, 1986; Crowe and Tadesse, 1984). Among forty seven insect pests of coffee were reported only two insect pests antestia bugs and coffee leaf minor are the major insect pests (Mendesil, et al., 2008).

But there is no sufficient recent information on the current distribution and status of major coffee insect pests in south western of the country, particularly in Buno Bedele and Ilu Aba Bora Zones. Survey of insect pests on coffee is important to determine the level of damage caused by them and facilitate effective control strategies.

Survey of coffee insect pest is important to determine status of the insect pests and give information for management strategy/s in the study areas. Thus, this work was initiated with the objective was to assess prevalence, incidence and damage level of coffee insect pests infestation at both Buno Bedele and Ilu Aba Bora Zones areas.

Materials and Methods

Description of study areas

Survey was conducted in potential coffee districts of Buno Bedele and Ilu Aba Bora zones. Six major coffee producing districts (Gachi, Chora and Didesa) from Buno Bedele zone and (Ale, Halu and Yayo) from Ilu Aba Bora zone were purposively selected. Geographical information was recorded by using GPS at the point of farm assessed across districts (Table 1).

Table 32.Weather conditions of surveyed districts of Buno Bedele and Ilu Aba Bora zones

Districts	Altitude (masl)	Latitude N	Longitude E	Annual Rainfall (mm)	Min.Temp. (oC)	Max.Temp (oC)
Ale	1648-2377	8o02’0.00”	35o39’59.99”	1982	14	19
Chora	1470-2516	8o19’60.00”	36o14’60.00”	1350	9	31
Didesa	1428-2512	8o04’60.00”	36o39’59.99”	1800	13	28
Gachi	1363-2553	8o19’60.00”	36o39’59.99”	1100	13	18
Halu	1370-1917	8o8’51.26”	35o20’27.74”	1450	18	24
Yayo	1304-2587	8o20’35.09’’	35o48’58.83’’	2300	7	32

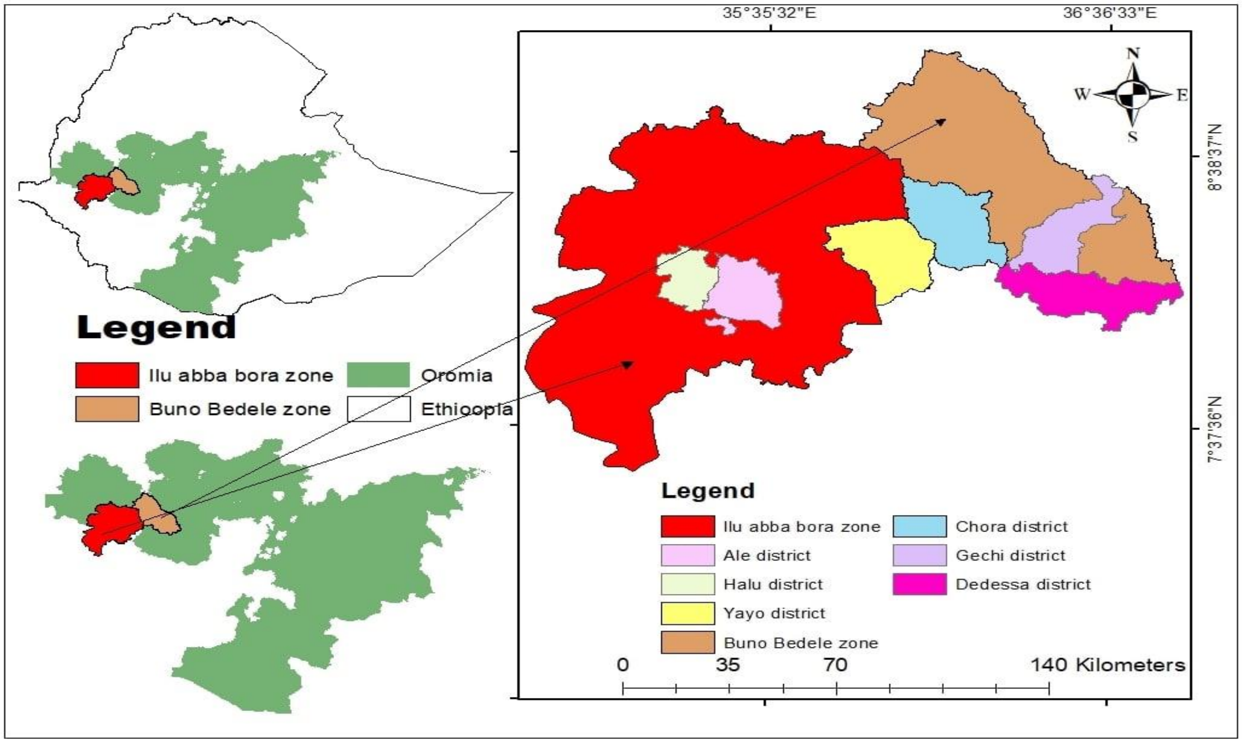

Figure 24. Map of the study area

Coffee Insect pest Survey Methods

Each district was categorized into agro ecologies kindly highland, midland and lowland. From each agro ecology 5 farms were used in interval of 3-5 km and 25 trees per farm were assessed. Totally, 90 coffee farms were surveyed for the insect pest infestations and other required data were collected. At each farm a questionnaire was administered and the owner was asked about the age the tree, type of coffee cultivar/landraces and disease history. The farms also were diagnosed for agronomic practice applied, weed control method, shade tree condition (shaded or un-shaded) and factors which contribute in occurrence, distribution, infestations and severity of insect pests. Assessment methods like prevalence, incidence and damage level were used during field assessment. Generally, collected coffee insect pest data insect pest infestations and insect pest damage level were summarized according to the following formula

Insect pest Infestations: from each sampled farms 25 trees were diagonally assessed for the presence or absence of insect pests. Then infestation calculated as follows:

Infestation (%)= $\frac{Total\ infected\ trees}{Total\ assessed\ trees} X100$

Insect pest damage level: each tree selected was classified into top, middle and bottom branches strata. From each stratum, a pair of branches was selected for pest data recording. Pest damaged and healthy berries/leaves were counted, then calculated as follows:

$$\text{Damage (\%)} = \frac{Total\ infected\ berries\ or\ leaves}{Total\ counted\ berries\ or\ leaves} X100$$

Insect Pest Prevalence: The infested farms counted, and then calculated.

$$\text{Prevalence (\%)} = \frac{Total\ infested\ farms}{Total\ assessed\ farms} X100$$

Data analysis

Collected data was pooled in to computer using Excel Spread Data Sheet and analyzed by using SPSS computer software.

Results and Discussions

Status of Coffee Insect pest Prevalence at Buno Bedele and Ilu Aba Bora Zones

The prevalence of Antestia bug showed that highest prevalence (86.7%) recorded from Ale district followed (80.0%) recorded from Didesa district. The lowest prevalence (46.7%) Antestia bug recorded from Yayo district. The highest Blotch leaf minor (93.3%) prevalence recorded at Yayo district and the lowest (53.30%) Blotch leaf minor prevalence was recorded at Ale district. The only (40.0%) of white stem borer prevalence recorded from Gachi district. This result shows Antestia bug and Blotch leaf minor insects are more serious at Buno Bedele and Ilu Aba Bora zones (Table 2).

Table 33. The Prevalence status of Insect Pests at Buno Bedele and Ilu Aba Bora zones

Districts	Insect pest Prevalence		
	ANB	BLM	WSB
Gachi	60.0	73.3	40.0
Chora	66.7	90.0	0.0
Didesa	80.0	80.0	0.0
Ale	86.7	53.3	0.0
Halu	73.3	83.3	0.0
Yayo	46.7	93.3	0.0
Mean	68.9	78.9	6.7

Where: AnB: Antestia Bug, BLM: Blotch Leaf Minor, WSB: White Stem Borer

Status of Insect pest Infestations and Damage level at Buno Bedele and Ilu Aba Bora Zones

The assessment was carried out to study the current status of major coffee insect pests. Antestia Bug (AnB), Blotch Leaf Minor (BLM) and White Stem Borer were identified as major coffee insect pests in the Buno Bedele and Ilu Aba Bora zones. From the Assessed areas maximum

(30.75%) number of Antestia bug was recorded at Ale followed by Didesa (30.5%) districts and minimum (12.7) recorded at Yayo district (Table 3). Similarly, Blotch leaf minor was also observed in all districts. From the survey result the average infestation of coffee blotch leaf miner at Yayo, Chora, Halu, Gachi, Didesa, Ale 64.9%, 64.5%, 61.6%, 55.5%, 55.0% and 51.8% were recorded respectively (Table 3). Survey result showed coffee White stem borer (WSB) was recorded only at Gachi with the infestation level 3.1% district. According to this survey result BLM was recorded with high infestation rate across surveyed districts. This might be due to climate change the condition is more favor to this insect. This survey result was agrees with the previous findings reported by (Tamiru, 2017) who concluded that at south western parts, blotch leaf miner recorded with the damage level ranged from 2.25 - 96.4% per coffee seedling and average of infestation with 52.10%.

Table 34. The mean Infestations of major coffee insect pests at Buno Bedele and Ilu Aba Bora zones during 2021

Districts	Infestations (%)			Damage level (%)	
	AnB	BLM	WSB	AnB	BLM
Gachi	29.0	55.5	3.1	23.9	38.3
Chora	22.3	64.5	0.0	19.9	40.9
Didesa	30.5	55.0	0.0	24.3	36.2
Ale	30.75	51.8	0.0	26.7	40.4
Halu	12.95	61.6	0.0	7.4	42.0
Yayo	12.7	64.9	0.0	8.8	47.7
Range	4.5-42	38-77	0-5.2	3-39	35-68
Mean	23.0	58.8	0.52	18.5	40.9

Where: AnB: Antestia Bug, BLM: Blotch Leaf Minor, WSB: White Stem Borer

The Effect of Agro ecology on the Infestations and Damage level of coffee insect pests

From the results the highest (46.4%) coffee blotch leaf miner infestation level was recorded at lowland of Ale while the lowest (12.8%) was recorded at Highland of Halu district (Table 4). However, white stem borer insects recorded from different agro ecologies of Gachi district.

The assessed results showed that coffee blotch leaf miner was found in all assessed coffee farms of districts with high infestation and damage level. This might be due to the current climate changes. This result has agree with the work of Ano, et al., (2022) which revealed the occurrence and distribution of coffee blotch miner has been increased and which becoming the most important insect pest in the southern Ethiopia.

The highest (30.0%) Antestia bug infestation was recorded at Highland of Yayo, while the lowest (3.2%) was recorded at the midland of Halu district. This might be due to the increase of antestia bug population in higher elevation at low temperature was found. This study is agreement with (Ahmed et al., 2016) who reported based on intrinsic rate of increase obtained from laboratory study showed the pest prefers low temperature.

Table 35. Mean Infestations of coffee major insect pests under different Agro ecology during 2021 in surveyed areas

Districts	Infestations of Insects (%) per Agro ecology								
	ANB			BLM			WSB		
	Highland	Midland	Lowland	Highland	Midland	Lowland	Highland	Midland	Lowland
Gachi	12.0	10.0	8.4	22.4	28.0	29.6	4.8	6.8	6.0
Chora	10.0	6.0	4.0	20.8	17.6	22.4	0.0	0.0	0.0
Didesa	12.0	6.0	8.0	18.4	18.4	26.4	0.0	0.0	0.0
Ale	29.6	24.4	9.0	28.8	41.2	46.4	0.0	0.0	0.0
Halu	5.6	3.2	4.8	12.8	27.6	40.0	0.0	0.0	0.0
Yayo	30.0	17.6	13.6	13.6	29.2	24.8	0.0	0.0	0.0
Mean	16.5	11.2	7.9	19.4	27.0	31.6	0.8	1.1	1.0
Std. dev	10.5	8.2	3.5	5.9	8.6	8.5	1.9	2.7	3.4

Where: AnB: Antestia Bug, BLM: Blotch Leaf Minor, WSB: White Stem Borer

The highest (24.8%) damage level of Antestia bug recorded from highland of Yayo district followed by (22.4%) highland of Ale district, whereas the lowest (1.6%) from midland of Halu district. The highest (42.4%) damage level of Blotch leaf minor recorded from lowland of Ale district followed by (37.2%) from midland then (28.8%) from lowland of Halu district, whereas lowest (10.4%) recorded from highland Halu and Yayo districts (Table 5). This result shows the damage level of Antestia bug favored highland areas, while Blotch leaf minor favored at lowland areas.

Table 36. Mean Damage level of major coffee insect pests under different agro ecology during 2021 in surveyed areas

Districts	Damage level of Insects (%) per Agro ecology					
	ANB			BLM		
	Highland	Midland	Lowland	Highland	Midland	Lowland
Gachi	8.0	7.0	4.0	16.0	21.6	22.4
Chora	6.0	4.0	2.0	15.2	12.8	16.8
Didesa	8.0	3.0	4.0	16.0	13.6	17.6
Ale	22.4	12.0	7.0	24.8	37.2	42.4
Halu	4.0	1.6	3.2	10.4	24.4	28.8
Yayo	24.8	13.6	9.6	10.4	25.2	21.6
Mean	12.2	6.8	4.9	15.4	22.4	24.9
Std. Dev.	9.0	4.9	2.8	5.2	8.9	9.5

Where: AnB: Antestia Bug, BLM: Blotch Leaf Minor, WSB: White Stem Borer

The Effects of shade condition on infestation and Damage level of insect pest in surveyed areas

The highest infestation and damage level was recorded with the mean 20.0% and 17.6% for Blotch leaf minor with and BLM respectively and while the highest (2.6%) White stem borer infestation under shaded condition. The highest (8.4%) infestation and the highest (6%) damage level Antestia bug was recorded under shaded condition (Figure 3). This result implied that Antestia bug, Blotch leaf minors and White stem borers are more common close to shade trees (Rutherford and Phiri 2006). Previously this result agrees with Mattias, et al., (2014) who reported the infestation levels in the shaded plantations were strikingly high, with on average 56 % of the trees infested, compared to 27 % at the most sun-exposed sites. This might be under shady environment some insect pests such like Antestia bug, Blotch leaf minors and White stem borer gained important hosts from it then they gets favored condition for their life cycles. This result is supported by the previous work done of Staver et al. (2001) and Teodoro et al. (2008) who reported high infestation and severity leaf miners on coffee, due to lower temperatures and higher humidity under shaded conditions. The Antestia bug also increased under shade condition by making favorable conditions, since they prefer dense coffee foliage (Crowe and Tadesse, 1984).

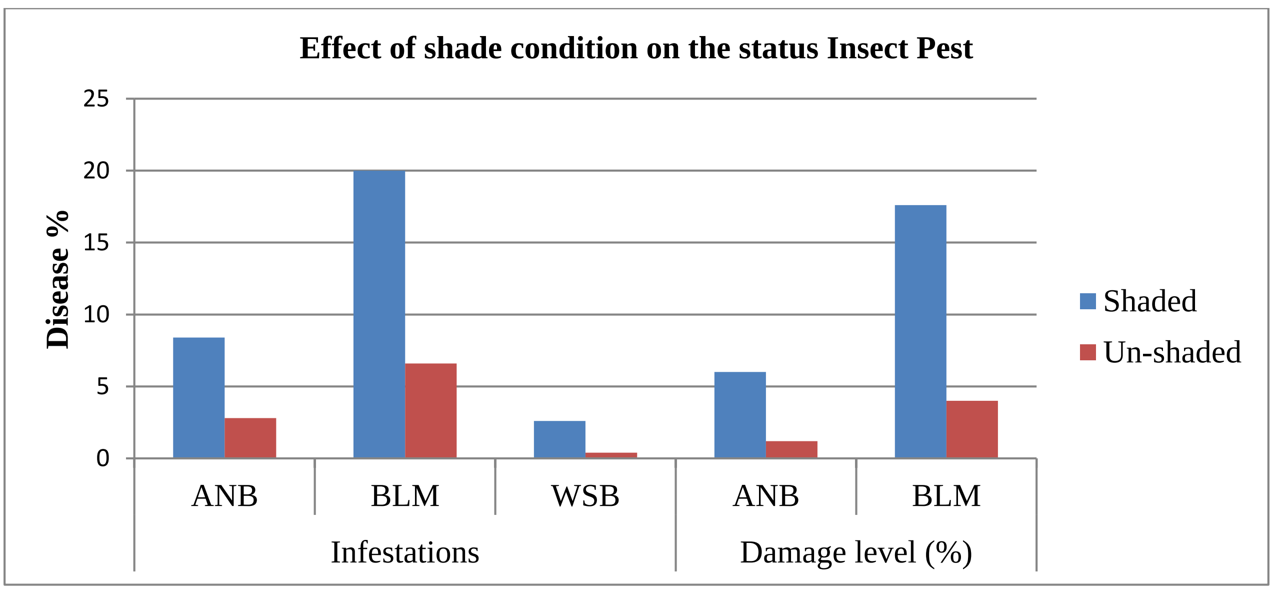

Figure 25. Shade condition on Insect pest Infestation and Damage level

The Impacts of Agronomic Practices on Infestations and Damage level of Coffee Insect Pests in surveyed areas

The assessment result showed that 3.3, 4.1 and 2.7% mean infestations level of Antestia bug, Blotch leaf minor and White stem borer was recorded from pruned coffee farm respectively.

While 5.6% of Antestia bug recorded from the hoeing one and 4.8% Blotch leaf minor recorded from the slashed coffee farms. Mean infestation level 16.8, 19.2 and 6.4% was recorded for Antestia bug, Blotch leaf minor and White stem borer from the intercropped coffee farms (Figure 4). This shows that pruning can reduce insect pest infestations compared to the un-pruned canopy (Feed the Future, 2017). This result is agrees with the findings of Mugo et al. (2013) who reported that in open canopy of pruned coffee makes the habitat unsuitable for rapid reproduction of the insect pest. Whereas intercropping practices with others crops might be problem due to favoring the occurrence of insect pests. This also supported by (Le Pelley, 1968; Jameson, 1970; Bardner, 1985) who reported Intercropping with crops such as bananas that shade coffee trees is to favour higher insect pest infestations.

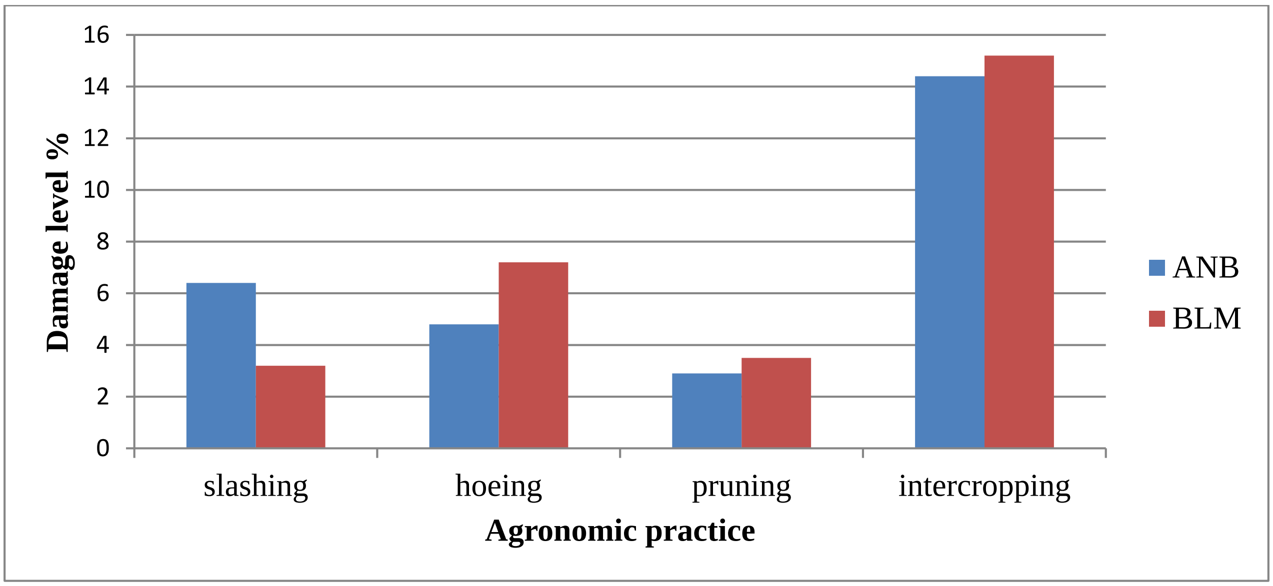

Figure 26. Damage level of Insect Pests under Agronomic practices

Conclusion and Recommendation

AnB and BLM are identified as major coffee insect pests in surveyed area. While, WSB insect pest only occurred in Gachi district. Coffee blotch leaf miner infestation becomes increased in the study areas. The infestation and damaging level might be based on the management practices, agro ecologies and shade.

Detail survey on distribution, infestation and identification of critical season at which the high damage level occurred by insect pest should implemented in order to generate soundness management.

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8. Assessment of Weed Flora Composition in Coffee (Coffea arabica L.) Farms at Buno Bedele and Ilu Aba Bora, South Western Oromia, Ethiopia

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Abstract

Coffee (Coffea arabica L.), which is originated in Ethiopia, is the backbone of the country's economy. However, weed species are great challenges to decrease the yield and quality of coffee in the growing areas. Therefore, this activity initiated to determine composition of coffee weeds species in the study areas. Assessment was conducted in the selected districts of Buno Bedele and Ilu Aba Bora zones including Gachi, Chora, Didesa, Ale, Halu and Yayo. 0.5m x 0.5m quadrats size with zigzag sampling method was used. The result of this study revealed that the weed assessment fields were dominated by large number of weed species. Averagely across surveyed areas, the frequency value of the species was ranged from 13 – 89.9% and 33.3-95.1% at Buno Bedele and Ilu Aba Bora, respectively. The highest frequency value (89.9%) recorded by Justicia schimperiana followed Perilla frutescens (84.8%) at Buno Bedele zone, while in Ilu Aba Bora the highest frequency value (95.1%) was recorded by Bidens pilosa followed by Oplismenus hirtellus (94.2%) and Polygonum nepalense (93.7%). Whereas, the least frequency value recorded from Trifolium repens (40%), Crassocephalum rubens (13%), Cuscusta campestris (33%), Lantana camara (33%), Cynodon dactylon (33%) and Leucas martinicensis (40%) at both zones. The weed species compositions influenced by different districts. Thus, different weed management options would be required for the locations because of less than sixty percent (<60%) similarity indices were recorded from different locations of BunoBedele and Ilu Aba Bora zones. Generally from the results weed species were very important in production and productivity of coffee at the study areas. Thus there should be great considerations and practicing integrated weed management (IWM) is very important in order to reduce weed infestation with coffee farm in study areas.

Keywords: Coffea arabica L., Weeds species, Abundance, Dominance, Frequency, Similarity index

Introduction

Coffee (Coffea Arabica L.), which is originated in Ethiopia, is the backbone of the country's economy. It accounts for 70% of the foreign exchange earning, 10% of the government revenue and employs 25% of the domestic labor force (Tsegaye et al., 2000). It is the most important and valuable commodity in Ethiopia and in the world supporting the economic growth and providing job opportunity to millions of people. Traditionally, coffee trees are cultivated only for the berries, which are processed using dry or wet techniques directly in the growing areas to the final raw product green coffee; this serves as the basis for various coffee products (Taye and Tesfaye, 2002). However, the yield and quality of coffee affected by weed species (Tadese and Tesfu, 2015). In Ethiopia, the warm wet and humid conditions prevailing in the coffee growing areas of south west Ethiopia not only result diverse weed flora ranging from soft annuals to extremely difficult to control perennials but also encourage the continuous growth of weeds all year round.

Weed competition, coffee growth, yield, and quality are seriously decreased and weed control is one of the largest tasks, which entails high cost (Ronchi & Silva, 2006 and Silva & Ronchi, 2008). Crop yield losses due to weed competition varied from 24% to 92% (Lemes et al., 2010). According to Tadesse (2015) yield loss as a result of weed competition can reach as high as 65 % to complete crop failure depending on the type of weeds, coffee growth stage and the prevailing growth conditions. Excluding environmental variables, yield loss in coffee is caused mainly by competition with weeds. Weed interference is a severe problem in coffee, especially in the early part of the growing years, due to slow early growth, narrow canopy, and wide row spacing. Weeds compete with the coffee plants for resources such as light, nutrients, space, and moisture that influence the morphology and phenology of the crop. Furthermore, high weed infestation increases the cost of cultivation, lowers the value of land, and reduces the returns of coffee growers. These factors vary across regions and influence the composition and number of predominant weeds of economic importance to coffee production.

Therefore, assessment of weed composition, distribution and density is essential for a comprehensive understanding of the weed problem that poses negative impacts on coffee production in the study areas. Such assessment of the nature of weed flora determines, to a large extent, the type of weed management measures to be adopted. To design effective weed control measures, identification and quantification of weed species are important steps. Information on weed density, distribution, and species composition may help to predict yield losses and such information helps in deciding whether it is economical to control a specific weed problem. But, in both Buno Bedele and Ilu Aba Bora zones there is poor information regards to weeds composition similarly, the relative importance of common weed species in coffee and cropping systems is not well documented in study areas. Hence, this work was done to assess weed flora composition in coffee growing belts of Buno Bedele and Ilu Aba Bora zones.

Materials and Methods

Description of study areas

Assessment was conducted in potential coffee growing areas of both Buno Bedele and Ilu Aba Bora zones. Depending on major coffee producing areas 6 districts were purposively used for this work. The selected districts were Gachi, Chora and Didesa from Buno Bedele zone and Ale, Halu and Yayo from Ilu Aba Bora zone. Geographical information was recorded by using GPS at the point of farm assessed (Table 1).

Table 37.Weather conditions of assessed districts of Buno Bedele and Ilu Aba Bora zones during 2021

Districts	Altitude (m.a.s.l)	Latitude N	Longitude E	Rainfall (mm)	Min.Temp. (oC)	Max.Temp (oC)
Ale	1648-2377	8o02’0.00”	35o39’59.99”	1982	14	19
Chora	1470-2516	8o19’60.00”	36o14’60.00”	1350	9	31
Didesa	1428-2512	8o04’60.00”	36o39’59.99”	1800	13	28
Gachi	1363-2553	8o19’60.00”	36o39’59.99”	1100	13	18
Halu	1370-1917	8o8’51.26”	35o20’27.74”	1450	18	24
Yayo	1304-2587	8o20’35.09’’	35o48’58.83’’	2300	7	32

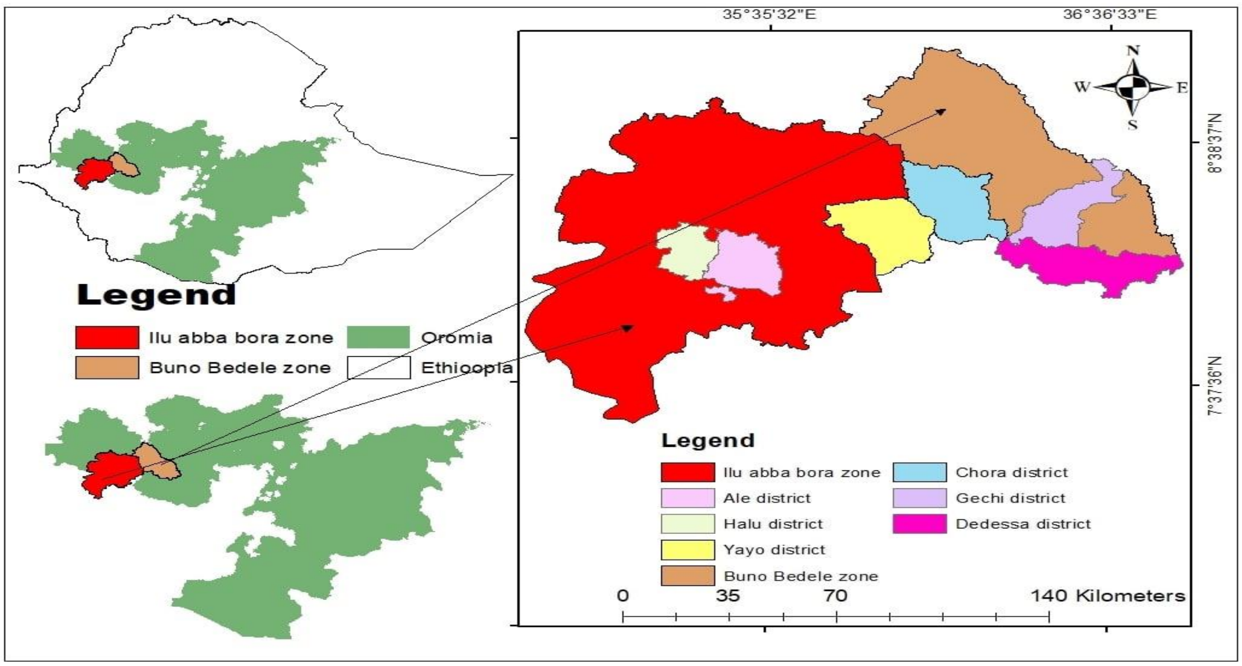

Figure 27.Map of the study area

Coffee weed Assessment procedures

The assessment of the weed coffee in the study areas was carried out during the rainy season from June to September 2021. Ninety Coffee farms were assessed and other required data were collected. Each district was categorized into highland, midland and lowland. From each agro ecology 5 coffee farms were sampled within the interval of 3-5 km. At each farm a questionnaire was administered and the owner was asked about the age the tree, type of coffee species and weed species history. The factors which contribute in occurrence, distribution, frequency and dominance of weeds were identified. Weed population density and diversity was taken with quadrate size 0.5m × 0.5m area with the forwarding throwing method. Zigzag sampling method was used during the survey. Four to five quadrates were taken depending on farm size. Each and every weed species were counted manually and recorded.

Data analysis

The data on weed species composition was analyzed used by quantitative measurements including abundance (A), dominance (D), frequency (F) and similarity index (SI) determinations using the formula as follows described by (Thomas, 1985).

Frequency (F) = It is defined percentage of sampling plots (vegetation registrations) on which a particular weed species is found. It explains how often a particular weed species occurs in the survey area. Frequency was calculated for all weed species as follows:

$F = \frac{X*100}{N}$ Where, F= frequency of particular weed species; X= number of samples in which particular weed species occurs; N= total number of samples

Abundance (A) = It is defined as population density of a weed species expressed as the number of individuals of weed plants per unit area. This was calculated as follows:

$$A = \frac{\sum W}{N}$$

Where, A= abundance; ∑W= sum of individuals of particular weed species; N= total number of samples

Dominance (D) = is abundance of an individual weed species in relation to the total weed abundance (infestation level). It was measured as follows,

$$D = \frac{A * 100}{\sum W}$$

Where, D= dominance of particular weed species; A = abundance of the same species; ∑W = total abundance of all weed species

Similarity Index (SI): It is expressed as similarity of weed communities among different locations. It was calculated as follows $\boldsymbol{SI = 100 * Epg/(Epg + Epa + Epb)}$

Where, SI= similarity index; Epg = number of weed species found in all locations; Epa = number of species only in location a; Epb = number of species only in locatio

Results and Discussions

Status of Weeds in Coffee Farms at Buno Bedele and Ilu Aba Bora Zones

Weed Compositions at Buno Bedele and Ilu Aba Bora zones

Generally 35 weed species were identified from the surveyed 90 fields across surveyed districts. These weed species were distributed in 35 genera and 19 families. The majority of these weed species were fallen to broad leaves (22). In other way, 16 Annuals and 6 perennials, 4 grasses, 4 herbs, 2 shrubs, 2 parasite and 1sedge were recorded (Table 2).

The most dominant families according to the frequency and number of weed species were Asteraceae, Poaceae, Lamiaceae, Amarantheae, Malvaceae and Solanaceae. Moreover, Asteraceae, Poaceae and Fabaceae were also found to be most important in other studies in the tropics (Getachew et al., 2018). These families were also reported to be economically important and common in different parts of the country (Roger et al., 2015).

Table 38.Weed Species Composition Descriptions at Buno Bedele and Ilu Abba Bora Zones during 2021 Weed Survey

No	Families	Common name	Scientific name	Life Cycle and Morphology
1	Acanthaceae	-	Justicia schimperiana	Perennial Shrub
2	Amaranthaceae	Devil's Horsewhip	Achyranthes aspera	Perennial Broadleaf
3	Amaranthaceae	Spiney pigweed	Amaranthus spinosus	Annual Broadleaf
4	Asteraceae	Billy goat	Ageratum conyzoides	Annual Broadleaf
5	Asteraceae	Canada Thistle	Cirsium arvense	Perennial Broadleaf
6	Asteraceae	Dandelion	Taroxacum officinale	Perennial Herb
7	Asteraceae	Goat weed	Ageratum conyzoides	Annual Broadleaf
8	Asteraceae	Black Jack	Bidens pilosa	Annual Broadleaf
9	Asteraceae	-	Crassocephalum rubens	Annual Broadleaf
10	Asteraceae	Gallant Soldier	Galinsoga parvilov	Annual Broadleaf
11	Asteraceae	GuzotiaScabra	-	Annual Broadleaf
12	Boraginaceae	Cynoglossum	Cynoglossum lanceolatum	Annual Broadleaf
13	Commelinaceae	Tropical spiderwort	Commelina benghalensis L.	Annual Broadleaf
14	Convolvulaceae	Dodder	Cuscusta campestris	Parasite
15	Cyperaceae	Sedge	Cyperus esculenta	Sedge
16	Euphorbiaceae	Wild Poinsettia	Euphorbia esula	Annual Broadleaf
17	Fabaceae	Clover	Trifolium repens	Perennial Herb
18	Lamiaceae	Ground Ivy	Glechoma hederacea	Perennial Broadleaf
19	Lamiaceae	Bobbin Weed	Leucas martinicensis	Annual Broadleaf
20	Lamiaceae	Damakase	Ocimum lamilifolium	Perennial Broadleaf
21	Lamiaceae	Shiso/beefsteak	Perilla frutescens	Annual Herb
22	Lamiaceae	Meskel Flower	Bidens pachyouma	Annual Broadleaf
23	Malvacea	Chinese jute	Abutilon theophrasti	Annual Broadleaf
24	Malvacea	-	Sida rhombifolia	Perennial Broadleaf

25	Orobanchaceae	Yerba sosa	Orobanche ramose L.	Parasite
26	Poaceae	African Coach Grass	Digitaria abyssinica	Perennial Grass
27	Poaceae	Bermuda grass	Cynodon dactylon	Perennial Grass
28	Poaceae	Basket Grass	Oplismenus hirtellus	Perennial Grass
29	Poaceae	Ethiopian Grass	Snowdenia polystachya	Perennial Grass
30	Polygonaceae	Snake weed	Polygonum nepalense	Annual Broadleaf
31	Portulacaceae	Purslane	Portulaca oleracea	Annual Broadleaf
32	Solanaceae	Thorn Apple	Datura stramonium	Annual Broadleaf
33	Solanaceae	Wild Egg Plant	Solanum xanthocarpum	Perennial Herb
34	Urticaceae	Himalayan nettle	Girardinia diversifolia	Annual Broadleaf
35	Verbenaceae	Lantana Camara	Lantana camara L.	Perennial Shrub

Frequency of weed species at Buno Bedele and Ilu Aba Bora coffee growing belts during 2021

The weed assessment fields of Ilu Aba Bora and Buno Bedele zones were dominated by large number of species. This result shows weeds increased due to long duration of rain fall, fertilizer application and humidity which create conducive environment for its growth. Averagely over locations, the frequency value of the species ranged from 13 – 89.9% and 33.3 - 95.1% at Buno Bedele and Ilu Aba Bora respectively. The highest frequency value (89.9%) recorded by Justicia schimperiana followed by Perilla frutescens (84.8%) at Buno Bedele zone and the highest frequency value (95.1%) recorded by Bidens pilosa followed by Oplismenus hirtellus (94.2%) and Polygonum nepalense (93.7%) at Ilu Aba Bora zones.

Whereas, the least frequency value recorded from Trifolium repens (40%), Crassocephalum rubens (13%), Cuscusta campestris (33%), Lantana camara (33%), Cyno don dactylon (33%) and Leucas martinicensis (40%) at both zones (Table 3). Most of coffee fields of the study areas occurred by annual weeds rather than perennials. This result line with (Begum, 2008) who reported that different frequencies of different weed species including broad leaves, grasses, and sedges. Most of the common weeds in all surveyed areas were found in annual nature followed by perennials.

Abundance of weed species in Buno Bedele and Ilu Aba Bora coffee growing belts during 2021

The results showed that from 35 weed species the averagely range of weed abundances were from 2.7- 25.5 at Ilu Aba Bora and 3.4 – 22.4 at Buno Bedele zone. The highest abundance value (25.5) was recorded by Polygonum nepalense followed by Trifolium repens (22.8) and (22.6) was recorded by Portulaca oleracea. Whereas, the least abundance value (2.7) was recorded for Argemone mexicana L. at Ilu Aba Bora zone. While, the highest abundance value 22.4, 19.1, 16.5 were recorded by Perilla frutescens, Justicia schimperiana and Cyperus esculenta respectively, whereas the least abundance value 3.5 recorded by Cynoglossum lanceolatum at

Buno Bedele zone (Table 3). From this results most abundant weed species were Broadleaf then grasses, shrubs and herbs were occurred in both zones.

Weed species field density in Buno Bedele and Ilu Aba Bora coffee growing areas during 2021

The top ten of weed species field density at the study areas was recorded with Polygonum nepalense (24.8), Portulaca oleracea (20.2), Bidens pilosa (19.8), Oplismenus hirtellus (19.7), Justicia schimperiana (19.2), Perilla frutescens (19.2), Glechoma hederacea (18.2), Ageratum conyzoides (14.6), Galinsoga parvilov (13.0) and Amaranthus spinosus (12.5) were recorded. The lowest result (1.9) was recorded by Argemone mexicana L. at the study area (Table 3).

This field density varied from district to district and even from kebele to kebele, farm to farm. Unlike field, density has resulted due to some factors like weed managements practiced by growers including cultural, mechanical, chemical and so on, biological including eaten by wild animals, birds, insects, over dominated by anther weed species and etc., physically like poor germination, soil pH, soil moisture stress and etc.

Dominance of weed species at Buno Bedele and Ilu Aba Bora coffee growing areas during 2021

The results showed that from assessment areas the weed dominance ranged between 22.4% and 1.6% which was recorded by Perilla frutescens and Argemone mexicana L., respectively (Table 3). Weed species Perilla frutescens (22.4), Justicia schimperiana (18.9), Glechoma hederacea (11.2) were occurred most dominantly in Buno Bedele coffee growing areas, while Justicia schimperiana (18.0) Oplismenus hirtellus (15.2) and Bidens pilosa (15.0) were occurred dominantly in Ilu Aba Bora zones during 2021 coffee growing season. Similar results were found from Gidesa et al., (2016) reported that if the specific plant species had higher dominance value, it indicate the economic importance of it. Therefore, this study confirmed that Perilla frutescens and Justicia schimperiana species are the major social, environmental and economic threats in the study area.

Table 39. The Quantitative Weed Species composition in Buno Bedele and Ilu Abba Bora rainy season during 2021

		Frequency		Density		Abundance		Dominance	
No	Scientific Name	BB	IAB	BB	IAB	BB	IAB	BB	IAB
1	Abutilon theophrasti	63.5	66.7	4.6	3.5	6.9	5.4	4.6	2.6
2	Achyranthes aspera	68.6	72.7	2.7	7.3	4.2	9.7	2.9	5.7
3	Ageratum conyzoides	60.0	77.8	3.8	14.6	5.9	19.0	3.8	9.7
4	Amaranthus spinosus	69.2	87.9	8.0	12.5	10.8	13.7	7.2	8.7
5	Argemone mexicana L.	66.7	69.1	2.6	1.9	4.2	2.7	2.9	1.6
6	Bidens pachyouma	60.0	66.7	5.4	9.6	10.2	14.1	7.0	7.0
7	Bidens pilosa	80.7	95.1	9.9	19.8	11.6	20.8	10.5	15.0
8	Cirsium arvense	0.0	0.0	0.0	2.0	0.0	3.7	0.0	1.4
9	Commelina benghalensis L.	68.2	82.2	5.2	8.6	7.3	9.9	5.9	6.2
10	Crassocephalum rubens	13.0	66.7	6.0	7.4	6.0	12.1	5.6	5.1
11	Cuscusta campestris	66.7	33.3	4.2	3.3	6.4	10.0	5.0	2.2
12	Digitaria abyssinica	83.4	58.3	5.3	2.4	6.0	4.3	7.0	1.9
13	Cynodon dactylon	33.3	0.0	3.7	0.0	11.0	0.0	3.9	0.0
14	Cynoglossum lanceolatum	66.7	57.2	2.1	3.8	3.4	6.5	2.6	2.7
15	Cyperus esculenta	66.7	70.4	11.5	5.7	16.5	7.3	8.7	3.8
16	Datura stramonium	73.4	50.0	3.5	4.2	4.4	8.3	4.3	3.1
17	Euphorbia esula	65.4	76.2	4.5	9.2	6.8	11.4	5.4	7.2
18	Galinsoga parvilov	69.8	87.9	8.4	13.0	12.2	14.8	10.3	9.8
19	Girardinia diversifolia	61.9	79.2	7.0	7.0	10.2	8.2	6.8	4.5
20	Glechoma hederacea	73.6	92.2	10.7	18.2	13.6	19.3	11.2	13.9
21	Guizotia scabra	51.8	88.9	6.5	11.5	12.6	13.3	7.6	8.9
22	Justicia schimperiana	89.9	88.1	18.2	19.2	19.1	22.0	18.9	18.0
23	Lantana camara	0.0	33.3	0.0	3.7	0.0	11.0	0.0	2.8
24	Leucas martinicensis	40.0	66.7	3.3	7.0	8.9	10.3	2.8	4.7
25	Ocimum lamilifolium	66.7	66.7	5.8	8.2	8.5	9.5	4.2	5.9
26	Oplismenus hirtellus	79.8	94.2	8.9	19.7	11.4	20.8	10.0	15.2
27	Orobanche ramosa L.	66.7	0.0	8.3	0.0	12.5	0.0	10.5	0.0
28	Perilla frutescens	84.8	85.1	19.2	17.9	22.4	20.3	22.7	13.4
29	Polygonum nepalense	73.9	93.7	10.3	24.8	13.7	25.8	9.9	14.8
30	Portulaca oleracea	72.2	83.3	9.5	20.2	13.5	22.6	9.8	14.1
31	Sida rhombifolia L.	51.5	66.7	2.1	2.7	4.4	4.1	2.3	2.0
32	Snowdenia polystachya	66.7	70.4	4.3	7.8	6.5	11.3	6.2	5.2
33	Solanum xanthocarpum	56.0	63.0	2.6	2.7	4.0	4.4	2.8	2.1
34	Taroxacum officinale	0.0	62.7	0.0	4.4	0.0	6.5	0.0	3.3
35	Trifolium repens	40.0	44.4	3.3	8.6	9.2	22.8	4.7	6.5

Effect of Different Management Practices on Weed Species Occurrences and Distributions

The survey results showed that the current status of management practices in the study areas was visually observed. The present study identified the cultural practices (Slashing, hoeing, hand weeding, mulching, cropping systems, soil fertility) which had contributions in the abundances and occurrences of weed species.

During survey time, most of farmers coffee field was exposed to weeds due to lack management. According to many farmers, there are no weeds affecting coffee yield and also they only slashing the weeds when they are ready to harvest.

Depend on this reason; the variation was observed in abundance, dominance and frequency of weed species in the study areas. Some factors including farmer's practices, agro-ecology, soil types and climatic conditions were made vary in case of weed quantitative measurements.

This result was agree with the findings of Mennan and Isik (2003) who reported that difference in field management practices applied to the different survey strata could be the cause vary in distribution, abundance and dominance of the weed species.

Similarity Indices

Similarity index is the similarity of plant species composition among different districts in two Zones. The result showed a similarity index value of 36 - 38% and 36 - 40% among the districts of Buno Bedele and Ilu Aba Bora zones respectively (Table 4 & 5). As described by (Begum, 2008), if the index of similarity is below 60%, it is said that the two locations have different weed communities. The weed species composition was dissimilar between districts of both zones noted that weed growth, population density and distribution vary from place to place depending upon soil and climatic factors that affect the weed species and farmers management practices. Thus, different weed management options would be required for the locations differing in weed flora composition, while all surveyed areas had shown the similarity indices less than sixty percent (<60%).

Table 40. Similarity index of weed species at three districts of Buno Bedele Coffee growing areas

Districts	Gachi	Chora	Didesa
Gachi	100.0	37.5	36.3
Chora		100.0	36.7
Didesa			100.0

Table 41. Similarity index of weed species at three districts of Ilu Abba Bora Coffee growing areas

Districts	Ale	Halu	Yayo
Ale	100.0	36.5	40.0
Halu		100.0	37.8
Yayo			100.0

Note: - Similarity indices between both zone districts were less than sixty percent (<60%)

Conclusion and Recommendation

A total of 35 coffee weed species belongs to 19 families were identified. The large majority of these, 22 were fallen to broad leaf species from this 16 Annuals and 6 (Six) perennials. While, the remaining species fallen to grasses (4), herbs (4), shrubs (2), Parasite (2) and sedge (1).

The occurrences and distributions of some weed species is influence due to management practices, agro ecologies and shade conditions in the study areas. Weed species composition also varied between and within the locations in zones at all surveyed areas. Thus, different weed management options would be required for the locations differing in weed composition, while all surveyed areas had shown the similarity indices less than sixty percent (<60%). Further identification of weed species composition, characteristics, competition, and flora shift is necessary to adopt effective weed management options.

Therefore, coffee producers or growers should consider time of weed competition with the crops and controlling time.The importance of appropriate and readily available practices for weed control should be overemphasized for increasing of coffee production and enhancement of harvesting hard currency. The weed control methods of (cultural, physical, biological, chemical etc.) should be combined in an integrated weed management strategy (IWM).

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