Review Article

Ecological suitability analysis for beekeeping using GIS and AHP Model in Gedeo Zone of Southern Ethiopia

Abstract

All areas looking green may not be suitable for beekeeping. Therefore, the aim of the study was to identify and map suitable beekeeping ecology in Gedeo Zone of Southern Ethiopia. Seven suitability elements that have an impact on beekeeping activity were chosen. From each of the study districts, both primary and secondary data sources were gathered. The weighted linear combination analytical technique was utilized to determine if the land was suitable for beekeeping using a multi-criteria decision analysis. The Gedeo Zone contained 98 identified bee foraging plant species. Five significant and abundant bee foraging plants, including *Coffee, Croton, Eucalyptus, Syzygium, and Vernonia species* were identified and mapped *as* monofloral honeys source plant species. With the exception of Bule and Gedeb districts, every area in the Gedeo Zone produced coffee honey. Four honey harvesting months were identified. Accordingly, In January to February, February to March, April, May to June, and June, respectively, *Vernonia, Coffee, Syzygium, Eucalyptus, and Croton honeys* were gathered. The majority (84.5%) of the area's rainfall and 71.6% of its temperatures were very favourable for the development of beekeeping. However, the relative humidity of the zone's was 100% highly suitable for beekeeping. About 12.94% of the Gedeo Zone's total land ecology was highly appropriate, while 52.96% of it was suitable for beekeeping. Additionally, 18.18% of the zone's land had conditions that made beekeeping less feasible. Only 15.92% of the zone's land was unsuitable for beekeeping, as a result of various limitations. This revelation is essential for planning land uses for protecting honeybee habitat and for guiding investors in establishing commercial beekeeping operations as well as in the collecting and processing of honey.

Keywords: Beekeeping, bee flora, map, ecology, GIS

Introduction

Beekeeping is crucial for increasing rural people's income in rural areas (Bareke et al., 2021). It is the management of honeybees for the production of honey and other bee products as well as for the pollination of crops (Bareke et al., 2018). Moreover, beekeeping provides an incentive for establishing trees and maintaining existing trees, because plants are offered pollen and nectar for honeybees (Bareke et al., 2014). A land's appropriateness for beekeeping can be determined using physical, environmental, social, and economic information. To choose the best location based on beekeeping preferences, land use suitability is planned to meet human requirements and ensure the sustainability of ecosystems (Ahamed et al., 2000). Multiple criteria must be met in order for a piece of land to be suitable for beekeeping, and these criteria can be determined by using a geographic information system (GIS), which incorporates datasets from various environmental layers such as temperature, humidity, vegetation, land cover, and water resources (Amiri et al. 2011; Amiri & Shariff, 2012).

The primary factors impacting beekeeping production are climatic variables like temperature, precipitation, and relative humidity. It has been discovered that temperature affects honey bee activity in general, including foraging and brood raising (Al-Ghamdi, 2005). However, relative humidity is also thought to have a significant impact on egg hatchability and brood rearing. When developing the maps showing the appropriateness for honey bees, the relative humidity and the availability of water resources are combined factors (Amira, 2012). The most crucial element is vegetation cover, which honeybees use as sources of nectar and pollen and is regarded as a crucial variable in suitability modelling for beekeeping.

Ethiopia is blessed with cultivated and natural flora, as well as a variety of agro-ecological and climatic conditions that are ideal for beekeeping (Addi and Bareke, 2019; Bareke and Addi, 2018; Addi et al., 2014; Fichtl and Addi, 1994). However, Ethiopia's thriving natural resource base has not been fully tapped into by the beekeeping industry. To ensure effective and long-lasting beekeeping production, management and monitoring of beekeeping resources are becoming increasingly crucial. Additionally, when choosing the best areas for beekeeping, economic, ecological, environmental, and social factors should be taken into account (Zhang et al., 2015). Because honeybees are the primary crop pollinators, agricultural operations generate a significant amount of hidden economic gain (Oldroyd and Nanork, 2009; Maris et al., 2008).In the South Nation Nationality and People Regional State (SNNPR) of Ethiopia, Gedeo is a zone. Agroforestry vegetation like fruit trees, coffee, and spices predominate there. The majority of the plants in this agroforestry are bee plants.

The Gedeo Zone's beekeeping potential is not systematically categorized to make advantage of the floral resources available. Without taking into account other crucial factors that may affect beekeeping, the physical evaluation of vegetation resources is the only method used to assess the viability of a given area for beekeeping. For example, all green plants might not be appropriate for beekeeping. In order to plan land uses for preserving honeybee habitat and to direct investors to launch commercial beekeeping business in this zone, recognizing the optimal sites for beekeeping is crucial. Additionally, the major bee forage plants and types of honey in connection to appropriate beekeeping locations were known; as a result, an effort was made in this study to locate and map appropriate beekeeping regions.

Materials and methods

Study area

The study was conducted in Gedeo zone of South Nation Nationality and People Regional State of Ethiopia (Figure 1). The exact location of the Gedeo zone lies between 5^o 50’ 26” to 6^o 12’ 48” N Latitude and 38^o 12’ 48” to 3^o 13’ 02” E Longitude.

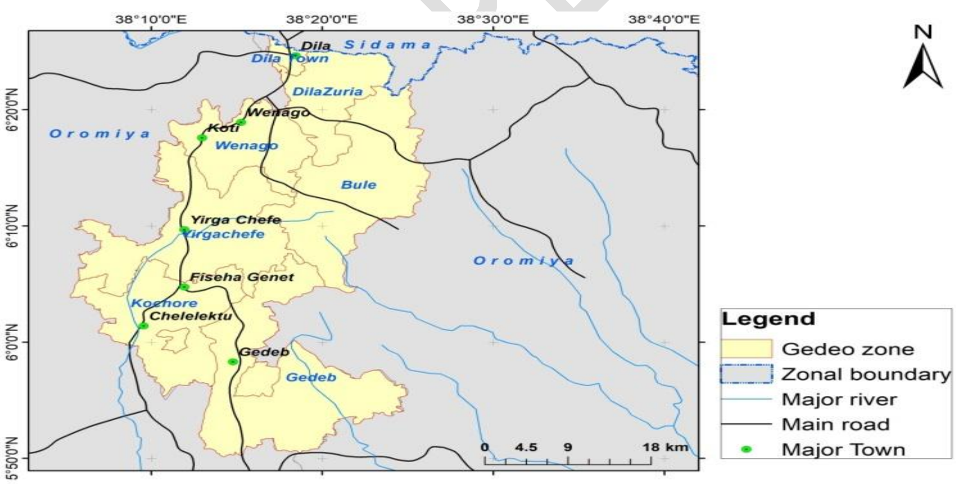

Figure 1: Map of the study area

Data sources

Primary and secondary data sources were used to gather information for the study area. Using Landsat 8 data from 2019 and ERDAS Imagine 2014, supervised classification was used to examine the land use and land cover of the study region. Data on temperature, relative humidity, and rainfall were collected from the Ethiopian Meteorology Agency in tabular and geographical formats. Data on settlements and road networks were gathered from the Gedeo Zone Agricultural Office and the Ethiopian Mapping Agency.

Determination and preparation of the criteria

Criteria Selection and Reclassification

The requirements, expectations, and limitations of beekeeping activities on a designated location were taken into consideration when determining the criteria for bee ecological appropriateness. Some expectations and assumptions about ecological and social issues have been made in this study. We were able to pinpoint seven crucial elements affecting beekeeping activity based on our experiences, literature research, and expert consultations. Based on their function in the hives, honeybee performance, and colony management, these criteria were selected.

Table 1: Factors affecting beekeeping activity, rate, classification, area and percentage of area coverage

Factor	LULC (Type)	Rate	Classification	Area(ha)	%
Land use Land cover (LULC) (types of bee flora)	Bare land, built up and wetland	1	Not Suitable	982.704	0.73
	Cropland, grassland	2	Less Suitable	23,184.754	17.14
	Shrub land and vegetation	3	Suitable	604.318	0.45
	Agroforestry	4	Highly Suitable	11,0471.611	81.68
Elevation	<500 and >3200	1	Not Suitable	0	0
	500-1000 and 2800-3200	2	Less Suitable	14,053.44	10.4
	1001-1500 and 2401-2800	3	Suitable	28,158.60	20.8
	1501-2400	4	Highly Suitable	93,031.33	68.8
Rainfall	<500 and >2500	1	Not Suitable	0	0
	500-800 and 2100-2500	2	Less Suitable	0	0
	801-1200 and 1901-2100	3	Suitable	20,898.93	15.5
	1201-1900	4	Highly Suitable	114,344.51	84.5
Temperature	<10 and >35	1	Not Suitable	0	0
	10 -15 and 31 - 35	2	Less Suitable	38,374.08	28.4
	16 – 22 and 28-30	3	Suitable	96,869.33	71.6
	23- 27	4	Highly Suitable	0	0
Relative humidity	<30 and >90	1	Not Suitable	0	0
	30-40 and 81-90	2	Less Suitable	0	0

	41-50 and 71-80	3	Suitable	0	0
	51-70	4	Highly Suitable	135,243.44	100
Distance to water source (m)	>1,500	1	Not Suitable	69,424.329	51.33
	1,001 -1,500	2	Less Suitable	31,811.720	23.52
	501-1000	3	Suitable	12,334.890	9.12
	100-500	4	Highly Suitable	21,672.508	16.03
Bee forage	Bare land	1	Not Suitable	982.704	0.73
	Minor bee forage plants	2	Less Suitable	23,184.754	17.14
	Major and medium abundant bee forage plants	3	Suitable	604.318	0.45
	Major and abundant bee forage plants	4	Highly Suitable	11,0471.611	81.68

Multi Criteria Decision Analysis (MCDA) and Analytical Hierarchy Process (AHP) Pairwise comparison

Utilizing the analytical approach of the weighted linear combination, multi-criteria decision analysis was utilized to determine if the land was suitable for beekeeping (WLC). The criteria and sub-criteria of the AHP used in this study are its structural components. The chosen parameters include ecological (temperature, rainfall, relative humidity, and elevation), food supply (closeness to a water source, availability of bee forage), and economic considerations (distance from settlements and road networks).

According to Saaty, an Analytical Hierarchical Process (AHP) pairwise matrix model is one of the most popular weight determination models. It uses ranking values from 1 to 9 to determine the weights of each criterion (1980). By providing the relative weights of each criterion, criteria weights are first determined using a pairwise matrix through AHP. The weights must add up to 1, and they must. The pairwise comparison matrix is provided in Table 2 along with the estimated weights (Table 3), which are relative and chosen by the decision maker.

Sub-criteria that define beekeeping appropriateness are included in each chosen beekeeping criteria; these were reclassified using expert-level judgement and scientific advice. Each criterion's suitability was divided into four categories: 4 (very suitable), 3 (suitable), 2 (less suitable), and 1 (not suitable).

When creating suitability maps using multi-criteria factors, it is necessary to balance each criterion to establish how important it is in relation to other criteria. To determine each criterion layer's relative value, each layer was standardized, reclassified, and rated. Through a quantitative rating, each layer of the criterion has an impact on the result in its own way. As a result, it is feasible to create the most effective criteria that have a positive effect on the outcome.

Table 2. Saaty 1 to 9 Scale.

1	3	5	7	9	2,4,6,8
Equal	Moderately	Strongly	Very	Extremely	Intermediates

Table 3. Pairwise comparison matrix

A	**C_1**	**C_2**	**C_3**	**…**	**C_n**
C_1	a_{11}	a_{12}	a_{13}	…	a_{1n}
C_2	a_{21}	a_{22}	a_{23}	…	a_{2n}
…	… … … …	… … … … … …	… … … … … …	… … … …	… … …
C_n	a_{n1}	a_{n2}	a_{n3}	a_{n3}	a_n

To establish the weights, the pairwise comparison square matrix is defined for the primary and supporting criteria. The comparison matrix's diagonal component is number one. To create a normalized matrix with Formula 1, each component of the comparison matrix is divided by the sum of its own column.

$$a_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad \ldots\ldots (1)$$

The sum of the normalized matrix's columns is 1. The normalized matrix is then divided by the matrix order for each row sum. The weights assigned to each criterion in the pairwise comparison matrix are represented by the average of the sum (Formula 2).

$$w_{i} = \left(\frac{1}{n}\right) \sum_{i=1}^{n} a_{ij} \,, (i, j = 1,2,3, \ldots, n) \quad \ldots\ldots (2)$$

It was determined whether or not comparisons met the criterion for consistency by calculating the consistency of the pairwise comparison matrix. The assigned preference values are combined to create a ranking of the important criteria in terms of a number that corresponds to the weights of each parameter. As a result, the eigenvalues and eigenvectors of the square pairwise comparison matrix are generated, providing crucial information about trends in the data matrix (Saaty and Vargas 1991). One approach to defining the consistency coefficient of the pairwise comparison matrix is the consistency index (CI). Utilizing Formula 3, CI is calculated (Saaty, 1994).

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad \ldots\ldots (3)$$

Calculating consistency index depends on the λmax (Eigen value) value with Formula 4 (Saaty, 1994).

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\left[\frac{\sum_{j=1}^{n} a_{ij}w_j}{w_i}\right] \quad \text{……………………………………………………….(4)}$$

In addition to this, the Random Index (RI) value must be calculated to determine the consistency index.

Formula 5 can be used to determine the consistency ratio (CR) after calculating the CI and RI. The pairwise comparisons in a judgement matrix are deemed to be sufficiently consistent in the AHP technique if the corresponding CR is less than 10%. If the corresponding CR is greater than 0.1, Saaty & Vargas (1991) advise a rewrite of the pairwise comparison matrix with different values (Saaty, 1980).

$$CR = \frac{CI}{RI} \quad \text{……………………………………………………………………….. …… (5)}$$

Table 4: Ranking of the relevant factors in terms of a numerical value which is equivalent to the weights of each parameter

Criteria	Ecology	Social	Economy	AHP Weight
Food source	1	3	5	0.633
Ecological	1/3	1	3	0.260
Consistency 5%				

Table 5: Ranking of ecological factors in terms of a numerical value which is equivalent to the weights of each parameter

Ecology	Temperature	Rainfall	Humidity	Elevation	AHP Weight
Temperature	1	2	3	5	0.482
Rainfall	½	1	2	3	0.272
Humidity	1/3	½	1	2	0.158
Elevation	1/5	1/3	1/2	1	0.088
Consistency 1%					

Table 6: Ranking of food source and economic factors in terms of a numerical value which is equivalent to the weights of each parameter

Food source	Distance to bee forage plants	Distance to water source	AHP Weight
Distance to bee forage plants	1	2	0.667
Distance to water source	1/2	1	0.333
Consistency 0%			

Statistical data Analyses

Immanent V 3.2.0 and ARC GIS software were used for statistical and spatial data analyses.

Results and discussions

Bee flora

Ninety eight (98) bee foraging plants were identified from the Gedeo Zone. Despite varying abundances, *Coffea arabica, Croton macrostachyus, Cordia africana, and Eucalyptus camaldulensis* were found throughout the zone's districts. From the listed bee forage plants, honeybees received nectar and pollen from 86.7% of them, pollen from 13.3%. This finding suggests that the majority of identified plant species offer honeybees both nectar and pollen, while just a small number of species only offer pollen. Herbs, shrubs, trees, and climbers represented 43.8%, 33.7%, and 22.45% of the identified bee foraging plants, respectively (Table 7). A related study by Bareke et al. (2019) in the Gera Forest in south-western Ethiopia revealed that the life forms of bee foraging plants were represented by 35.1% herbs, followed by shrubs and trees at 25.7% each, and climbers/lianas at 10%. Bareke and Addi (2018) in the Guji Zone of Ethiopia, on the other hand, also reported that of the total bee food plants detected in the zone, 64.7% were trees, 25.5% were shrubs, and 9.8% were herbs. These earlier investigations showed that bee foraging plants vary from location to location.

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Table 7: Lists of bee forage plants in Gedeo Zone

No.	*Scientific name*	Local name	Habit	Food sources
1	*Acanthus sennii*	Sokorru	Shrub	N
2	*Achyranthes aspera*	Maxxanne	Herb	P
3	*Achyranthes aspera*	Maxxanne	Herb	P
4	*Aframomum corrorima*	Kororima	Herb	N,P
5	*Ajuga integrifolia*	Harma gusa	Herb	N,P
6	*Albizia gummifera*	Mukarba	Tree	N,P
7	*Albizia gummifera*	Mukarba	Tree	N,P
8	*Allium cepa*	Onion	Herb	N,P
9	*Aningeria altisimma*	Kararo	Tree	N,P
10	*Annona reticulata*	Gishxa	Shrub	N,P
11	*Arjimon mexican*		Herb	N,P
12	*Bidens pachyloma*	Kello	Herb	P
13	*Bothriocline schimperi*		shrub	N,P
14	*Brassica carinata*	Gommen zer	Herb	N,P
15	*Brugmansia suaveolens*	Turumba Ababa	Shrub	N,P
16	*Caesalpinia decapetala*	Harangama	Climber	N,P
17	*Callistemon citrinus*	Bottle brush	Shrub	N,P
18	*Calpurnia aurea*	Cheka	Shrub	N,P
19	*Capsicum annuum*	Qara	Herb	N,P
20	*Carica papaya*	Papaya	Tree	N,P

21	*Catha edulis*	Chat	Shrub	P
22	*Citrus aurantifolia*	Lomi	Shrub	N,P
23	*Citrus sinensis*	Burtukana	Shrub	N,P
24	*Coffea arabica*	Buna	shrub	N,P
25	*Cordia africana*	Wadessa	Tree	N,P
26	*Coriandrum sativum*	Dembilala	Herb	N,P
27	*Croton macrostachyus*	Bisanna	Tree	N,P
28	*Cucurbita pepo*	Dubba/buqee	Climber	N,P
29	*Cyanotis barbata*	Dinnicha sare	Herb	P
30	*Datura stramonium*	Manji (qobo bada)	Herb	N,P
31	*Daucus carota*	Karrot	Herb	P
32	*Dioscorea esculenta*	Boyina	Climber	N,P
33	*Dovyalis caffra*	Koshommi	Shrub	N,P
34	*Ekebergia capensis*	Sombo	Tree	N,P
35	*Ekebergia capensis*	Lolchisa	Tree	N,P
36	*Ekebergia capensis*	Sombo	Tree	N,P
37	*Eleusine floccifolia*	Chokorsa (qobi)	Herb	N,P
38	*Ensete ventricosum*	Enset	Herb	P
39	*Erythrina brucei*	Walensu	Tree	N,P
40	*Eucalyptus camaldulensis*	Bargamo dima	Tree	N,P
41	*Eucalyptus globulus*	Bargamo adi	Tree	N,P
42	*Euphorbia abyssinica*	Adammi	Tree	N,P
43	*Galinsoga quadriradiata*	Kasa/Abbadabbo	herb	N, P
44	*Glycine max*	Bolokke	Herb	N,P
45	*Grevillea robusta*	Gravelia	Tree	N,P
46	*Grewia ferruginea*	Lanqisa	Shrub	N,P
47	*Guizotia schimperi*	Hada	Herb	N,P
48	*Hgyrophila schulli*	Shulti	Herb	N,P
49	*Hypoestes forskaolii*	Dargu	Herb	N,P
50	*Ipomoea batatas*	Sikar dinnich	Climber	N, P
51	*Jacaranda mimosifolia*	Jakaranda	Tree	N
52	*Justicia schimperiana*	Dhumuga	Shrub	N,P
53	*Kalanchoe petitiana*	Bosoqqe	Shrub	N,P
54	*Lycopersicon esculentum*	Timatima	Herb	P
55	*Maesa lanceolata*	Abbayi	Shrub	P
56	*Malus sylvestris*	Apple	Shrub	N,P
57	*Malva verticillata*	Litti	Herb	N,P
58	*Mangifera indica*	Mango	Tree	N,P
59	*Maytenus gracilipes*	Kartamme/Hacace	shrub	N,P
60	*Millettia ferruginea*	Berbera	Tree	N,P
61	*Morus alba*	Enjorri	Shrub	N,P
62	*Musa paradisica*	Muz	herb	N,P
63	*Nicandra physaloides*	Bokollu	Herb	N,P
64	*Ocimum basilicum*	Basobila	Herb	N,P
65	*Ocimum urticifolium*	Wancabbi	Herb	N,P
66	*Opuntia ficus -indica*	Gurra	Shrub	N,P
67	*Passiflora edulis*	Passion fruit	Climber	N,P
68	*Pavetta abyssinica*	Yejib bunna/Buniti	Shrub	N,P

69	*Pavonia urens*	Incinni	shrub	N,P
70	*Pavonia urens*	Inchinni	Herb	N,P
71	*Pentas schimperiana*		Shrub	N,P
72	*Persea americana*	Avocado	Tree	N,P
73	*Phytolacca dodecandra*	Andode	Climber	N,P
74	*Pisum sativum*	Atera	Herb	N,P
75	*Plantago lanceolata*	Kortobbi	Herb	N,P
76	*Prunus persica*	Koke	Shrub	N,P
77	*Psidium guajava*	Zeyituna	Shrub	N,P
78	*Rhamnus prinoides*	Gesho	shrub	N,P
79	*Ricinus communis*	Kobbo/Gulo	Shrub	N,P
80	*Rosa x richardii*	Tsigereda	Shrub	P
81	*Rumex nervosus*	Angago	Shrub	P
82	*Ruta chalepensis*	Teneddam	Herb	N,P
83	*Salvia merjamie*		Herb	N,P
84	*Schefflera abyssinica*	Gatama	Tree	N
85	*Schinus molle*	Kundebarbare	Tree	N,P
86	*Sesbania sesban*	Sesbania	Shrub	N,P
87	*Sida rhombifolia*	Chifriggi	Herb	N,P
88	*Solanum incanum*	Hiddi	Herb	N,P
89	*Syzygium guineense*	Dokma	Tree	N,P
90	*Terminalia brownii*	Birdhesa	Tree	N,P
91	*Trifolium spp*	Sidisa	Herb	N,P
92	*Urtica simensis*	Dobbi	Herb	P
93	*Vernonia adonesis*	Sukke	Shrub	N,P
94	*Vernonia amygdalina*	Ebicha	Shrub	N,P
95	*Vernonia auriculifera*	Reji	Shrub	N,P
96	*Vernonia hochstetteri*	Damot gurra	Shrub	N,P
97	*Vicia faba*	Bakela	Herb	N,P
98	*Zea mays*	Bokollo	Herb	P

Types of honey

Five different varieties of monofloral honey were produced throughout the zone. These included *coffee, Croton, Eucalyptus, Syzygium, and Vernonia* honeys (Figure 2). Additionally, research by Bareke and Addi (2019) and Addi and Bareke (2021) revealed that *coffee, croton, and Vernonia* monofloral honeys were produced in southwest Oromia. Additionally, *Syzygium and Eucalyptus* monofloral honey were produced in Southern Oromia (Bareke and Addi, 2018).

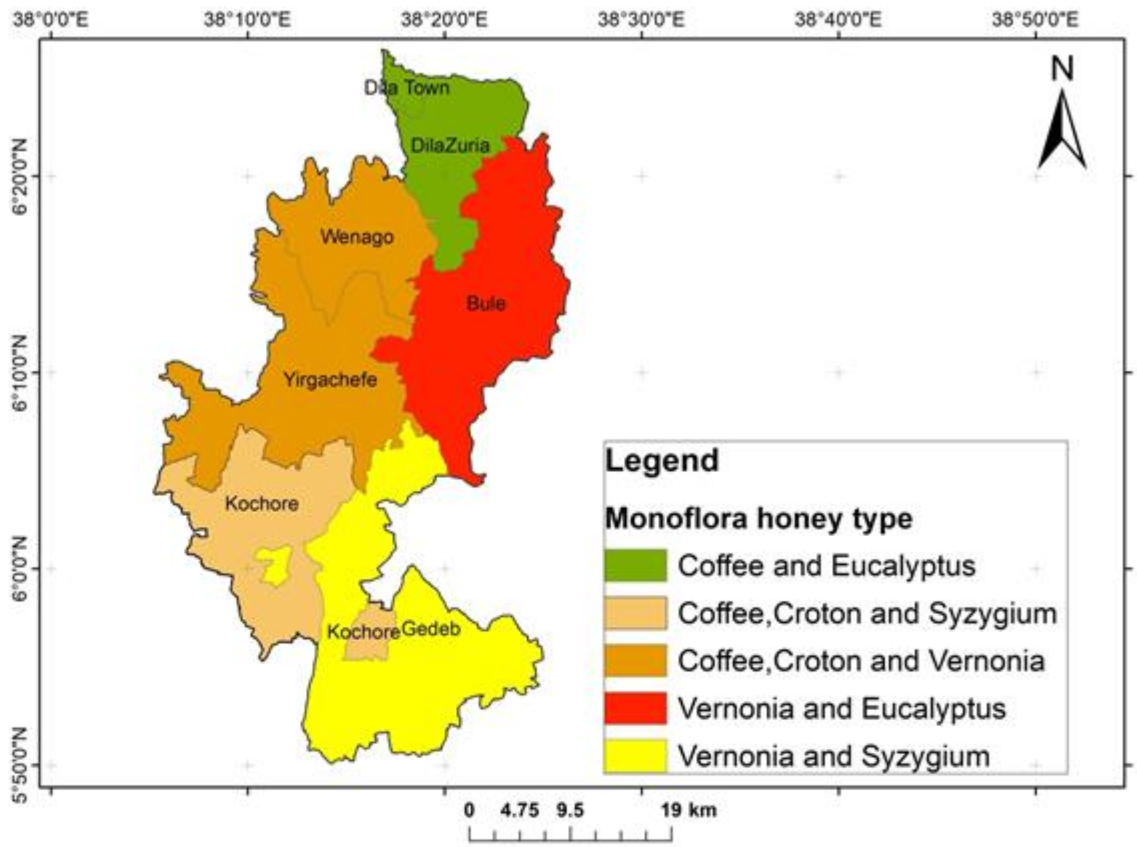

Figure 2: Types of monofloral honey in the Gedeo Zone

Honey harvesting calendars

In January to February, February to March, April, May to June, and June, respectively, *Vernonia*, *coffee*, *Syzygium*, *Eucalyptus, and Croton honeys* were gathered (Figure 3). *Vernonia*, *coffee, and Croton* honey were all produced in January, March, and early June, respectively, according to the research done by Bareke and Addi (2019) in Gera District Jimma Zone Oromia Region.

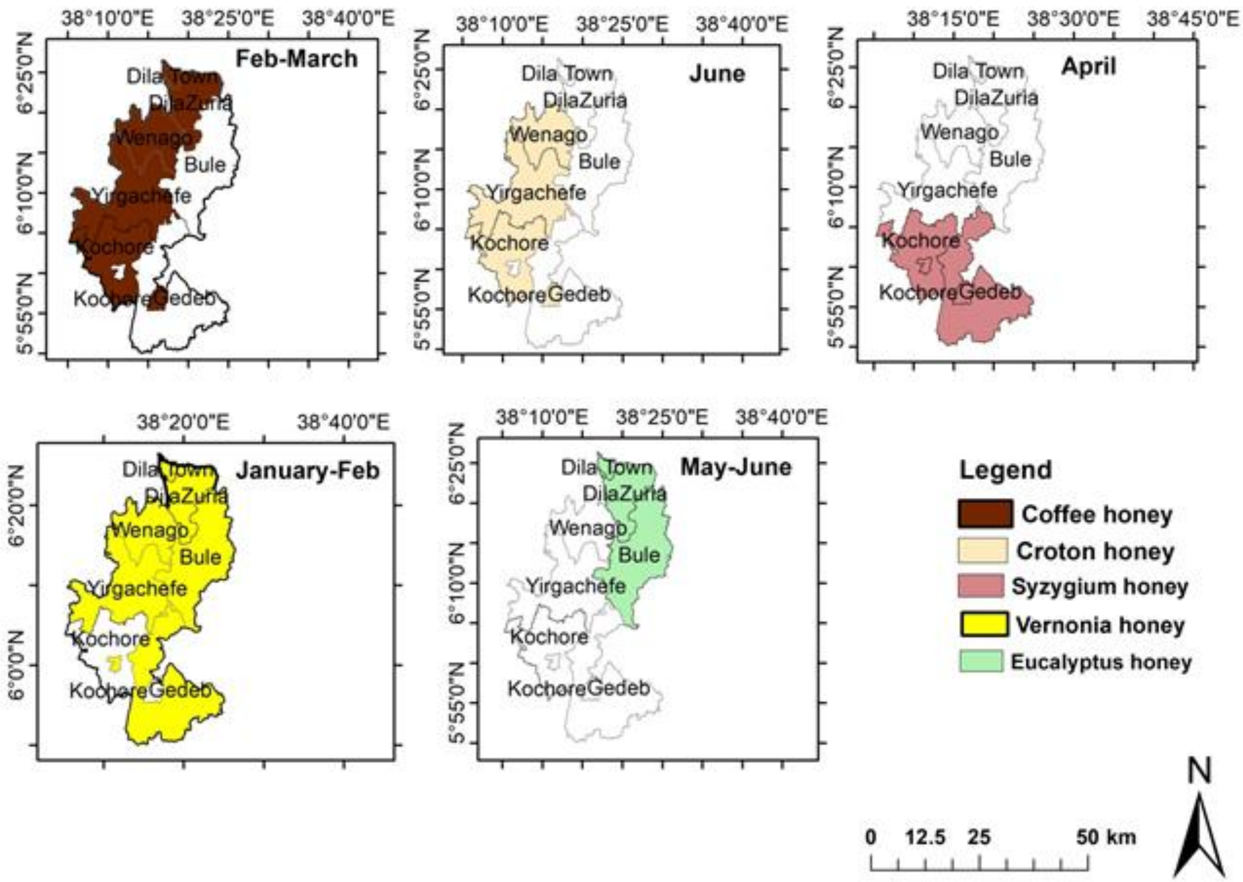

Figure 3: Monofloral honey harvesting period in different districts of Gedeo Zone

Elevation

Elevation is a factor that influences beekeeping operations along with other factors, but it has no immediate impact on honeybees (Sari and Ceylan, 2017a). It has a determining standard for honeybee flora, temperature, amount of precipitation, humidity, and other environmental variables (Sari and Ceylan, 2017b). For instance, the temperature drops at higher altitudes while rising at lower altitudes. Because of this, the varieties of honeybee flora, their capacity for producing honey, the flowering season and lengths, as well as the aforementioned environmental conditions, vary with elevation.

For beekeeping, the majority (68.8%) of the research area's elevation was very favorable, while just 20.8% and 10.4% of it was suitable or less ideal for producing honey. In the study region, elevations between 1500 and 2400 meters above sea level are ideal for producing honey, while elevations between 500 and 3200 meters above sea level are not (Figure 4).

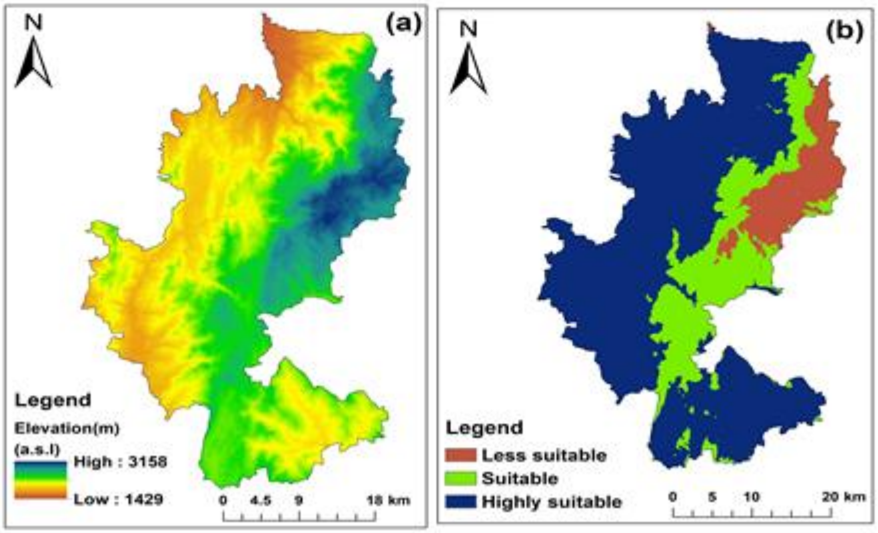

Figure 4: Map of elevation classification of Gedeo Zone

Precipitation

The duration and timing of the honeybee flora's flowering season are directly impacted by precipitation, which also has an impact on beekeeping activities. In the Gedeo zone, 84.5% of the precipitation (1200-1900 mm) was highly acceptable, whereas just 15.5% of the area (800-1200 and 1900-2100 mm) was suitable (Figure 5).

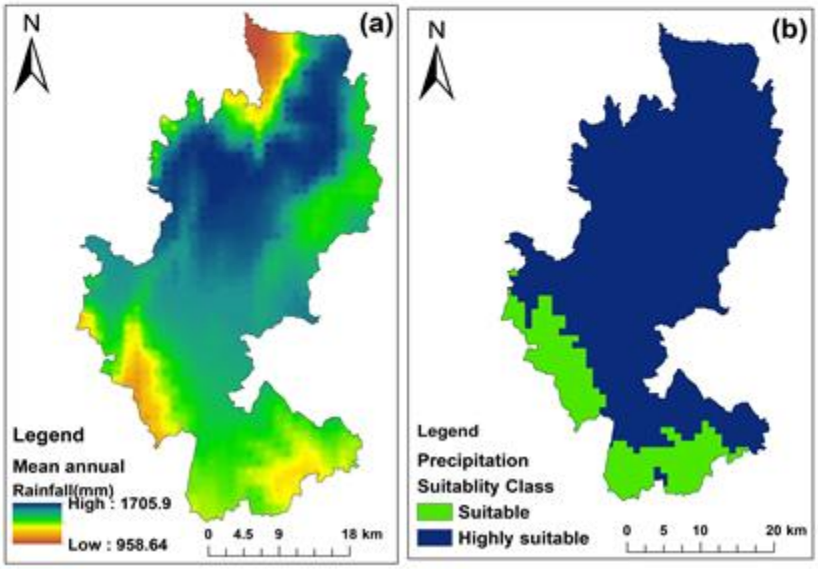

Figure 5: Map of precipitation classification of Gedeo Zone

Temperature:

According to Campolo et al. (2014) and Régnière et al. (2012), one of the most important ecological elements that affect insect activity and biological development is temperature. It influences the volume and concentration of nectar secreted by bee plants (Bareke et al., 2020), as well as the internal and exterior activities of honeybee colonies (Abou-Shaara et al., 2012; Zoccali et al., 2017).

Honeybee colonies often have hives that are between 33 and 36^{0}C, depending on local temperature (Petz et al., 2004; Abou-Shaara et al., 2012). Honeybee development can be impacted by hive temperature above and below this range, including immature stages, rate of emergency, color of newly emerged honeybees, wing morphology, and disease prevalence (Groh et al. 2004; Ken et al. 2005). Honeybee flying activity is halted at temperatures below 10^{0}C. (Blazyte-Cereskiene et al. 2010; Joshi, 2010). The majority of Gedeo Zone (71.6%) has temperatures that are ideal for beekeeping, while 28.4% of the region has temperatures that are less ideal for beekeeping operations (Figure 6).

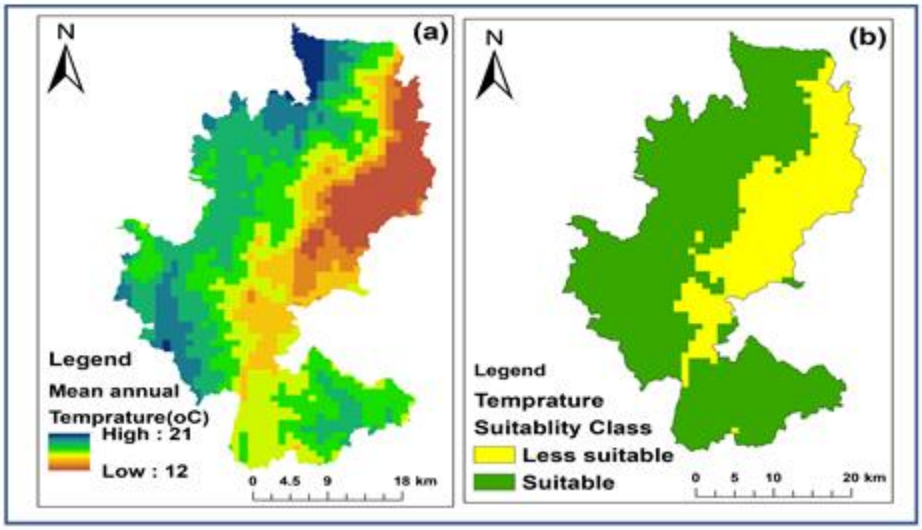

Figure 6: Map of Temperature of Gedeo Zone

5) Relative humidity:

Bee plants' nectar volume and nectar concentration are influenced by relative humidity (Bareke et al., 2021). For several honeybee plant species, nectar volume rose as humidity increased while nectar concentration dropped as humidity increased. At the immature phases of honeybee development, relative humidity affects brood development (Human et al., 2006; Ellis et al., 2008; Abou-Shaara et al., 2012). Additionally, relative humidity has an impact on honey ripeness, which can impact honey quality. The honey is sometimes not ripped at the proper quality and is not timely sealed in high humidity areas. Gedeo Zone's relative humidity was perfectly acceptable (100%) for beekeeping (Figure 7).

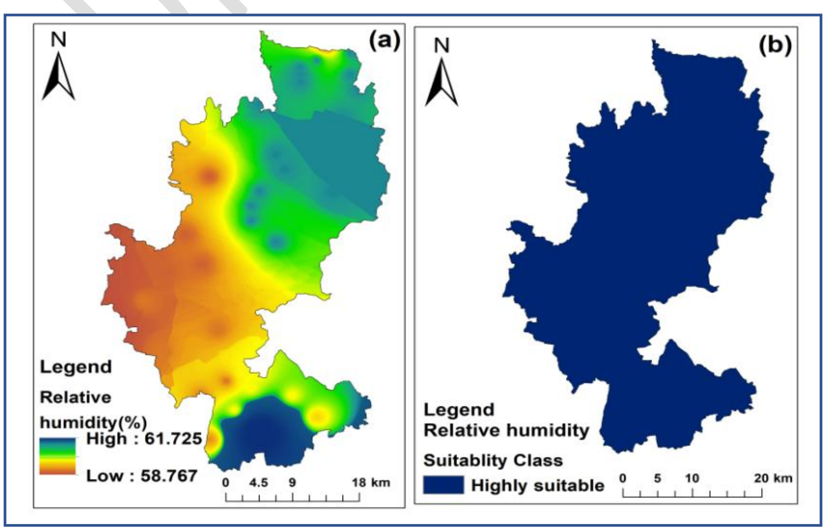

Figure 7: Map of relative humidity of Gedeo Zone

6) Distance to water source

Distance from a water source is crucial for honeybees to minimize water collection time. Water is necessary all year round for the preparation of larval feeding and the delivery of minerals. The bee hive does not store water. Therefore, it needs to be collected daily. 16.03 percent of the Gedeo Zone's total land is extremely suited for proximity to water sources, while 51.3 percent is not (Figure 8).

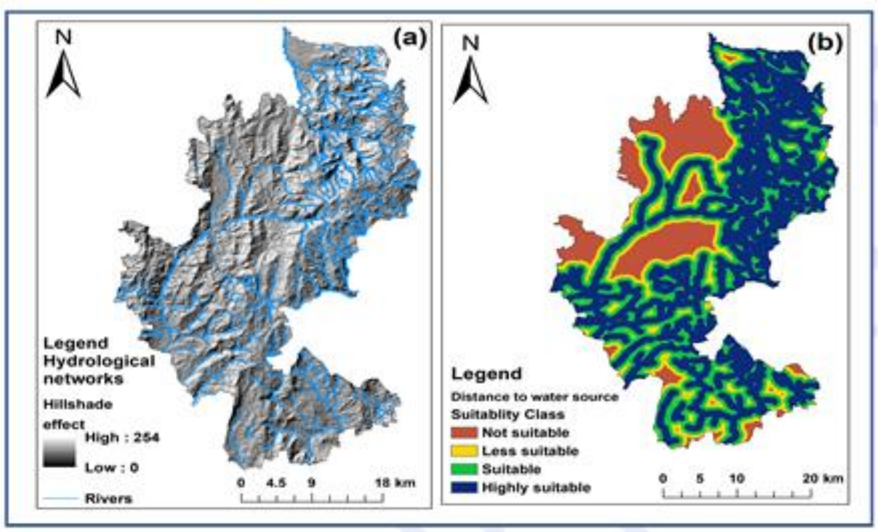

Figure 8: Map of Distance to water source of Gedeo Zone

Potential Beekeeping ecological suitability Map

Based on a review of the literature in terms of ecological, food supply, and economic aspects, the methodology of this study adopts appropriate criteria for the identification of beekeeping suitable location. The spatial extents of the study area's possible beekeeping site suitability areas were discovered using an AHP analysis that took into account several physical layers.

Based on the weighted linear combination (WLC) of the aggregate suitability index values, all the criteria and sub-criteria were combined to give four suitability classes (Figure 9).

The suitability map was created for each district in the Gedeo zone based on the parameters that were chosen. About 12.94% of the Gedeo Zone's total land area (135244.4 hectares) was highly appropriate for beekeeping, and 52.96% of the zone's land was suitable for beekeeping. Additionally, 24587.656 ha (18.18%) of the zone's land had conditions that made it less favorable for beekeeping (Figure 9). Only 15.92% of the zone's land was unfit for beekeeping, which was justified as a result of limitations. It denotes a construction site.

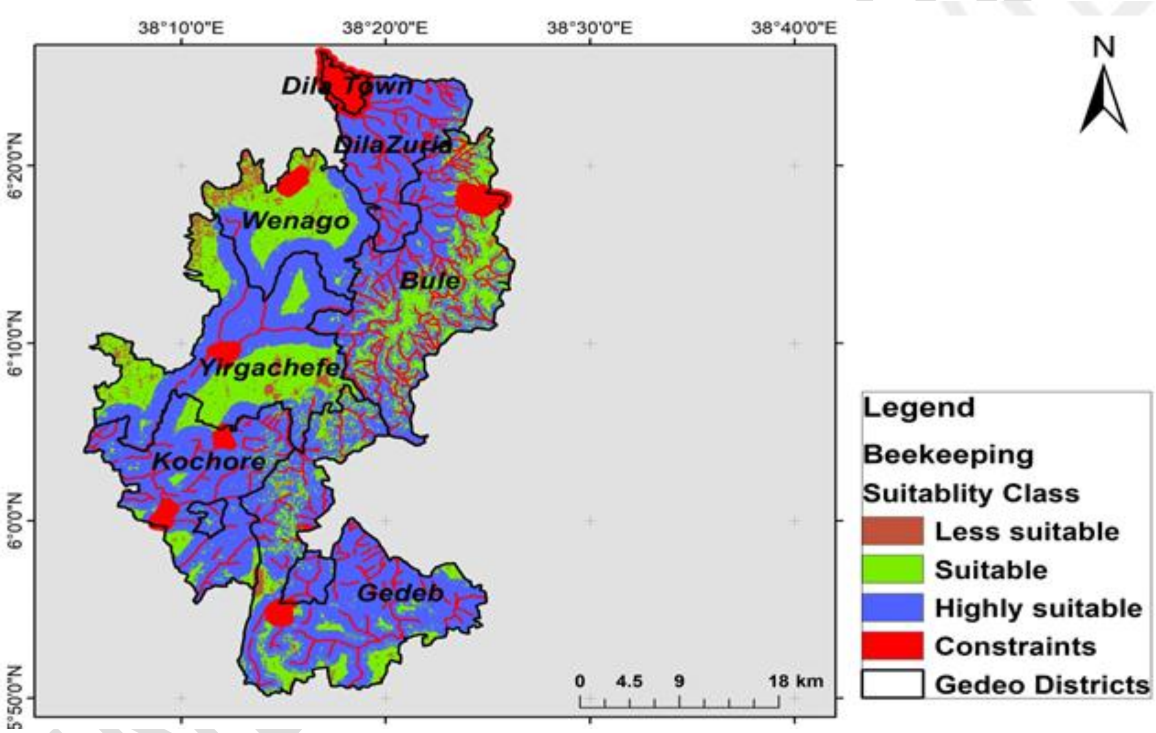

Figure 9: Map of ecological suitability for beekeeping in Gedeo Zone

Ecological suitability area at District level

The majority of the area in Bule District (31.2%) was highly suitable for beekeeping, followed by suitable (30.3%), not suitable (24.4%), and less suitable (14.1%). 32.3% of the district was unsuitable for beekeeping activities, whereas the majority (65.5%) of the Dila Zuria area was not. It is used as a building site. 7636.547 hectares (23.86%) of the area in the Gedeb District was highly appropriate for beekeeping, while the remaining 29.97%, 33.2%, and 12.95% of the district's land were, respectively, suitable, less suitable, and unsuitable. A total of 14543.07 hectares (67.5%) of the Kochore District were suitable for beekeeping, and 3.66% of that area was extremely favorable. However, due to building, 16.8% of the district's land was unsuitable for beekeeping, and roughly 12% of it was less so. Approximately 9635.565 hectares (68.07%) of the area in the Wonago Territory was suitable for beekeeping, whereas 6.2% of the district was unsuitable. Yirga Cheffe District land was primarily (77.5%) appropriate for beekeeping techniques, while just 6.86% of the district's area was unsuitable (Table 8).

Table 8: Gedeo Zone suitability area for beekeeping

	Bule	Dila Zuria	Gedeb	Kochore	Wonago	Yirga cheffe
Total Area(ha)	27299.4	12225.9	31998.2	21532.6	14155.1	26604.9
Less suitable	3846.707	191.2993	10628.07	2583.362	3392.393	3945.825
Suitable	8274.899	8945.076	9591.183	14543.07	9635.565	20630.71
Highly suitable	8518.594	110.5843	7636.547	788.4659	244.2417	200.9684
constraints	6659.2	4407.2	4142.4	3617.7	882.9	1827.4

Conclusion

From the total area of Gedeo zone, 12.9%, 52.96%, 18.18%, and 15.92% were highly suitable, suitable, less suitable and not suitable respectively. The zone contains a variety of bee foraging plants, including 43.88% herbs, 33.67% shrubs, and 22.45% trees, respectively. Major and many bee plants in the area included *Coffea arabica, Croton macrostachyus, Cordia africana, Eucalyptus camaldulensis, Vernonia amygdalina, Syzygium guineense, Schefflera abyssinica, and Vernonia auriculifera.* All of the zone's districts generated monofloral honeys despite the zone's diverse plant life. All of the Gedeo Zone's districts, with the exception of Bule and Gedeb, produced coffee honey. Thus, it is crucial to plan land uses in order to protect honeybee habitat and to provide investors with guidance when starting a commercial beekeeping enterprise.

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