



Ecological Suitability Analysis for Beekeeping Using GIS and AHP Model in Gedeo Zone of Southern Ethiopia

Tura Bareke ^{a*}, Getachew Haile ^b, Admassu Addi ^a
and Kibebew Wakjira ^a

^a Oromia Agricultural Research Institute, Holeta Bee Research Center, Holeta, Ethiopia.

^b Oromia Agricultural Research Institute, Addis Ababa, Ethiopia.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

All areas looking green may not be suitable for beekeeping. Therefore, the study aimed to identify and map a suitable beekeeping ecology in the Gedeo Zone of southern Ethiopia. Seven suitability elements that have an impact on beekeeping activity were chosen. Both primary and secondary data sources were collected from each district. Using a multi-criteria decision analysis, the weighted linear combination analytical technique was utilized to determine if the land was suitable for beekeeping. The Gedeo Zone contained 98 identified bee forage plant species. Five significant and abundant bee forage plants, including *Coffee*, *Croton*, *Eucalyptus*, *Syzygium*, and *Vernonia* species, were identified and mapped as monofloral honey source plant species. Except for Bule and Gedeb districts, every area in the Gedeo Zone produced coffee honey. Four honey-harvesting months were identified. Accordingly, *Vernonia*, *Coffee*, *Syzygium*, *Eucalyptus*, and *Croton* honeys were gathered from January to mid of February, end of February to March, April, May to June, and

*Corresponding author: E-mail: turabareke25@gmail.com;

June. The majority (84.5%) of the area's rainfall and 71.6% of its temperatures were very favourable for the development of beekeeping. On the other hand, the relative humidity of the zone was 100%, making it 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 study is essential for planning land uses for protecting honeybee habitats 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.

1. INTRODUCTION

Beekeeping is crucial for increasing rural people's income in rural areas [1]. It is the management of honeybees for the production of honey and other bee products as well as for the pollination of crops [2]. Moreover, beekeeping provides an incentive for establishing trees and maintaining existing trees, because plants are offered pollen and nectar for honeybees. 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 [3]. 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. [3], Amiri & Shariff, [4]).

The primary factors influencing 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 [3, 4]. 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 [4]. 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, [5], Bareke and Addi, [6]). 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 [7]. Because honeybees are the primary crop pollinators, agricultural operations generate a significant amount of hidden economic gain (Oldroyd and Nanork, [8], Maris et al., [9]). Gedeo Zone is found in the South Nation Nationality and People Regional State (SNNPR) of Ethiopia. It is predominated with agroforestry vegetation like fruit trees, coffee, and spices. 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. In addition to considering other important elements that may influence beekeeping, the physical examination of vegetation resources is the primary method used to determine the sustainability of a given location 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.

2. MATERIALS AND METHODS

2.1 Study Area

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

2.2 Data Sources

Primary and secondary data sources were collected for this 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.

2.3 Determination and Preparation of the Criteria

2.3.1 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.

2.3.2 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 area and its structural components. The chosen parameters include ecological (temperature, rainfall, relative humidity, and elevation) and food supply (closeness to a water source, availability of bee forage).

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.

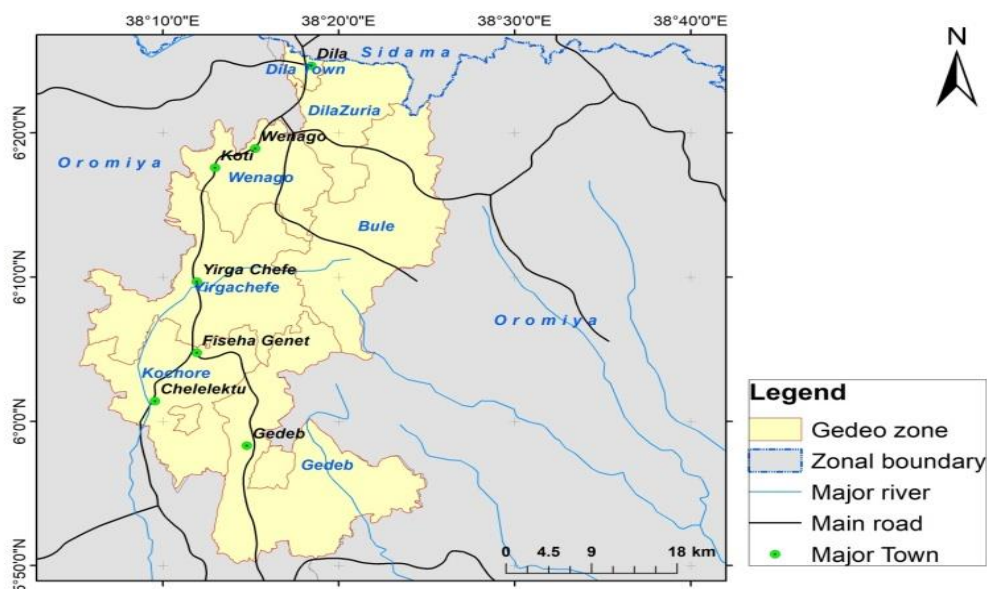


Fig. 1. Map of the study area

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

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	<i>a</i> ₁₁	<i>a</i> ₁₂	<i>a</i> ₁₃	...	<i>a</i> _{1n}
C ₂	<i>a</i> ₂₁	<i>a</i> ₂₂	<i>a</i> ₂₃	...	<i>a</i> _{2n}
...
C _n	<i>a</i> _{n1}	<i>a</i> _{n2}	<i>a</i> _{n3}	<i>a</i> _{n3}	<i>a</i> _n

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.

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.

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

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).

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

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 [10]. One approach to defining the consistency coefficient of the pairwise comparison matrix is the consistency index (CI). Utilizing Formula 3, CI is calculated [11].

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

Calculating consistency index depends on the λ_{max} (Eigen value) value with Formula 4 [11].

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

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 [10] advise a rewrite of the pairwise comparison matrix with different values [12].

$$CR = \frac{CI}{RI} \dots\dots\dots (5)$$

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	1/2	1	2	3	0.272
Humidity	1/3	1/2	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 (m)	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%			

2.4 Statistical data Analyses

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

3. RESULTS AND DISCUSSION

3.1 Bee Flora

Ninety eight (98) bee foraging plants were identified from the Gedeo Zone (Table 7). 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. [13] 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 [2] 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.

3.2 Types of Honey

Five different types of monofloral honey were produced throughout the zone. These included *coffee*, *Croton*, *Eucalyptus*, *Syzygium*, and *Vernonia* honeys (Fig 2). Additionally, research by Bareke and Addi [13] and Addi and Bareke [14] revealed that *coffee*, *croton*, and *Vernonia* monofloral honeys were produced in southwest Oromia. Additionally, *Syzygium* and *Eucalyptus* monofloral honey were produced in Southern Oromia [6].

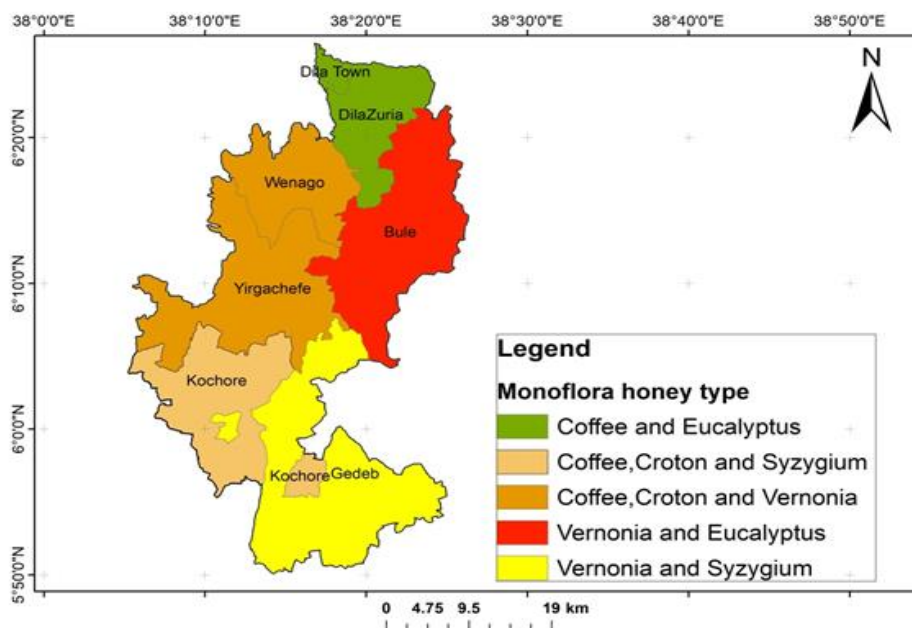


Fig. 2. Types of monofloral honey in the Gedeo Zone

Table 7. Lists of bee forage plants in Gedee Zone

No.	Scientific name	Local name	Habit	Food sources
1	<i>Acanthus sennii</i>	Sokorru	Shrub	N, P
2	<i>Achyranthes aspera</i>	Maxxanne	Herb	P
3	<i>Aspilia mossambicensis</i>	Arbi	Herb	P
4	<i>Aframomum corrorima</i>	Kororima	Herb	N,P
5	<i>Ajuga integrifolia</i>	Harma gusa	Herb	N,P
6	<i>Albizia schimperiana</i>	Sesa	Tree	N,P
7	<i>Albizia gummifera</i>	Sesa	Tree	N,P
8	<i>Allium cepa</i>	Key shunkurt	Herb	N,P
9	<i>Aningeria altissima</i>	Kararo	Tree	N,P
10	<i>Annona reticulata</i>	Gishxa	Shrub	N,P
11	<i>Arjimon mexican</i>		Herb	N,P
12	<i>Bersama abyssinica</i>	Lolchisa	Tree	N,P
13	<i>Bidens pachyloma</i>	Adeabeba	Herb	P
14	<i>Bothriocline schimperi</i>		shrub	N,P
15	<i>Brassica carinata</i>	Gommen zer	Herb	N,P
16	<i>Brugmansia suaveolens</i>	Turumba Ababa	Shrub	N,P
17	<i>Caesalpinia decapetala</i>	Harangama	Climber	N,P
18	<i>Callistemon citrinus</i>	Bottle brush	Shrub	N,P
19	<i>Calpurnia aurea</i>	Cheka	Shrub	N,P
20	<i>Capsicum annum</i>	Qara	Herb	N,P
21	<i>Carica papaya</i>	Papaya	Tree	N,P
22	<i>Catha edulis</i>	Chat	Shrub	P
23	<i>Citrus aurantifolia</i>	Lomi	Shrub	N,P
24	<i>Citrus sinensis</i>	Burtukana	Shrub	N,P
25	<i>Coffea arabica</i>	Buna	shrub	N,P
26	<i>Cordia africana</i>	Wadessa	Tree	N,P
27	<i>Coriandrum sativum</i>	Dembilala	Herb	N,P
28	<i>Croton macrostachyus</i>	Bisanna	Tree	N,P
29	<i>Cucurbita pepo</i>	Dubba/buqee	Climber	N,P
30	<i>Cyanotis barbata</i>	Dinnicha sare	Herb	P
31	<i>Datura stramonium</i>	Manji (qobo bada)	Herb	N,P
32	<i>Daucus carota</i>	Karrot	Herb	P
33	<i>Dioscorea esculenta</i>	Boyina	Climber	N,P
34	<i>Dovyalis caffra</i>	Koshommi	Shrub	N,P
35	<i>Ekebergia capensis</i>	Sombo	Tree	N,P
36	<i>Dodonea angustifolia</i>	Kitkita	Tree	N,P
37	<i>Eleusine floccifolia</i>	Chokorsa (qobi)	Herb	N,P
38	<i>Ensete ventricosum</i>	Enset	Herb	P
39	<i>Erythrina brucei</i>	Walensu	Tree	N,P
40	<i>Eucalyptus camaldulensis</i>	Bargamo dima	Tree	N,P
41	<i>Eucalyptus globulus</i>	Bargamo adi	Tree	N,P
42	<i>Euphorbia abyssinica</i>	Adammi	Tree	N,P
43	<i>Galinsoga quadriradiata</i>	Kasa/Abbadabbo	herb	N, P
44	<i>Glycine max</i>	Bolokke	Herb	N,P
45	<i>Grevillea robusta</i>	Gravelia	Tree	N,P
46	<i>Grewia ferruginea</i>	Lanqisa	Shrub	N,P
47	<i>Guizotia schimperi</i>	Hada	Herb	N,P
48	<i>Hgyrophila schulli</i>	Shulti	Herb	N,P
49	<i>Hypoestes forskalii</i>	Dargu	Herb	N,P
50	<i>Ipomoea batatas</i>	Sikar dinnich	Climber	N, P
51	<i>Jacaranda mimosifolia</i>	Jakaranda	Tree	N, P
52	<i>Justicia schimperiana</i>	Dhumuga	Shrub	N,P
53	<i>Kalanchoe petitiiana</i>	Bosoqqe	Shrub	N,P
54	<i>Lycopersicon esculentum</i>	Timatima	Herb	P

No.	Scientific name	Local name	Habit	Food sources
55	<i>Maesa lanceolata</i>	Abbayi	Shrub	P
56	<i>Malus sylvestris</i>	Apple	Shrub	N,P
57	<i>Malva verticillata</i>	Litti	Herb	N,P
58	<i>Mangifera indica</i>	Mango	Tree	N,P
59	<i>Maytenus gracilipes</i>	Kartamme/Hacace	shrub	N,P
60	<i>Millettia ferruginea</i>	Berbera	Tree	N,P
61	<i>Morus alba</i>	Enjorri	Shrub	N,P
62	<i>Musa paradisiaca</i>	Muz	herb	N,P
63	<i>Nicandra physaloides</i>	Bokollu	Herb	N,P
64	<i>Ocimum basilicum</i>	Basobila	Herb	N,P
65	<i>Ocimum urticifolium</i>	Wancabbi	Herb	N,P
66	<i>Opuntia ficus -indica</i>	Gurra	Shrub	N,P
67	<i>Passiflora edulis</i>	Passion fruit	Climber	N,P
68	<i>Pavetta abyssinica</i>	Yejib bunna/Buniti	Shrub	N,P
69	<i>Pavonia urens</i>	Incinni	shrub	N,P
70	<i>Pavonia schimperiana</i>	Inchinni	Herb	N,P
71	<i>Pentas schimperiana</i>		Shrub	N,P
72	<i>Persea americana</i>	Avocado	Tree	N,P
73	<i>Phytolacca dodecandra</i>	Endode	Climber	N,P
74	<i>Pisum sativum</i>	Atera	Herb	N,P
75	<i>Plantago lanceolata</i>	Kortobbi	Herb	N,P
76	<i>Prunus persica</i>	Koke	Shrub	N,P
77	<i>Psidium guajava</i>	Zeyituna	Shrub	N,P
78	<i>Rhamnus prinoides</i>	Gesho	shrub	N,P
79	<i>Ricinus communis</i>	Kobbo/Gulo	Shrub	N,P
80	<i>Rosa x richardii</i>	Tsigereda	Shrub	P
81	<i>Rumex nervosus</i>	Angago	Shrub	P
82	<i>Ruta chalepensis</i>	Teneddam	Herb	N,P
83	<i>Salvia merjamie</i>		Herb	N,P
84	<i>Schefflera abyssinica</i>	Gatama	Tree	N, P
85	<i>Schinus molle</i>	Kundebarebare	Tree	N,P
86	<i>Sesbania sesban</i>	Sesbania	Shrub	N,P
87	<i>Sida rhombifolia</i>	Chifriggi	Herb	N,P
88	<i>Solanum incanum</i>	Hiddi	Herb	N,P
89	<i>Syzygium guineense</i>	Dokma	Tree	N,P
90	<i>Terminalia brownii</i>	Birdhesa	Tree	N,P
91	<i>Trifolium spp</i>	Sidisa/Amaget	Herb	N,P
92	<i>Urtica simensis</i>	Samma	Herb	P
93	<i>Vernonia adonensis</i>	Sukke	Shrub	N,P
94	<i>Vernonia amygdalina</i>	Grawa	Shrub	N,P
95	<i>Vernonia auriculifera</i>	Reji	Shrub	N,P
96	<i>Vernonia hochstetteri</i>	Damot gurra	Shrub	N,P
97	<i>Vicia faba</i>	Bakela	Herb	N,P
98	<i>Zea mays</i>	Bokollo	Herb	P

3.3 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 (Fig 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 [13] in Gera District Jimma Zone Oromia Region.

3.4 Elevation

Elevation is a factor that influences beekeeping operations along with other factors, but it has no immediate impact on honeybees [15]. It has a determining standard for honeybee flora, temperature, amount of precipitation, humidity, and other environmental variables [16]. 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 (Fig 4).

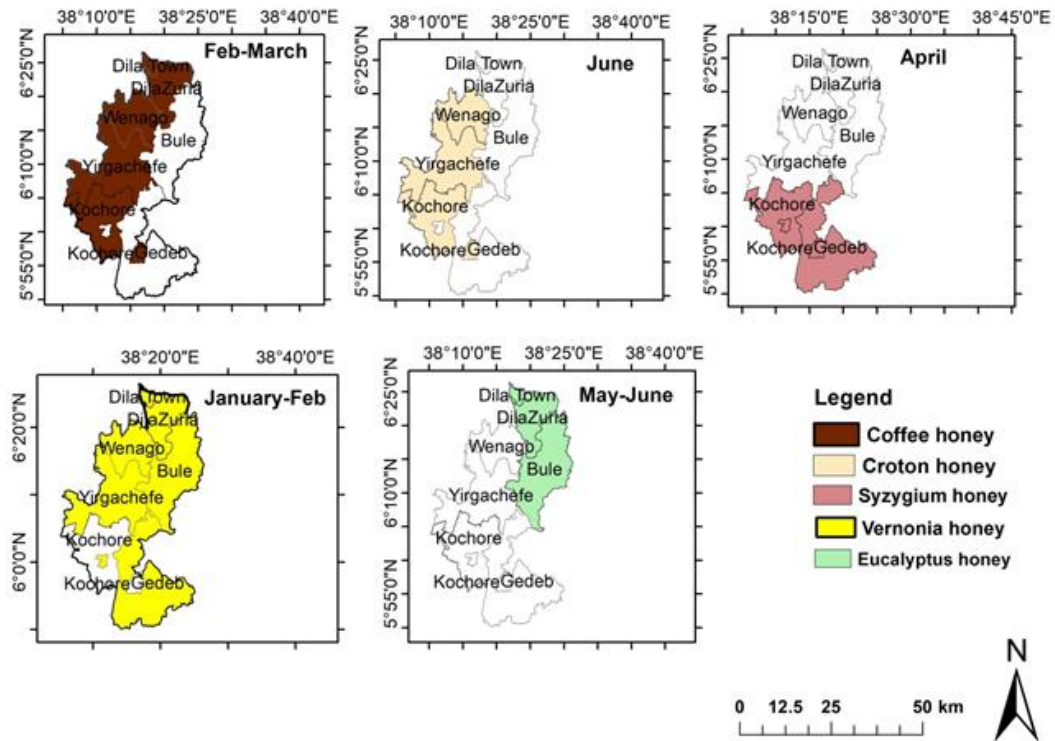


Fig. 3. Monofloral honey harvesting period in different districts of Gedeo Zone

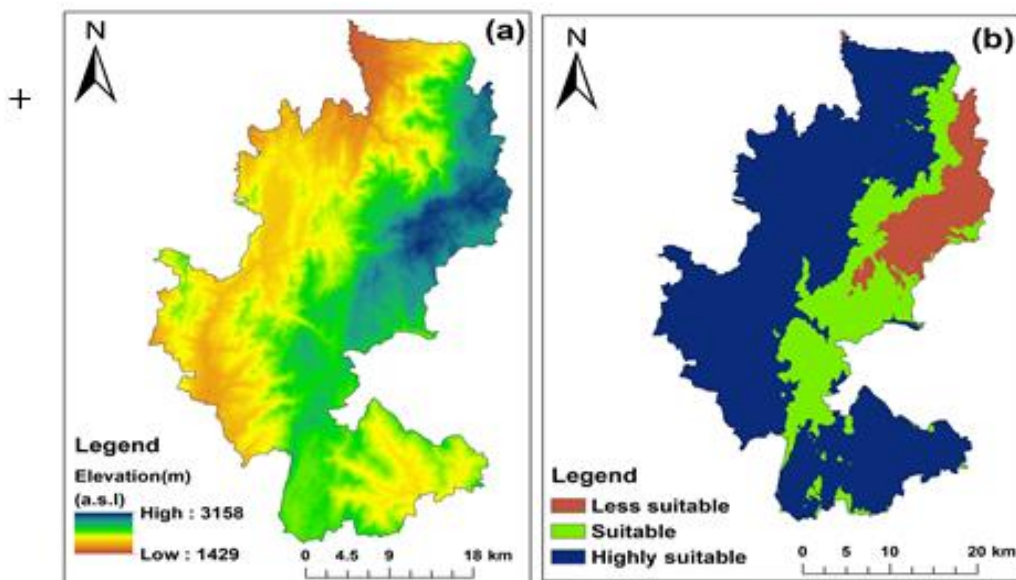


Fig. 4. Map of elevation classification of Gedeo Zone

3.5 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 (Fig 5).

3.6 Temperature

According to Campolo et al. [17] and Régnière et al. [18], 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 [19], as well as the internal and

exterior activities of honeybee colonies (Abou-Shaara et al., [20], Zoccali et al., [21]).

Honeybee colonies often have hives *temperature* that are between 33 and 36°C, depending on local temperature (Petz et al., [22], Abou-Shaara et al., [20]). 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. [23], Ken et al. [24]). Honeybee flying activity is halted at temperatures below 10°C. (Blazyte-Cereskiene et al. [25], Joshi, [26]). 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 (Fig 6).

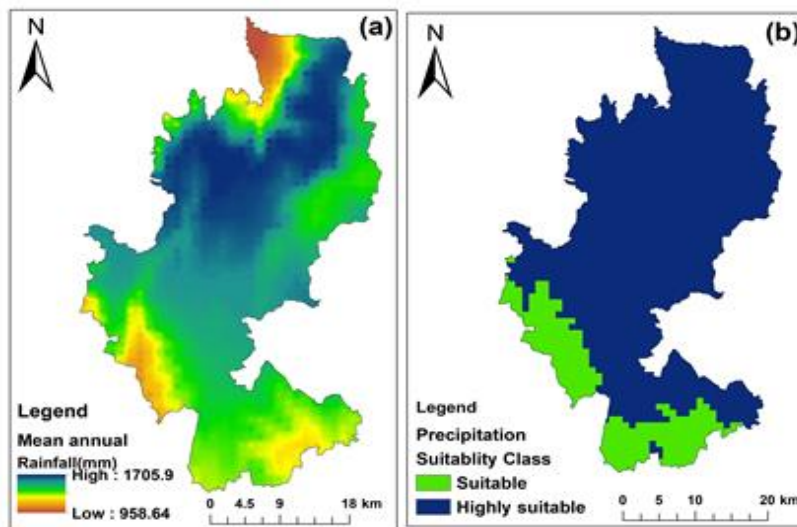


Fig. 5. Map of precipitation classification of Gedeo Zone

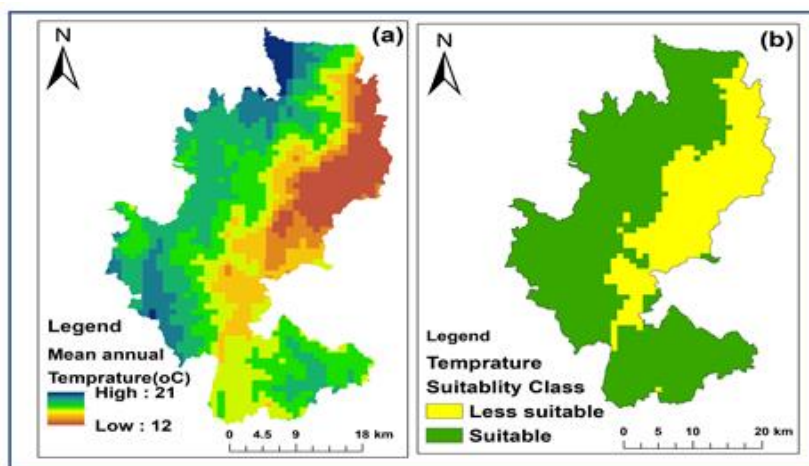


Fig. 6. Map of Temperature of Gedeo Zone

3.7 Relative Humidity

Bee plants' nectar volume and nectar concentration are influenced by relative humidity [1]. 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., [27], Ellis et al., [28], Abou-Shaara et al., [20]). Additionally, relative humidity has an impact on honey ripeness, which can impact honey quality. The honey is sometimes not ripened at the proper quality and is not timely sealed in high humidity areas. Gedeo Zone's

relative humidity was perfectly acceptable (100%) for beekeeping (Fig 7).

3.8 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 (Fig 8).

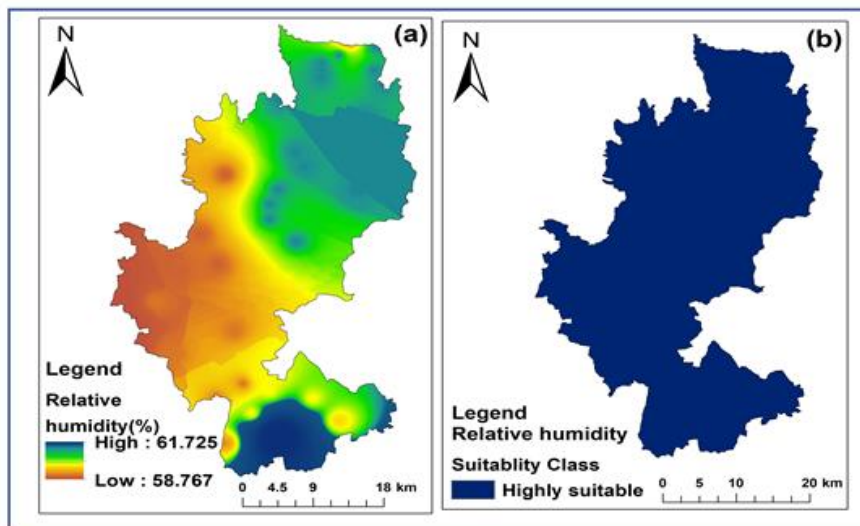


Fig. 7. Map of relative humidity of gedee zone

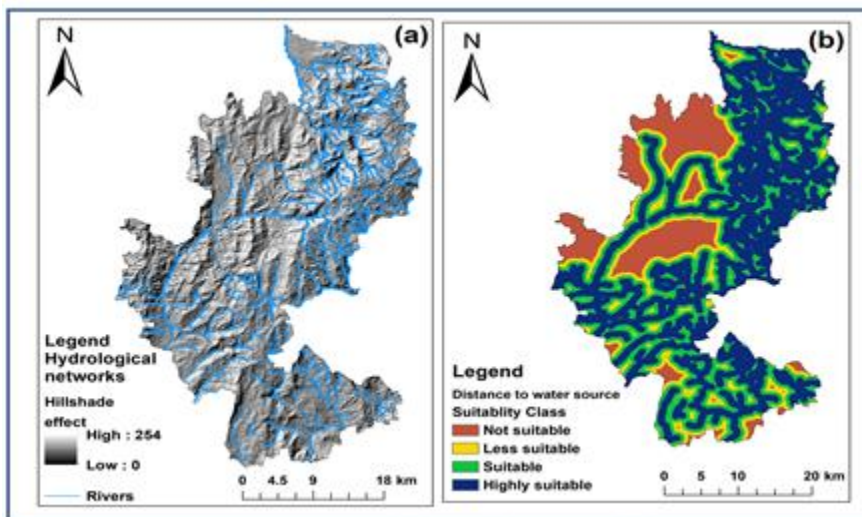


Fig. 8. Map of distance to water source of gedee zone

3.9 Potential Beekeeping Ecological Suitability Map

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 (Fig 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 (Fig 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 and cereal crops area.

Coffee and enset occupy the majority of the Gedeo agroforestry system, and both crops are important to the Gedeo people's livelihoods since they support their economy and social life. Coffee is primarily found in the mid and low land areas of the study area, and its coverage decreases as altitude increases to the highland. There are also numerous coffee shade plant

species that supply good nectar for honeybees that are used to produce honey.

3.10 Ecological suitability Area at District level

About 31.2% of the Bule districts' of the total land area was highly appropriate for beekeeping, and 30.31% of the district's land was suitable for beekeeping. Additionally, 14.09% of the district's land had conditions that made it less favourable for beekeeping (Table 8). Only 24.39% of the Bule district's land was unfit for beekeeping, which was justified as a result of limitations. This indicates that majority of Bule district has good potential for beekeeping. The inappropriate land area (24.39%) in Bule district was where crops are frequently grown with agrochemical intensification and in extreme highlands of the district [29].

In Dilla Zuriya district about 0.81% of the total land area was highly appropriate for beekeeping while the majority (65.51%) of the total land area was suitable for beekeeping. Additionally, 1.4% and 32.28% of the total land area of Dilla Zuriya district were less suitable and not suitable for beekeeping development, respectively (Table 8). The unfavourable land area for beekeeping development in Dilla Zuyira district was where crops were commonly produced and urban resettlement is expanding [30,31].

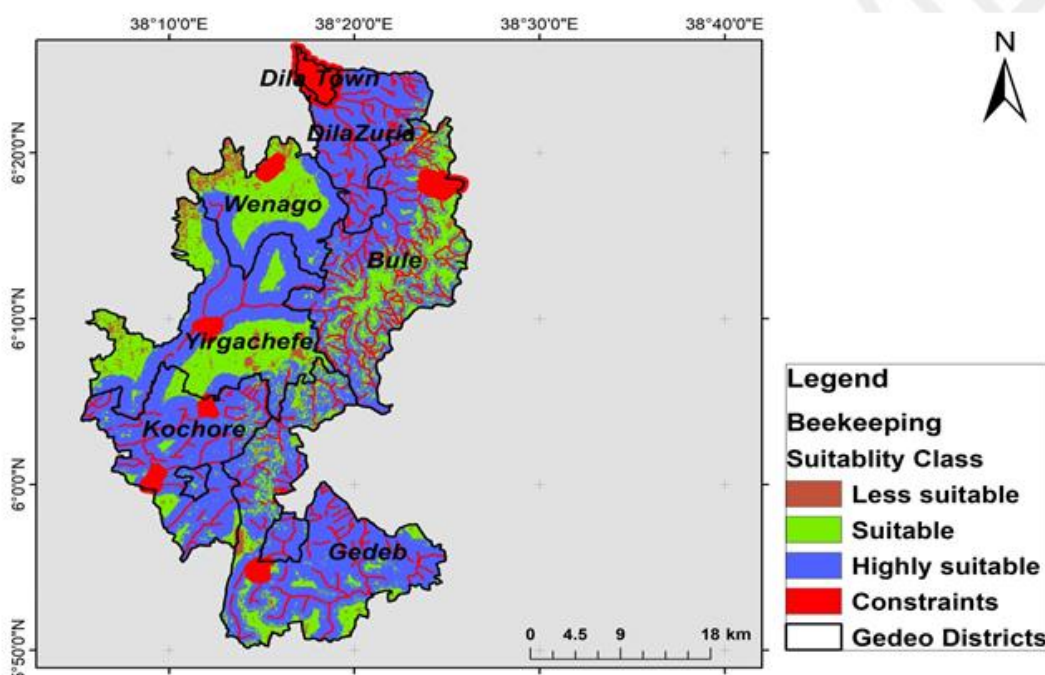


Fig. 9. Map of ecological suitability for beekeeping in Gedeo Zone

Table 8. Ecological beekeeping suitability area for Bule, Dilla Zuriya, Gedeb, Kochore, Wonago and Yirga Cheffe districts of Gedeo Zone

District	Not suitable (%)	Less suitable (%)	Suitable (%)	Highly suitable (%)
Bule	24.39	14.09	30.31	31.2
Dilla Zuria	32.28	1.4	65.51	0.81
Gedeb	12.95	33.23	29.97	23.87
Kochore	16.8	12	67.54	3.66
Wonago	6.24	23.97	68.07	1.73
Yirga cheffe	6.87	14.83	77.55	0.76

In Gedeb district, approximately 23.87% of the total land area was highly suited for beekeeping, while 29.97% was appropriate. On the other hand, 33.23% of Gedeb district's total land area was less favorable for beekeeping development, and 12.95% was unsuitable (Table 8). The inappropriate land area in Gedeb district (12.95%) is located in areas where crops are widely cultivated and resettlement occurs.

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. On the other hands, about 16.8% of the district's land was unsuitable for beekeeping development, and 12% of it was less suitable. The unsuitable land area (16.8%) in Kochore district was where crops are frequently grown, destruction of the forest for resettlement due to population growth of the district [32].

In Wonago district, only 1.73% of the total land area was highly favorable for beekeeping, while 68.07% was good for beekeeping. Furthermore, 23.97% and 6.24% of Wonago district's total land area were deemed unsuitable for beekeeping development, respectively (Table 8). The inappropriate land area in Wonago district included crop cultivation, resettlement for house construction, and the planting of no bee forage plants in the area.

In Yirga Cheffe district only 0.76% of the total land area was highly appropriate for beekeeping while the majority (77.55%) of the land was suitable for beekeeping. Moreover, 14.83% and 6.87% of the total land area of Yirga Cheffe district were less suitable and not suitable for beekeeping development, respectively (Table 8). The inappropriate land area in Yirga cheffe district was where crops are frequently grown, resettlement for house construction, and plantation of none bee forage plants in the area [33].

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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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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