World Applied Sciences Journal 22 (8): 1099-1105, 2013
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2013.22.08.7384

A Suitability Map for Keeping Honey Bees Under Harsh Environmental Conditions Using Geographical Information System

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Abstarct: Heat stress becomes a problem in different parts of the world and recently was considered as a threat to apiculture. Many countries suffer from extreme heat during certain periods of the year. There is a great diversity in the weather of Saudi Arabia throughout the year but the most extreme conditions occur during the summer season, when apiculture copes with extreme heat. Not all regions of Saudi Arabia are suitable for keeping honey bees and many beekeepers complain of annual honey bee colony losses especially during summer months. Therefore, identifying the most suitable regions for keeping honey bees is very important for beekeepers to avoid losing honey bee colonies. Geographical Information System (GIS) was employed to create a suitability map for managing honey bees under harsh environmental conditions. The most important factors affecting beekeeping were incorporated into the spatial analysis of the suitability map. The datasets were prepared as five raster layers; temperature, humidity, vegetation, land cover and water resources. The suitability map can guide beekeepers to suitable regions for keeping honey bees during the harsh environmental conditions of summer. Moreover, the described model here could be used elsewhere as a guide for creating general suitability maps.

Key words: *Apis mellifera* · GIS · Conservation · Beekeeping

INTRODUCTION

Climate change with extreme heat and drought conditions threaten apiculture worldwide. Different countries suffer from elevated seasonal temperatures (heat-suffering countries) including countries of the Arabian Peninsula as well as countries of South America, Asia and Australia. Saudi Arabia one such country, has diverse seasonal and regional environmental conditions. Summers in Saudi Arabia are hot and arid, which negatively affects beekeeping activities and result in many colony loses every year. Not all regions of Saudi Arabia are suitable for summer beekeeping. The most suitable regions for summer apiculture can be identified by employing the geographical information system (GIS) which was used previously for different purposes where Amiri *et al*. [1] identified the rangeland suitability to apiculture, Coulson *et al.* [2] evaluated suitability of the pine forest landscape to feral honey bees, Amiri and Shariff [3] identified land suitability for beekeeping. Also, Myung-Hee *et al.* [4] analyzed the habitation of Acacia honey plant and selected the most suitable areas using GIS.

Various factors were incorporated into the suitability model including environmental conditions, vegetation and water sources. The rangelands suitability for beekeeping correlated with suitable distribution of water resources, good climate condition (e.g. temperature) and flowering period [1]. The land suitability for beekeeping also increased with the availability of water resources, the suitable climate condition and dominant of plants with extended flowering period while reduced number of nectar or pollen species and shorter flowering periods decreased land suitability for beekeeping [3]. The main factors related to beekeeping are temperature, relative humidity, vegetation area and water resources.

Under normal conditions honey bees are able to regulate the microclimate of their colonies to favour brood development. Suitable temperatures for brood rearing range between 33-36 °C [5] with an average of 34.5°C [6].

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However, during the summer, workers struggle to maintain their brood nest temperature at the optimum level and below the level of the ambient temperature [7] and [8]. Temperature was found to impact on all principal activities of honey bees including foraging activity [9] and [10] as well as brood rearing activity [11]. On the other hand, relative humidity was considered as an important factor affecting on brood rearing [12] and [13] as well as eggs hatchability [14]. When low relative humidity conditions occur within the colony honey bee foragers are oriented for water collection to make the microclimate in the normal range. Thus the availability of water resources, an integrated factor to the relative humidity, was incorporated in creating the suitability maps for honey bees [1-3]. In some regions of Saudi Arabia, the summer temperature often exceeds 45°C [9] and relative humidity sometimes reach 10%.

Vegetation area, as sources of nectar and pollen for honey bees, is vital for honey bees life and was considered as an important variable in suitability modeling for beekeeping [3]. Identifying the suitable regions for keeping honey bees under harsh environmental conditions of summer season is the main aim of this paper using GIS, for creating a suitability map, which could help in conserving honey bees. The described model here could be used elsewhere as a guide and for the same purpose.

MATERIALS AND METHODS

Study Regions: The study was done on all Saudi Arabia regions to create a general suitability map for keeping honey bees during summer season. Saudi Arabia is located in the southwestern part of Asia between latitude 16° 22' 46" and 32° 14' 00 north, longitude 34° 29' 30" and 55° 40' 00 east and with total area of about 1950000 km^2 [15] and there are 13 administrative regions as shown in Fig. (1) and table (1). The majority of Saudi Arabia is desert and the general weather is dry and hot. Honey bee, *Apis mellifera*, colonies experience the most stress in the summer, when temperatures often reach extreme levels associated with very low humidity in most regions.

The most suitable regions for keeping honey bees during summer season were identified by performing spatial analysis using ArcGIS 10 program:

Input Datasets: The most important factors affecting honey bee colonies during summer were considered and arranged in layers as temperature, relative humidity, land cover, summer crops and water resources.

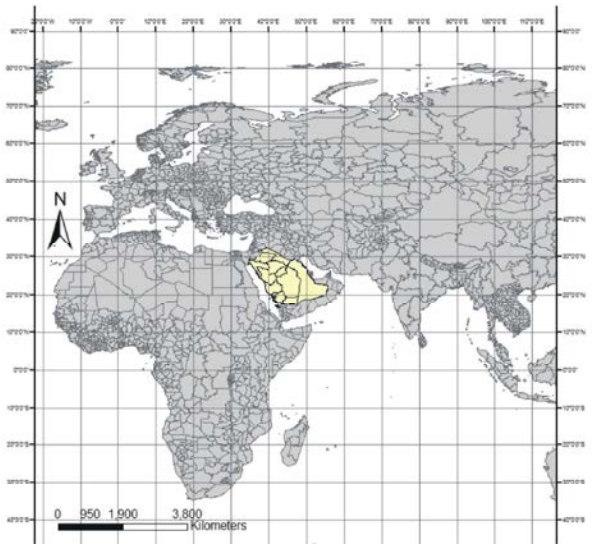

Fig. 1: The location of Saudi Arabia.

Table 1: Area of Saudi Arabia regions [15]

Region	Area (km^2)	%
Al-Riyadh	380,000	19.5
Makkah	137,000	7
Al-Madinah	150,000	7.7
Al-Quasim	73,000	3.7
Al-Sharqiyah	540,000	27.6
Asir	80,000	4.1
Tabuk	136,000	6.9
Hail	120,000	6.1
Al-Shamaliyah	104,000	5.3
Jazan	13000	0.6
Najran	130000	6.6
Al-Baha	12000	0.6
Al-Jawf	85000	4.3
Total area	1950000	100

These layers were first created as feature layers and converted to raster layers using the ArcGIS program. A map of Saudi Arabia showing regional boundaries as shape file was used in creating the raster layers. Data of temperature and relative humidity during summer season (June, July and August) from 2007 till 2011 were obtained from the Presidency of Metrology and Environment (PME) and their means were calculated and used in creating temperature and humidity layers. The mean of minimum temperature for all regions during summer season was ranged from 19.13 to 30.17°C which was considered suitable for beekeeping. The mean of maximum temperature for all regions ranged from 29.5 to 44.71°C which exceeded the high temperature tolerance of honey

Table 2: Suitability range and classification of input datasets

Datasets	Range	Description
Maximum temperature (°C)	25 – 37	More suitable
	> 38	Unsuitable
Relative Humidity (%)	< 15	Unsuitable
	16 – 40	Suitable
	> 41	More suitable
Summer crop area (%)	< 0.05	Unsuitable
	0.06 – 0.8	Suitable
	> 0.9	More suitable
Water resources (%)	0 – 33.3	Unsuitable
	33.4 - 66.7	Suitable
	> 66.8	More suitable
Land cover (type)	Barren lands	Unsuitable
	Plants	Suitable

bees and was used in regional suitability classification for beekeeping. Thus, the minimum temperature was excluded from the analysis and a layer with the maximum temperature means during summer season was incorporated into the spatial analysis. Estimated areas of summer crops for 2010 were obtained from the Ministry of Agriculture and summer crop percentage per each region was calculated by dividing the total cultivated summer crops area on area of each region. The calculated percentages were subsequently used in creating the summer crop raster layer. Some secondary factors such as road availability, elevation and soil were used in studying land suitability for beekeeping [1] and [3]. These factors have no direct impact on honey bees but may be benefit in determining where exactly the apiaries should be located and these factors were not included in the analysis because identifying the exact sites of apiaries is not the aim of the study.

Reclassification of Datasets: The datasets were reclassified into three levels (unsuitable, suitable and more suitable) as in Table (2). In previous studies the temperature limits were considered as highly suitable from 20 to 25°C, moderate suitable from 15 to 19°C and from 26 to 37°C and low suitable from 10 to14°C [1,3]. Here the range of maximum temperature was from 29.5 to 44.71°C thus somewhat similar classification, with respect to the calculated means, has been used in this study where temperature from 25 to 37°C was considered as more suitable and above 38°C was considered as unsuitable. High relative humidity is better for honey bee colonies and honey bee workers try to maintain relative humidity within the colony to be around 75% [16]. Relative humidity ranged from 6.75 to 51.26% thus three limits were assigned:1) below 15% was considered as unsuitable, 2) from 16 to 40% was considered as suitable and 3) above 40% was considered as more suitable. Such assigned limits were according to the obtained means of relative humidity for studied regions. The range of summer crop percentages was from 0.0003 to 2.1% with total of 3.44% and the majority of percentages was located below 0.8% thus percentages below 0.05% were considered as unsuitable and between 0.06 to 0.8% were considered as suitable while above 0.9% were considered as more suitable. In a previous study by Amiri *et al*. [1] vegetation cover percentage below 25% was considered as unsuitable while above 25% was considered as suitable for apiculture. Here somewhat a similar procedure was used where percentages above 0.9% (is equal to 0.9/3.7x100 = 26.1%) was considered as more suitable but below 26.1% was divided into two categories; suitable and unsuitable due to the very low percentages of summer crops.

The water resource percentages were classified into three equal ranges:1) below 33.3% was considered as unsuitable, 2) from 33.4 - 66.7% was considered as suitable and 3) above 66.8% was considered as more suitable. The distance from water resources was not calculated because distance could benefit only in case of studying the exact location of apiaries and percentages are more appropriate for identifying water sources abundance. Generally, foraging range of honey bees is from 45 m to a maximum of 5983 m [17] which is considered as relatively long distance. Land cover layer was classified into two main categories; plants (which contains all plant types including trees, shrubs, herbs and crops) and barren lands (which contains all unsuitable lands for beekeeping including water, desert and buildings) such classification is appropriate in identifying the general suitability of the regions while the exact characters of land cover including plant species, flowering period and nectar concentration are more benefit in identifying the exact apiary locations and rangeland of beekeeping. The summer crop area and land cover layers were considered as integrated layers where summer crop layer represents the percentage of cultivated crops during summer season that are suitable for beekeeping while land cover represents the availability of all plant types including perennial plants which could be suitable for honey bee colonies. Thus these two layers were considered as a good monitor for plant resources availability during summer season and also as an indirect indicator for road and water resources availability.

Table 3: Definitions for some intensity of importance numbers (from Saaty [18])

Intensity of importance	Definition
1	Equal importance
2	Weak or sight
3	Moderate importance
4	Moderate plus
5	Strong important
6	Strong plus
7	Very strong or demonstrated importance
8	Very very strong
9	Extreme importance

Table 4: Relative importance matrix and the derived weights for each variable

Variables	Temperature	Humidity	Summer crops	Water resources	Land cover
Temperature	1	5	9	9	9
Humidity	1/5	1	5	5	5
Summer crops	1/9	1/5	1	3	1
Water resources	1/9	1/5	1/3	1	1/3
Land cover	1/9	1/5	1	3	1
Derived weights for each variable.					
Variables	Temperature	Humidity	Summer crops	Water resources	Land cover
Weights	0.54	0.27	0.08	0.03	0.08

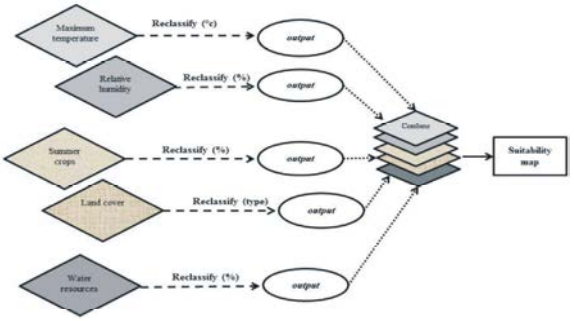

Fig. 2: A flow chart illustrating the major steps used to create the suitability map.

Weight and Combine Datasets: Due to the harsh conditions during summer season the priority was assigned for maximum temperature and relative humidity variables followed by summer crops and land cover and finally water resources. The Analytical Hierarchy Process (AHP) that was described by Saaty [18] was used for weights evaluation for each variable. Intensity of importance (Table 3) was assigned for each variable based on their relative importance then the weights were derived from the matrix as in Table (4).

Therefore, the contribution of maximum temperature and relative humidity in the final suitability map was 54% and 27%, respectively and that because of their importance during summer season while 8% for summer crops and 8% for land cover layers with total of 16% and that because these two layers were considered as integrated layers and because artificial feeding could be used sufficiently for maintaining hives during summer season. Finally, 3% of the influence was assigned for water resources and that because land cover and summer crops reflect indirectly the availability of water resources and water can be supplied for the apiaries during summer season. Weights were normalized and raster was calculated at the assigned weights for each variable followed by creating the general suitability map for honey bees (Fig. 2). A model described in the ESRI [19] spatial analysis manual was used in this research.

RESULTS AND DISCUSSION

To simplify results presentation, the five main factors affecting beekeeping during summer season were classified into two main categories: 1) summer uncontrolled factors (temperature and relative humidity layers) and these factors are continuous during summer season and beekeepers have no control over them. 2) summer controlled factors including; land cover, summer crops and water resource layers. These factors are not continuous during summer season especially flowering periods and beekeepers can control in such factors (e.g. by artificial feeding for honey bee colonies and by water supply). Therefore, two maps were created; one map for summer uncontrolled factors and one map for summer

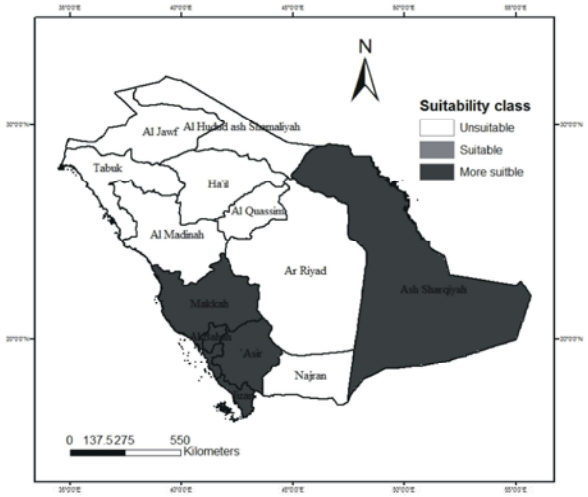

Fig. 3: Regional classification according to maximum temperature and relative humidity.

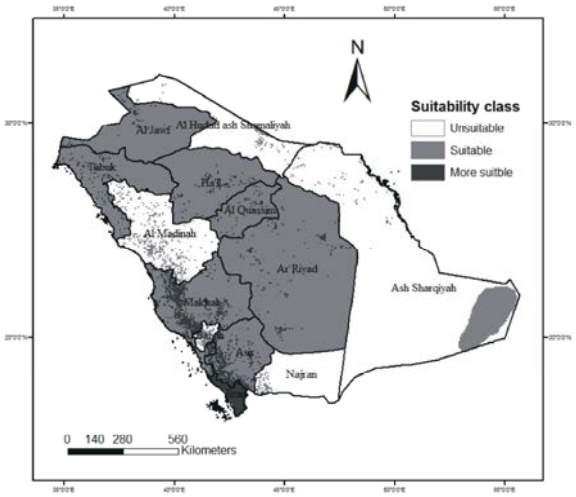

Fig. 4: Regional classification according to plant and water resources.

controlled factors. Moreover, a general map with all the layers at different weights were created as described in the materials and methods part.

Map of Summer Uncontrolled Factors: The regional classification according to maximum temperature and relative humidity of summer season showed that five regions are more suitable for beekeeping while the other regions were classified as unsuitable (Fig. 3). The unsuitable regions are with maximum temperature mean above 39°C and relative humidity less than 15%. The classification based on temperature and relative humidity reflects the nature of summer season conditions where temperatures often reach to extreme values accompanied with arid conditions. The importance of temperature as a limiting factor for honey bee activities is well known and Al-Qarni [9] found negative impacts of temperature on honey bee foraging during summer season at Riyadh city, Saudi Arabia. No flight activity was observed at or less than 10°C while the normal flight activity begins at 16°C [10] and pollen foragers decreased under high ambient temperature [20]. Exposing adult workers of giant honey bees, *Apis dorsata* to temperatures of 38°C and 45°C were found to kill them within 5 days and 48 hours, respectively accompanied with increasing of water consumption [21]. Moreover, at ambient temperature of 46°C, mean of honey bee head temperature was about 43°C [22] and such head temperature could be fatal for honey bees especially under the continuous heat stress.

Due to the arid nature of Saudi Arabia 8 regions out of the 13 regions were with mean of relative humidity between 4 to 15%. Relative humidity has special importance within the colony for brood development [13]. Relative humidity around 75% within the colony is better for normal egg hatchability [16] and under arid conditions honey bee workers regulate relative humidity within colonies by various means including; transpiration, evaporation of nectar water or water collection and evaporation [13].

Map of Summer Controlled Factors: The regional classification based on summer crops, land cover and water resource layers showed that one region and multi pocket areas are more suitable while seven regions and some pocket areas are suitable (Fig.4). Also, based on this classification three regions only were considered as unsuitable. From summer crop data, only one region was more suitable while 6 regions were suitable and six regions were unsuitable. In general the cultivated area with summer crops was very low to all regions and that may be partially explained by the harsh conditions during summer season (elevated temperature and low relative humidity). Not all summer crops are suitable for bee foraging but all cultivated areas with summer crops were incorporated into the analysis because; 1) cultivated areas generally serve as an indirect indicator for water and road access availability as well as weather suitablility for agriculture, 2) the presence of summer crops give a chance for the presence of other plants which could be used by honey bee foragers as well as give a chance for the presence of honeydew from some homopterans. Moreover, this layer was considered as an integrated layer with land cover and a relatively low weight was assigned for it.

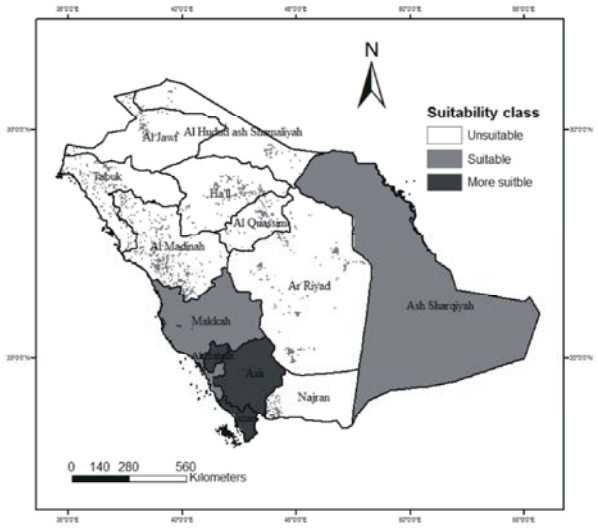

Fig. 5: Suitability map for keeping honey bees.

The presence of suitable pocket areas at different regions is due to plants distribution in the south and near the west. The plant cover, in general, is very low if compared with the total area of Saudi Arabia and that may be due to the general harsh conditions. Concerning water resources, there are no rivers in Saudi Arabia but multi small water areas. Therefore, providing the apiaries with a good source of water, in particularly continuous water source [23], is very important especially water is not stored in honey bee colonies [24]. Water requirements of honey bee colonies are strongly correlated with temperature and relative humidity, when randomly collected honey bees were caged and exposed to various temperatures honey bees were found to drink about 10 µl of water every day at 35°C and 40°C [25]. Also, water vapor loss from honey bee body was found to be increased at air temperature values above 33°C [26] as well as with elevated temperature and low humidity [27].

The General Suitability Map: The combination of all variables at different weights resulted in the general suitability map for keeping honey bees (Fig.5). Three regions only were considered as more suitable regions with total area of 105000 km^2 which represents about 5.38 % of Saudi Arabia while two regions and multi sites were considered as suitable and the rest of Saudi Arabia in general was considered as unsuitable for keeping honey bees. The more suitable regions (Al-Baha, Asir and Jizan) of the general suitability map exactly fit with the suitable regions in the previous two maps. The more suitable regions are recommended for keeping honey bee colonies during summer season while the suitable regions need some precautions for keeping honey bees. The unsuitable regions are not recommended for keeping honey bees during summer season. Also, supplying honey bee colonies with artificial feeding as well as water source is very essential during summer season. The obtained results were verified by the evaluation of the input datasets, some field trips as well as expert consultation.

CONCLUSION

The described model in this research using five main layers (maximum temperature, relative humidity, land cover, summer crops and water resources) succeeded in identifying the suitable regions for keeping honey bees under harsh environmental conditions (elevated temperature and low humidity). Thus, this model can be used sufficiently for regional classification and can be applied elsewhere for the same purpose.

ACKNOWLEDGMENTS

We would like to thank Deanship of Scientific Research and College of Food and Agriculture Science Research Center as well as Bee Research Unit for providing the necessary materials for the research. Thanks also to Eng. S. Mahmoud, Department of Agricultural Engineering, KSU for his assistance in performing the spatial analysis.

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