Online ISSN: 2588-3526

Journal of Wildlife and Biodiversity

Volume 9(2): 425-441 (2025) (http://www.wildlife-biodiversity.com/)

Research Article

Understanding the impact of climate change on honey bees' distribution in Pakistan: A predictive approach using historical data

Aqsa Saleem[1], Arshad Javid[1], Ali Hussain[1], Shahid Mehmood[2]

[1]Department of Wildlife and Ecology, University of Veterinary and Animal Sciences, Lahore, Pakistan.

[2]Department of Poultry Production, University of Veterinary and Animal Sciences, Lahore, Pakistan.

Corresponding Author: arshadjavid@uvas.edu.pk

Received: 29 December 2024 / Revised: 29 April 2025 / Accepted: 25 May 2025/ Published online: 27 May 2025.

How to cite: Saleem, A., Javid, A., Hussain, A., Mehmood, S. (2025). Understanding the impact of climate change on honey bees' distribution in Pakistan: A predictive approach using historical data, Journal of Wildlife and Biodiversity, 9(2), 425-441. **DOI**: https://doi.org/10.5281/zenodo.15528204

Abstract

This study investigated the potential future distribution of three honey bee species viz., *Apis florea, Apis cerana,* and *Apis dorsata,* in Pakistan. The data was collected based on sighting records from field surveys, literature reviews, and the Global Biodiversity Information Facility (GBIF). Maxent software was used to incorporate GPS coordinates and bioclimatic data to predict the future distribution of the honey bee species in Pakistan. A model habitat suitability based on 19 different bioclimatic variables from WorldClim was used to compare current and projected (2050) climatic scenarios. The results indicated a general warming trend for all three species with expected average annual increases in temperature and precipitation. *Apis florea* is expected to face a 2.5°C rise in the annual mean temperature, while *Apis cerana* and *Apis dorsata* will face increases of 2.4°C and 2.3°C, respectively. An increase in precipitation ranging from 50 to 60 mm annually is expected. This expected increase in temperature and precipitation could enhance foraging behaviour during a few months of the year, and the heat stress in warmer months poses a significant challenge for the survival of the honey bee species. Moreover, variations in seasonal patterns, including mild winters and increased humidity, could disrupt honey bees' activity, the colony dynamics, and plants' physiology. These factors require making resilient habitats for honey bees, and this can be done by planting resilient plants and maintaining habitats that provide suitable shelter from extreme heat. It is recommended that species distribution models should also take into account

other variables, including land use changes, pesticide use and disease prevalence, to provide a more comprehensive understanding of how honey bee species may respond to climate change in the future.
Keywords: *Apis florea, Apis cerana, Apis mellifera, Apis dorsata,* Pakistan

Introduction

Climate change, intensified by human activities, is affecting global ecosystems and influencing the biodiversity and species distribution (Ji, 2021). Honey bees are environmentally friendly creatures and play an important role in many ecosystems as pollinators. Pollinators are responsible for the reproduction of many plants that are vital for human food production. However, the climatic factors are altering the habitats and behavior of many animals. The honey bee hives and colony dynamics are dependent on temperature, rain, season, and types of vegetation (Orr et al., 2021). Historical distribution data provides information on the distribution trends of honey bees and indicates how climate change can alter the habitats (Ghassemi-Khademi et al., 2022).

For honey bees, future distribution models are often based on data related to temperature, rainfall and floral resources as these factors are critical to their foraging and survival (Gebremedhn et al., 2024). For example, the *Apis mellifera* has a strong correlation between its distribution and temperature gradients (Mitchell, 2022). Similarly, studies on *Apis cerana* and *Apis florea* indicated that regional climatic conditions, vegetation, and nesting sites play a key role in determining their geographical range (Harrison, 2021). The honey bee is a social insect that plays a vital role in the pollination of cereals, fruits, and vegetables. 80% of total pollination is done by honey bees and 20% is done by other pollinators. According to an estimate, if there are no honey bees, humans cannot live more than four years. Pakistan is represented by four species of the genus *Apis,* including *Apis mellifera*, *Apis florea*, *Apis cerana,* and *Apis dorsata* (Kumar et al., 2024). In Pakistan, honey bees have wide distribution range from subtropical areas to mountainous ranges in the north of the country. The *Apis mellifera* was introduced in 1977-78 in the Murree region, Pakistan, which is located 2291 m above sea level. This region is represented by 700 plant species, and this introduction has greatly influenced the beekeeping practices in Pakistan. The adaptability of *Apis mellifera* to diverse climatic conditions has resulted in its establishment in wider regions of Pakistan. Most beekeeping practices are focused in Khyber Pakhtunkhwa and central and north regions of Punjab but are growing rapidly (Khan et al., 2017). Beekeeping in Pakistan is not exploiting the full potential of bee forage plants found in forest cover and agricultural land, including linear plantations and rangelands. The bee flora present in the country can support up to 3.5 million bee colonies (Khan et al., 2017).

Natural hives of honey bees is affected by climatic conditions, type of vegetation, and human activities in Pakistan (Ostroverkhova et al., 2020). As climate change in Pakistan is expected to bring higher temperatures, alter rainfall patterns, and more extreme weather events, which may lead to an impact on honey bees (Makori et al., 2017). Future distribution modeling can guide conservation planning, support beekeepers, and inform agricultural management in pollination-dependent crops. For example, data from the Global Biodiversity Information Facility (GBIF) and field records provide valuable information on species occurrence, and this data can be used in distribution modeling (Harvey et al., 2023). Future climate scenarios from sources such as WorldClim enable researchers to simulate how these variables might evolve and how they could impact species habitats and distribution in the future. A better understanding of the effects of climate change and habitat degradation on honey bee populations can help wildlife biologists to adopt better management strategies, including protection of key habitats, better land use policies, and promoting pollinator-friendly plantations (Harmon-Threatt, 2020). Efforts can be made to implement conservation strategies that safeguard vital ecosystems by predicting where natural hives are likely to be in the future (Ghassemi-Khademi et al., 2022). The present study was planned to understand how climate change is impacting the distribution of natural hives and to explore how predictive modeling using historical data can offer insights into these shifts.

Materials and methods

Study Area and Data Collection

Three honey bee species, including *A. florea*, *A. Cerana,* and *A. Dorsata* were used in this research to project their future distribution in Pakistan. They were selected based on their ecological significance and widespread presence in the country. Sighting records, including longitude and latitude coordinates, were collected using a multi-faceted approach that combined field surveys, a literature review, and data from the Global Biodiversity Information Facility (GBIF). This comprehensive approach ensured broad coverage of beehive sightings across various geographical regions in Pakistan.

Geographic coordinates of hive sightings in different locations were obtained using the Global Positioning System (GPS). GPS played a crucial role in accurately identifying hive locations, ensuring the reliability of data used for habitat suitability modeling. For climate data, 19 bioclimatic variables were gathered from WorldClim. These variables, which play a key role in determining environmental factors affecting honey bee distribution, were collected for both present conditions and projected future (2050) climatic scenarios. This data was essential for assessing the potential impacts of climate change on species distribution.

Data Analysis

Maxent software was employed to model habitat suitability for the targeted bee species. Sighting records and the 19 bioclimatic variables (Table 1) served as input data for the Maxent model, enabling projections of potential honey bee habitats under both current and future climatic conditions. Maxent's habitat suitability index was utilized to interpret how climate variables would influence the distribution of such species over time.

Table 1. List of bioclimatic variables used during the present study.

Code	**Bioclimatic variables**
BIO1	Mean Temperature Per Year
BIO2	Monthly Mean Diurnal Range (Mean of max temp - min temp)
BIO3	Isothermality [(BIO2/BIO7) × 100]
BIO4	Temperature Seasonality (standard deviation ×100)
BIO5	Warmest Month of Maximum Temperature
BIO6	Coldest Month of Minimum Temperature
BIO7	Annual Range of Temperature (BIO5-BIO6)
BIO8	Wettest Quarter’s Mean Temperature
BIO9	Driest Quarter’s Mean Temperature
BIO10	Warmest Quarter’s Mean Temperature
BIO11	Coldest Quarter’s Mean Temperature
BIO12	Precipitation Per Year
BIO13	Wettest Month’s Precipitation
BIO14	Driest Month’s Precipitation
BIO15	Seasonality of Precipitation (Coefficient of Variation)
BIO16	Wettest Quarter’s Precipitation
BIO17	Driest Quarter’s Precipitation
BIO18	Warmest Quarter’s Precipitation
BIO19	Coldest Quarter’s Precipitation

Results

Bioclimatic variables for *Apis florea*

Table 2 indicates bioclimatic variables for *Apis florea* (dwarf honey bee) for the current climate and for 2050 under a projected climate, illustrating variation in temperature and precipitation patterns to be anticipated. Data indicate a substantial warming tendency in the region, with a sharp rise in temperature-related variables and a modest rise in precipitation. Annual mean temperature (BIO1) is anticipated to rise from 21.0 to 23.5 °C, a 2.5 °C rise from current levels, indicating a warmer climate, and is most likely to have an effect on habitat suitability for the species since temperature is a significant parameter for honey bee species existence and distribution. Similarly, maximum temperature in the warmest month (BIO5) is projected to increase from 39.0 to 41.0 °C, a 2.0 °C increase, indicating a general rise in heat extremes, and minimum temperature in the coldest month (BIO6) rises from 6.5 to 7.5 °C, a 1.0 °C increase. This trend points toward warmer winters, which could impact hibernation behavior and overall survival of the species during colder months. The annual temperature range (BIO7), which measures the difference between the warmest month's maximum and the coldest month's minimum, is expected to rise by 1.0 °C, from 32.5 °C to 33.5 °C. Regarding precipitation, annual precipitation (BIO12) is projected to rise by 50 mm, from 870 mm to 920 mm, suggesting a slightly wetter climate in the future. Precipitation in the wettest month (BIO13) is expected to increase by 15 mm, from 160 mm to 175 mm, while precipitation in the driest month (BIO14) will likely rise by 4 mm, from 18 mm to 22 mm. These trends indicate more rainfall during wet months and a slight increase in precipitation during dry months, potentially affecting water resources available for *Apis florea*. Additionally, the mean temperature in the wettest quarter (BIO8) is expected to rise by 2.5 °C, while the mean temperature in the driest quarter (BIO9) is projected to increase by 1.5 °C. These warming trends in both dry and wet seasons could influence the species' foraging behavior and survival ability in a changing climate. Likewise, mean temperature in the warmest quarter (BIO10) is projected to increase by 1.5 and mean temperature in the coldest quarter (BIO11) is projected to increase by 1.0 °C, indicating a generic trend towards warmer seasonal conditions in all quarters.

Precipitation seasonality (BIO15) is a measure of precipitation variability throughout a year and is anticipated to reduce to a small extent by 0.02 (0.23 to 0.21). This suggests a reduction in the fluctuation of precipitation, potentially leading to more consistent rainfall patterns. However, the precipitation of the wettest quarter (BIO16) will increase by 20 mm, from 355 mm to 375 mm, and the precipitation of the warmest quarter (BIO18) will rise by 25 mm, from 185 mm to 210 mm. These increases suggest that *Apis florea* could benefit from more rainfall during the warmer months, which might improve forage availability, though the increase in the precipitation of the driest quarter (BIO17) by 5 mm (from 55 mm to 60 mm) indicates that the driest periods may remain relatively dry. The precipitation of the coldest quarter (BIO19) is expected to increase by 7 mm, from 78 mm to 85 mm, reflecting a wetter trend in the winter months, which could affect bee activity and hive dynamics during the cold season. The predicted climate changes for 2050 show an overall warmer and slightly wetter environment for *Apis florea* in Pakistan. While the increase in temperature, particularly during the warm months, could pose challenges for habitat suitability, the rise in precipitation, especially during the wettest and warmest quarters, may provide more favorable conditions for forage availability and water resources. These shifts could lead to changes in the distribution and ecological requirements of *Apis florea*, and must be considered when planning for conservation and habitat management in the face of climate change.

Table 2. Comparison of current bioclimatic variables and projected year 2050 for *Apis florea.*

Bioclimatic Variable	**Current Value (°C/mm)**	**2050 Value (°C/mm)**	**Change**
BIO1: Annual mean temperature	21.0 °C	23.5 °C	+2.5 °C
BIO2: Monthly mean diurnal range (Mean of max temp-min temp)	10.1 °C	9.9 °C	-0.2 °C
BIO3: Isothermality [(BIO2/BIO7) × 100]	56.0	57.5	+1.5
BIO4: Temperature seasonality (standard deviation ×100)	150.5	157.0	+6.5
BIO5: Warmest month of maximum temperature	39.0 °C	41.0 °C	+2.0 °C
BIO6: Coldest month of minimum temperature	6.5 °C	7.5 °C	+1.0 °C
BIO7: Annual range of temperature (BIO5-BIO6)	32.5 °C	33.5 °C	+1.0 °C
BIO8: Wettest quarter’s mean temperature	21.0 °C	23.5 °C	+2.5 °C
BIO9: Driest quarter’s mean temperature	19.5 °C	21.0 °C	+1.5 °C
BIO10: Warmest quarter’s mean temperature	31.5 °C	33.0 °C	+1.5 °C
BIO11: Coldest quarter’s mean temperature	10.5 °C	11.5 °C	+1.0 °C
BIO12: Precipitation per year	870 mm	920 mm	+50 mm

BIO13: Wettest month's precipitation	160 mm	175 mm	+15 mm
BIO14: Driest month's precipitation	18 mm	22 mm	+4 mm
BIO15: Seasonality of precipitation (coefficient of variation)	0.23	0.21	-0.02
BIO16: Wettest quarter's precipitation	355 mm	375 mm	+20 mm
BIO17: Driest quarter's precipitation	55 mm	60 mm	+5 mm
BIO18: Warmest quarter's precipitation	185 mm	210 mm	+25 mm
BIO19: Coldest quarter's precipitation	78 mm	85 mm	+7 mm

Source: http://www.pmd.gov.pk

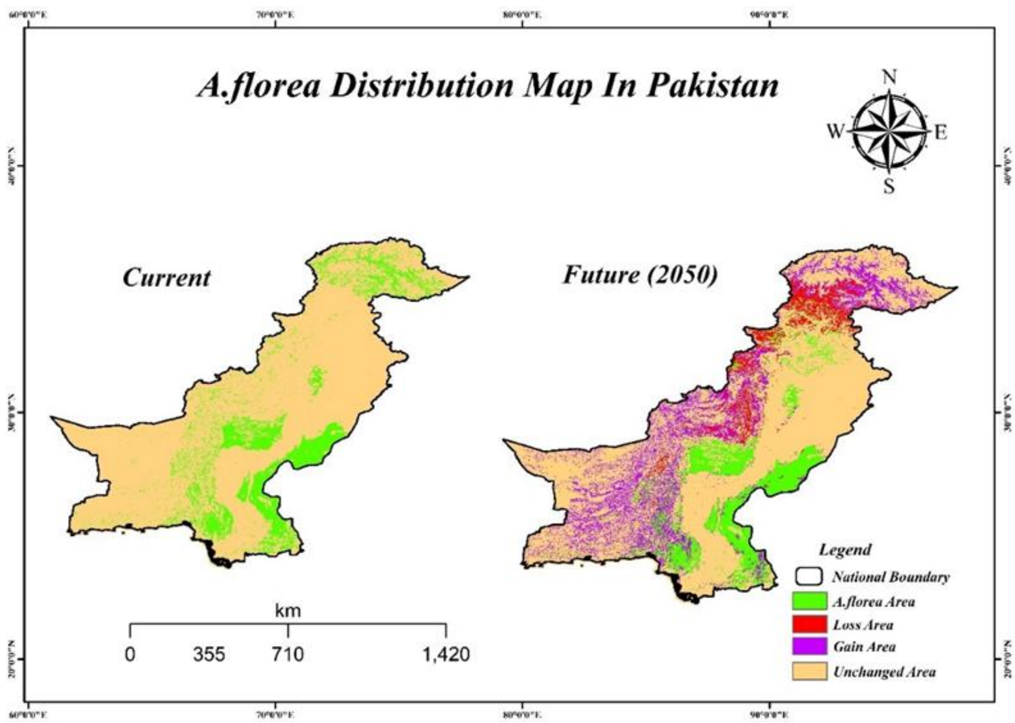

Figure 1. Current and future distribution map of *Apis florea* in Pakistan

Bioclimatic variables for *Apis cerana*

Table 3 presents the bioclimatic variables for *Apis cerana* (the Asian honey bee), comparing current values with predicted values for 2050. The annual mean temperature (BIO1) for *Apis cerana* is projected to rise by 2.4°C, from 20.8°C to 23.2°C, indicating a general warming trend in the region. This increase is similar to that observed for *Apis florea*, and suggests that *Apis cerana* will experience warmer conditions in the future. The maximum temperature of the warmest month

(BIO5) will increase by 2.0°C, from 38.5°C to 40.5°C, while the minimum temperature of the coldest month (BIO6) is expected to rise by 1.2°C, from 6.0°C to 7.2°C. These temperature alterations will result in warmer months being warmer and colder months being milder, and may influence bee species survival, hibernation, and reproductive cycles. The annual range of temperature (BIO7) or the highest temperature in the warmest month - the lowest temperature in the coldest month will increase 0.8°C, from 32.5 to 33.3°C. This will result in a small rise in summer and winter extremes of temperature, and can have an influence on the tolerance to seasonal extremes of temperature for the species. The temperature for the wettest quarter (BIO8) is forecast to rise by 2.4°C, from 20.7°C to 23.1°C, and for the driest quarter (BIO9) will rise by 1.6°C, from 19.2°C to 20.8°C. This will mean dry and wet seasons will warm, and this could affect foraging and nesting behavior in *Apis cerana*, particularly in warmer months when the species is typically under more heat stress. Other seasonal temperature changes include in mean temperature in the warmest quarter (BIO10) that will be raised by 1.6°C, from 30.8°C to 32.4°C, and in mean temperature in the coldest quarter (BIO11) that will be raised by 1.0°C, from 10.0°C to 11.0°C. These reflect a general warming trend that will affect all aspects of the year and have an effect on activity patterns in the species, e.g., foraging, nest building, and colony management.

In precipitation terms, annual precipitation (BIO12) for *Apis cerana* will increase by 50 mm, to 910 mm from 860 mm. This is a reasonably modest increase and is in line with that for *Apis florea*, and shows that while the area will be overall more damp, changes are not extreme. Similarly, precipitation in the wettest month (BIO13) will increase 15 mm, to 170 from 155 mm, and precipitation in the driest month (BIO14) will increase 4 mm, to 23 from 19 mm. These increases show a slight tendency for greater moisture, which could be a boon for foraging for the bees, although this will be subject to how evenly these increases are shared throughout the year. The precipitation seasonality (BIO15), which measures rainfall variability between dry and wet periods, will decrease slightly by 0.02, from 0.24 to 0.22. This shows that rainfall will be more evenly shared throughout the year, lowering dry spell extremity and enhancing a more stable water resource for *Apis cerana*. The precipitation in the wettest quarter (BIO16) will increase by 20 mm, from 340 to 360 mm, and precipitation in the warmest quarter (BIO18) will increase by 25 mm, from 180 to 205 mm. These increases show that greater moisture in warmer months could be a boon for *Apis cerana*, as this will improve nectar and water resource availability. Besides, precipitation in the driest quarter (BIO17) is forecast to increase by 5 mm, from 53 to 58 mm, and precipitation in the coldest quarter (BIO19) will increase by 7 mm, from 75 to 82 mm. These small increases in precipitation in the driest and coldest quarters mean that pressures from water shortages will decrease for *Apis cerana*, in particular in colder months when water can be a limiting resource for colony health. Forecast changes in temperature and precipitation for *Apis cerana* mean a warmer and slightly wetter climate in 2050. The increase in temperature, in particular in warmer months, can lead to heat stress and affect activity patterns in the species, and the increase in precipitation, in particular in warm and wetter quarters, can lead to improved forage and water resource conditions. The small increase in temperature in colder months can also lead to milder winters and improve colony survival and productivity. All these changes will have to be carefully taken into consideration when evaluating future distribution and ecological demands of *Apis cerana* in Pakistan.

Table 3. Comparison of current bioclimatic variables and projected year 2050 for *Apis cerana.*

Bioclimatic Variable	**Current Value (°C/mm)**	**2050 Value (°C/mm)**	**Expected Change**
BIO1: Annual mean temperature	20.8 °C	23.2 °C	+2.4 °C
BIO2: Monthly mean diurnal range (Mean of max temp-min temp)	10.3 °C	9.7 °C	-0.6 °C
BIO3: Isothermality [(BIO2/BIO7) × 100]	57.3	58.0	+0.7
BIO4: Temperature seasonality (standard deviation ×100)	149.2	155.8	+6.6
BIO5: Warmest month of maximum temperature	38.5 °C	40.5 °C	+2.0 °C
BIO6: Coldest month of minimum temperature	6.0 °C	7.2 °C	+1.2 °C
BIO7: Annual range of temperature (BIO5-BIO6)	32.5 °C	33.3 °C	+0.8 °C
BIO8: Wettest quarter's mean temperature	20.7 °C	23.1 °C	+2.4 °C
BIO9: Driest quarter's mean temperature	19.2 °C	20.8 °C	+1.6 °C
BIO10: Warmest quarter's mean temperature	30.8 °C	32.4 °C	+1.6 °C
BIO11: Coldest quarter's mean temperature	10.0 °C	11.0 °C	+1.0 °C
BIO12: Precipitation per year	860 mm	910 mm	+50 mm
BIO13: Wettest month's precipitation	155 mm	170 mm	+15 mm
BIO14: Driest month's precipitation	19 mm	23 mm	+4 mm
BIO15: Seasonality of precipitation (coefficient of variation)	0.24	0.22	-0.02
BIO16: Wettest quarter's precipitation	340 mm	360 mm	+20 mm

BIO17: Driest quarter's precipitation	53 mm	58 mm	+5 mm
BIO18: Warmest quarter's precipitation	180 mm	205 mm	+25 mm
BIO19: Coldest quarter's precipitation	75 mm	82 mm	+7 mm

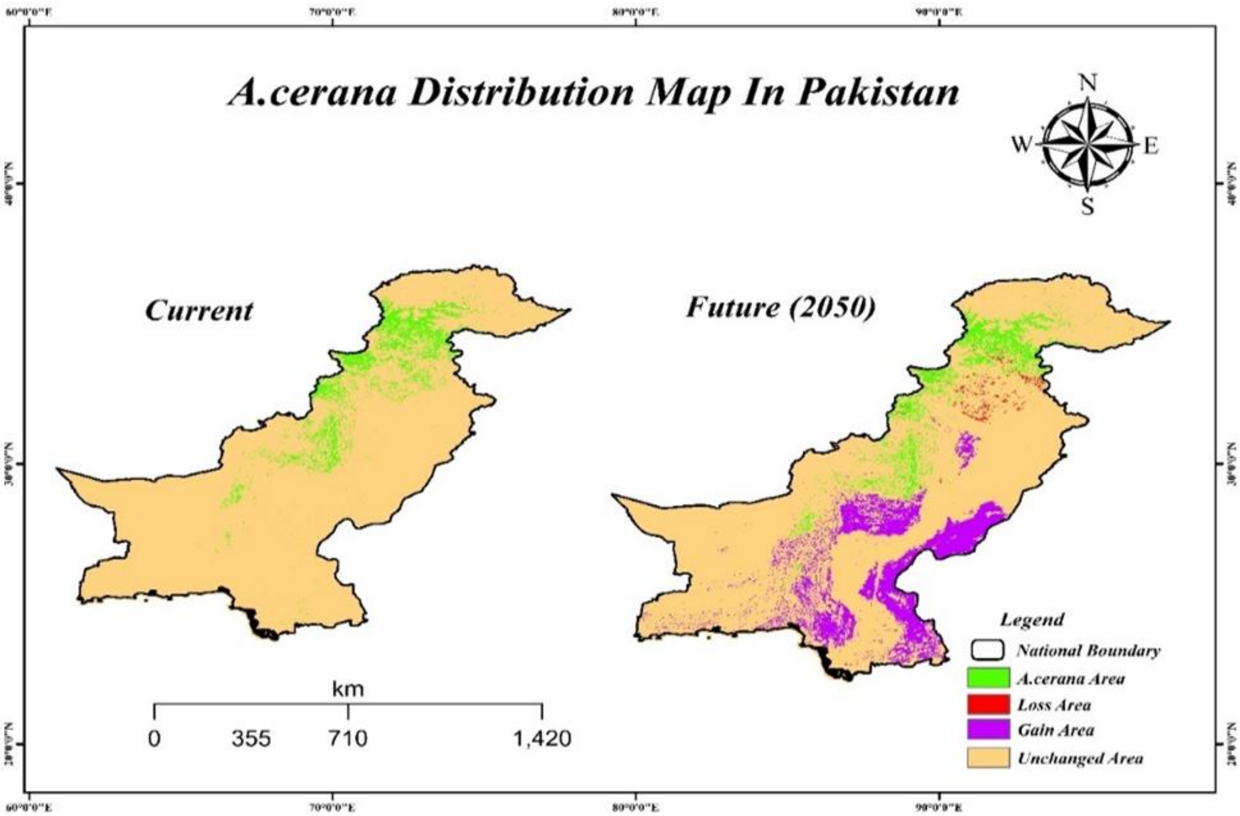

Figure 2: Current and future distribution map of *Apis cerana* in Pakistan

Bioclimatic Variables for *Apis dorsata*

Table 4 provides the bioclimatic variables for *Apis dorsata* (giant honey bee) with comparisons between present and projected values for 2050. According to the data, there is a consistent warming trend in temperature along with small increases in precipitation, which could significantly impact the habitat suitability and distribution of *Apis dorsata* in Pakistan. The annual mean temperature (BIO1) for *Apis dorsata* is expected to rise by 2.3°C from 21.5°C to 23.8°C, indicating a gradual warming of the region. Although this increase is lower than expected for *Apis florea* and *Apis cerana*, it still represents a significant warming trend that could affect the species' distribution. Similarly, the maximum temperature in the warmest month (BIO5) is expected to rise by 2.2°C, from 40.0°C to 42.2°C, while the minimum temperature in the coldest month (BIO6) will increase by 1.0°C, from 7.0°C to 8.0°C. These temperature increases suggest that *Apis dorsata* will experience hotter summers and mild winters, which in turn can affect its survival and reproduction. The annual temperature range (BIO7) is expected to rise by 1.2°C from 33.0°C to 34.2°C. The slight increase in seasonal temperature extremes may challenge *Apis dorsata*'s ability to adapt to new environmental conditions.

The mean temperature in the wettest quarter (BIO8) is expected to rise by 2.6°C, from 21.2°C to 23.8°C, marking the most significant temperature increase among all bioclimatic variables for *Apis dorsata*. This result suggested that the wettest months of the year will also be warmer and which can impact the foraging activity. Similarly, the mean temperature in the driest quarter (BIO9) is expected to rise by 1.6°C from 19.6°C to 21.2°C. This increase means that dry periods will be warmer, which can lead to maximum heat stress to *Apis dorsata.* The mean temperature in the warmest quarter (BIO10) will rise by 1.8°C, from 32.0 to 33.8°C, and that in the coldest quarter (BIO11) will rise by 1.0°C, from 11.0 to 12.0°C. These are all indicative of a universal warming trend for all seasons, and this could affect nesting behavior and seasonal activity patterns for the species.

In precipitation terms, annual precipitation (BIO12) is projected to increase 50 mm, from 880 mm to 930 mm. This is comparable to increases forecast for *Apis florea* and *Apis cerana* and indicates that the area will be a little wetter in the future. Precipitation in the wettest month (BIO13) is projected to increase 15 mm, from 165 mm to 180 mm, and precipitation in the dry month (BIO14) will increase 4 mm, from 22 mm to 26 mm. These indicate that the species will see a little more water and forage throughout both the dry and wet times, which could assist in keeping water and forage levels consistent throughout the year. Seasonality in precipitation (BIO15) is projected to decrease 0.02, from 0.25 to 0.23. This will mean that precipitation will be more uniformly distributed throughout seasons, and could shorten dry spells and give a more consistent water resource to *Apis dorsata*. Precipitation in the wet quarter (BIO16) is projected to increase 20 mm, from 365 mm to 385 mm, and precipitation in the warm quarter (BIO18) will increase 25 mm, from 190 mm to 215 mm. These increases will result in increased rainfall in warmer months, which could enhance foraging levels and water resources for colonies. Precipitation in the dry quarter (BIO17) is projected to increase 5 mm, from 58 mm to 63 mm, and precipitation in the cold quarter (BIO19) will increase 10 mm, from 80 mm to 90 mm. These modest increases mean that *Apis dorsata* could experience more favorable wet conditions in the driest and coolest months, which could improve survival rates in adversity and could allow colonies to persist in colder months when water is most crucial. Projected climate changes for 2050 for *Apis dorsata* show a net warming trend with modest increases in precipitation for most of the year. The warmer climate, and most particularly in the wettest and warmest quarter, could be difficult for *Apis dorsata*, most particularly with respect to heat stress and foraging behavior. However, increased precipitation, most particularly in times of dryness, could improve water and forage resources and favor the species in the long term. These changes should be carefully taken into consideration when assessing future distribution and habitat suitability for *Apis dorsata* in Pakistan, most particularly with respect to climate change impacts on bee populations.

Table 4. Comparison of current bioclimatic variables and projected year 2050 for *Apis dorsata.*

Bioclimatic Variable	**Current Value (°C/mm)**	**2050 Value (°C/mm)**	**Change**
BIO1: Annual mean temperature	21.5 °C	23.8 °C	+2.3 °C
BIO2: Monthly mean diurnal range (Mean of max temp-min temp)	10.0 °C	9.8 °C	-0.2 °C
BIO3: Isothermality [(BIO2/BIO7) × 100]	58.0	59.0	+1.0
BIO4: Temperature seasonality (standard deviation ×100)	151.0	158.0	+7.0
BIO5: Warmest month of maximum temperature	40.0 °C	42.2 °C	+2.2 °C
BIO6: Coldest month of minimum temperature	7.0 °C	8.0 °C	+1.0 °C
BIO7: Annual range of temperature (BIO5-BIO6)	33.0 °C	34.2 °C	+1.2 °C
BIO8: Wettest quarter's mean temperature	21.2 °C	23.8 °C	+2.6 °C
BIO9: Driest quarter's mean temperature	19.6 °C	21.2 °C	+1.6 °C
BIO10: Warmest quarter's mean temperature	32.0 °C	33.8 °C	+1.8 °C
BIO11: Coldest quarter's mean temperature	11.0 °C	12.0 °C	+1.0 °C
BIO12: Precipitation per year	880 mm	930 mm	+50 mm
BIO13: Wettest month's precipitation	165 mm	180 mm	+15 mm
BIO14: Driest month's precipitation	22 mm	26 mm	+4 mm
BIO15: Seasonality of precipitation (coefficient of variation)	0.25	0.23	-0.02
BIO16: Wettest quarter's precipitation	365 mm	385 mm	+20 mm
BIO17: Driest quarter's precipitation	58 mm	63 mm	+5 mm

BIO18: Warmest quarter’s precipitation	190 mm	215 mm	+25 mm
BIO19: Coldest quarter’s precipitation	80 mm	90 mm	+10 mm

Source: http://www.pmd.gov.pk

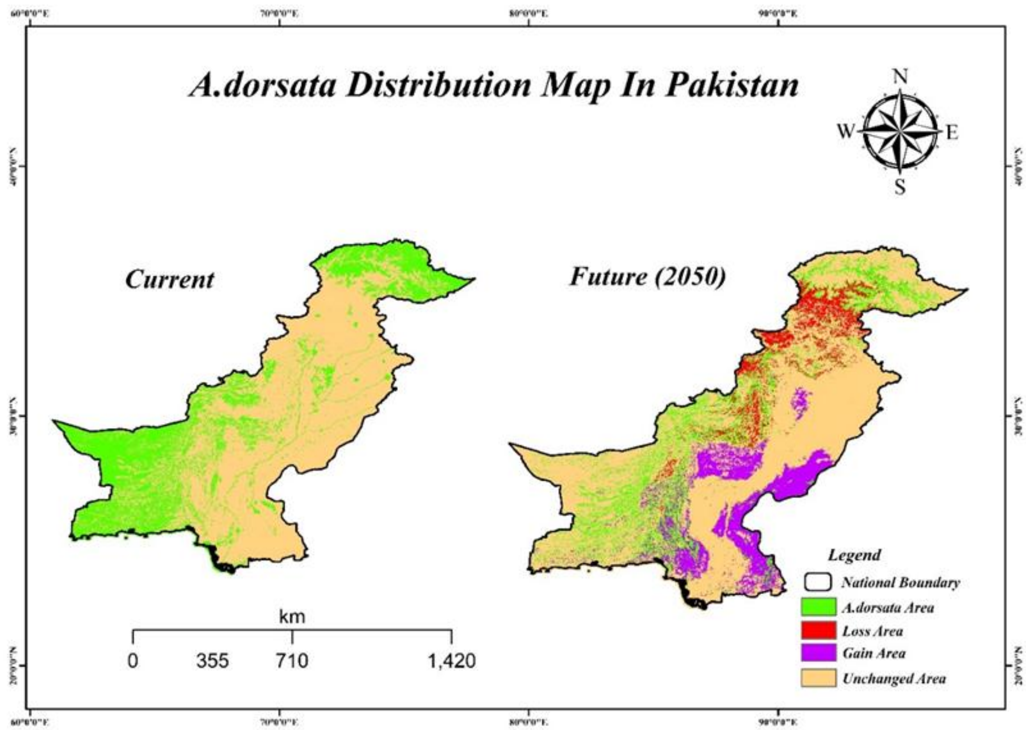

Figure 3. Current and future distribution map of *Apis dorsata* in Pakistan

Discussion

Projected bioclimatic variables for *Apis florea*, *Apis cerana*, and *Apis dorsata* showed all three species to experience increases in annual mean temperature (BIO1) of approximately 2.3–2.5°C, in line with predictions from global climate models for a prolonged rise in surface temperature over the next few decades. Recent studies have reported similar results that honey bees are highly sensitive to temperature changes, which can ultimately affect their developmental and foraging activity (Cook et al., 2022; Giannoni-Guzman et al., 2021). During the present study, it is estimated that 2.0–2.5°C increases in warm-month temperatures (BIO5) can provide heat stress to *Apis florea*, *Apis cerana*, and *Apis dorsata*, which in turn will affect colony dynamics (Fleming et al., 2021).

Apis florea has a distribution range in warmer climates, but they are sensitive to extreme heat. Heat stress can impact their ability to fly and forage. For the *Apis florea*, it was estimated that a

2.5°C increase in mean annual temperature and a 2.0°C rise in maximum temperature during the hottest months. The 1.0°C increase in minimum temperatures during the coldest month will lead to mild winter, however, this may help reduce their mortality, it could also alter floral distribution, potentially causing mismatches between the availability of plant resources for foraging (Villagomez et al., 2021). Similarly, for *Apis cerana*, the 1.2°C increase in minimum temperatures during cold months, combined with the overall warming trend, could disrupt foraging schedules and colony cycles for the species. The small but significant increase in *A. dorsata*'s coldest-month temperature by 1.0°C could similarly alter overwintering behavior and colony thermoregulation (Kevan et al., 2024). Moreover, the increase in temperature annual range (BIO7) by about 1.0–1.2°C for these species is equivalent to increased seasonal extremes, which can increase summer heat stress and winter hardships. Although honey bees can physiologically acclimate to heterogeneous temperature conditions, abrupt changes in temperature extremes can disrupt colony dynamics, reduce brood production, and impact survival unless supplemented with floral resource supplies (Harvey et al., 2023).

Along with warming, *A. florea*, A. cerana, and *A. dorsata* annual rainfall (BIO12) is projected to increase about 50 mm, with a trend towards comparatively greater wetness. This is consistent with region-specific climate projections for modest rainfall increases in certain places in South Asia (Krishnan et al., 2020). The +15–25 mm in rainfall in months with most rainfall (BIO13, BIO16) and the +4–5 mm in months with least rainfall (BIO14, BIO17) indicate a more balanced rainfall distribution, which can improve nectar levels in crucial seasons (Akram et al., 2024; Saeed, 2022). However, even small shifts in precipitation timing can affect floral phenology, leading to changes in blooming periods that either favor or disadvantage bee foraging (Diaz Calafat, 2024). Precipitation seasonality (BIO15) is expected to decrease slightly (by 0.02) in all three species' models, suggesting a marginally more uniform rainfall pattern throughout the year. This could benefit bee populations if the additional precipitation coincides with major foraging seasons, improving pollen and nectar availability. However, increased rainfall during already humid periods might exacerbate colony stress related to high humidity, disease transmission, and reduced flight activity (Mishra et al., 2023). For *A. dorsata*, the +2.6°C rise in mean temperature of the wettest quarter (BIO8) coupled with an extra 20–25 mm precipitation in the same period could lead to hotter, wetter monsoons, which can pose challenges for nest site stability and brood development.

Further long-term monitoring is needed to validate these modeled projections and capture local microclimatic variations, as bees are sensitive to fine-scale habitat conditions. Integrated field studies that track colony performance, floral resource phenology, and climatic variables will be crucial for predicting how *Apis florea*, *Apis cerana*, and *Apis dorsata* adapt—or fail to adapt—to warming trends and changing precipitation regimes. Moreover, modeling studies that incorporate additional factors (e.g., land-use changes, pesticide exposure, or disease prevalence) would provide a more holistic view of future habitat suitability for these vital pollinators. The climate changes projected will see all three Pakistani *Apis* species face increased temperature and moderately increased precipitation. While such a climate may enhance certain aspects of bee life cycles (e.g., more foraging in more favorable seasons), enhanced heat stress and potential phenological mismatches may challenge colony viability. Anticipatory habitat management, adaptive beekeeping, and research will therefore be essential to safeguard these species from imminent climate change challenges.

Conclusion

The present study assessed the impact of climate change on the future distribution patterns of *Apis florea, Apis cerana,* and *Apis dorsata* in Pakistan. The results revealed that a constant tendency of warming and annual mean temperature is expected to rise to 2.3-2.5°C by the year 2050. The variations in seasonal patterns, such as mild winters and high humidity, could disrupt honey bee activity, colony dynamics, and their survival. The variations in climatic conditions required making resilient habitats for honey bees. This can be achieved by planting resilient plants and maintaining critical habitats that provide better shelter from extreme heat. It can be concluded that species distribution models should also consider variables such as land use, pesticide use and disease prevalence to have a more comprehensive understanding of how honey bee species may respond to climate change in the future.

References

Akram, W., Sajjad, A., Ali, M., Khurram, H., & Rafique, M. K. (2024). Communities of Arid Bees as Affected by Weather Factors and Foraging Resources in Southern Punjab, Pakistan. Pakistan Journal of Zoology, https://dx.doi.org/10.17582/journal.pjz/20240218031246

Cook, D., Tarlinton, B., McGree, J. M., Blackler, A., & Hauxwell, C. (2022). Temperature sensing and honey bee colony strength. Journal of Economic Entomology, 115(3), 715-723.

Diaz Calafat, J. (2024). Boreal pollinators in a changing climate. Acta Universitatis Agriculturae Sueciae. https://doi.org/10.54612/a.18rsgbp5pk

Fleming, J. M., Carter, A. W., & Sheldon, K. S. (2021). Dung beetles show metabolic plasticity as pupae and smaller adult body size in response to increased temperature mean and variance. Journal of Insect Physiology, 131, 104215.

Gebremedhn, H., Gebrewahid, Y., Haile, G. G., Hadgu, G., Atsbha, T., Hailu, T. G., & Bezabih, G. (2024). Projecting the impact of climate change on honey bee plant habitat distribution in Northern Ethiopia. Scientific Reports, 14(1), 15866.

Ghassemi-Khademi, T., Khosravi, R., Sadeghi, S., & Ebrahimi, M. (2022). Historical, current, and future climate niche of the red dwarf honey bee across its native range. Journal of Apicultural Research, 61(2), 271-283.

Giannoni-Guzmán, M. A., Rivera-Rodriguez, E. J., Aleman-Rios, J., Melendez Moreno, A. M., Pérez Ramos, M., Pérez-Claudio, E., & Agosto-Rivera, J. L. (2021). The role of colony temperature in the entrainment of circadian rhythms of honey bee foragers. Annals of the Entomological Society of America, 114(5), 596-605.

Harmon-Threatt, A. (2020). Influence of nesting characteristics on health of wild bee communities. Annual Review of Entomology, 65(1), 39-56.

Harrison, P. A. (2021). Climate change and the suitability of local and non-local species for ecosystem restoration. Ecological Management & Restoration, 22, 75-91.

Harvey, J. A., Tougeron, K., Gols, R., Heinen, R., Abarca, M., Abram, P. K., & Chown, S. L. (2023). Scientists' warning on climate change and insects. Ecological monographs, 93(1), e1553.

Ji, Y. (2021). The geographical origin, refugia, and diversification of honey bees (*Apis* spp.) based on biogeography and niche modeling. Apidologie, 52(2), 367-377.

Kevan, P. G., Rasmont, P., & Martinet, B. (2024). Thermodynamics, thermal performance and climate change: temperature regimes for bumblebee (*Bombus spp*.) colonies as examples of superorganisms. Frontiers in Bee Science, 2, 1351616.

Khan, W., Khan, N., & Naz, S. (2017). Beekeeping in federally administered tribal areas of Pakistan: Opportunities and constraints. Sarhad Journal of Agriculture, 33(3), 459-465.

Kumar, A., Rajwar, N., & Tonk, T. (2024). Climate Change Effects on Plant-Pollinator Interactions, Reproductive Biology and Ecosystem Services. In Forests and Climate Change: Biological Perspectives on Impact, Adaptation, and Mitigation Strategies (pp. 97-117). Singapore: Springer Nature Singapore.

Makori, D. M., Fombong, A. T., Abdel-Rahman, E. M., Nkoba, K., Ongus, J., Irungu, J., & Landmann, T. (2017). Predicting spatial distribution of key honeybee pests in Kenya using remotely sensed and bioclimatic variables: Key honeybee pests distribution models. ISPRS International Journal of Geo-Information, 6(3), 66. https://doi.org/10.3390/ijgi6030066

Mishra, M., Bhunia, P., Sen, R., Bhunia, R., Gulia, J., Mondal, T., & Kaushal, L. (2023). The Impact of Weather Change on Honey Bee Populations and Disease. Journal of Advanced Zoology, 44. 180. https://doi.org/10.17762/jaz.v44is7.2755

Mitchell, D. M. (2022). Honey bee (*Apis mellifera*) size determines colony heat transfer when brood covering or distributed. International Journal of Biometeorology, 66(8), 1653-1663.

Orr, M. C., Hughes, A. C., Chesters, D., Pickering, J., Zhu, C. D., & Ascher, J. S. (2021). Global patterns and drivers of bee distribution. Current Biology, 31(3), 451-458.

Ostroverkhova, N. V., Konusova, O. L., Kucher, A. N., Kireeva, T. N., & Rosseykina, S. A. (2020). Prevalence of the *Microsporidian nosema* spp. in honey bee populations (*Apis mellifera*) in some ecological regions of North Asia. Veterinary Sciences, 7(3), 111.

Saeed, S. (2022). Bee Diversity of Pakistan. In Biodiversity, Conservation and Sustainability in Asia: Volume 2: Prospects and Challenges in South and Middle Asia (pp. 487-519). Cham: Springer International Publishing.

Villagomez, G. N., Nürnberger, F., Requier, F., Schiele, S., & Steffan-Dewenter, I. (2021). Effects of temperature and photoperiod on the seasonal timing of Western honey bee colonies and an early spring flowering plant. Ecology and Evolution, 11(12), 7834-7849.