Niche modelling of Azadirachta indica under current and future climate scenarios of Punjab, Pakistan

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Abstract

In recognition of *Azadirachta indica* great economic and therapeutic value, the natural population of This plant species should be propagated extensively to meet its increasing demand for medicinal and other applications. The most effective strategy for the preservation and restoration of this valuable plant species is the identification and selection of ecologically suitable habitats under changing climatic conditions. The present research suggests possible *Azadirachta indica*-friendly locations in Pakistan. The maximum entropy model, MaxEnt programme is employed in this study to pinpoint the places that are particularly suitable for neem. The model's accurateness was indicated by its Area Under Curve of 0.942. The geographical spread of *Azadirachta indica* was considerably influenced by the seasonality of precipitation, precipitation in the wettest month, and maximum temperature in the warmest month. Considering RCP (4.5 plus 8.5) for the years 2050 using 19 bioclimatic factors and 173 occurrence locations, future acceptable habitats for A. indica were determined. *A. indica* now has a very appropriate area of around 290,144 km2 (33%) and an unsuitable area of about 585,892 km2 (67%). The region that is appropriate for *A. indica* in the RCP 4.5 and RCP 8.5 climate change regime is 301,748 km2 and 291,226 km2, respectively. The extreme suitability increases about 3% in future climate change scenarios. A. indica's present habitats that are suitable are the areas of Salt Range, the central region of Punjab (Faisalabad, Nankana sahib, Lahore, Bahawalpur and Okara), Thal, Hyderabad, Sukkar, Mirpur areas of Sindh. The exceptionally favorable area for *A. indica* was predicted to increase under possible future climate scenario. The study would be important for the advancement of *A. indica* management and conservation strategies in future.

1. Introduction

The inhabited space and biological elements of the region required for an inhabitant, such as abiotic characteristics and other species, make up a species' habitats. The size and qualities of regional plant habitats have had a considerable influence on their dispersion and ecological pattern(Arshad et al., 2022). SDM is founded on the concept of environmental niches(Mendoza et al., 2020). Understanding niches is essential for comprehending trends and dispersion of biological variety, identifying important habitat to lessen the consequences of climate change, and reconstructing clade evolutionary paths. By identifying links between areas where a species is believed to be commonly found and the environmental conditions at those locations, niche discovers environmental factors that are favorable to a species and according to the feasibility of the ecological conditions specifies role and functions of the species(Smith et al., 2019). SDMs identify niches in the environment of species and are capable of being used to infer patterns in the distribution of appropriate habitat for target species. SDMs have been utilized for estimating a wide range of population metrics, from occurrences to genetic variation, as it is anticipated that habitat appropriateness will have an impact on the demography of population(A. Lee-Yaw et al., 2022). The diversity and adaptability of Earth's populations will be profoundly impacted by the changing climate worldwide(Rana et al., 2021). Droughts are occurring more frequently due to global warming along with more erratic rainfall patterns, which may cause significant changes in the distribution of species(Oliveira et al., 2019). A plant's life cycle traits, such as its blooming and fruit ripening and growing conditions and habitat requirements, are impacted by climate change(Arshad et al., 2022). The susceptibility of species to changing climate is also influenced by internal characteristics, such as species features and life histories. Because of their restricted capacity to detect new favorable circumstances, indigenous species, for instance, are frequently more susceptible to changes in the environment than other species, and as a result, they seem to be more prone to go extinct(Xxxii et al., 2020). Human access to ecological services will also directly impacted by shifts in biodiversity brought on by climate change(Anadón et al., 2014).

A basic concept in ecological conservation is the interaction among the species or community of species and its ecosystem(Kaky et al., 2020). If feasible, species should have been kept in their own natural habitats, which is a fundamental tenet of conservation(Casazza et al., 2021). SDMs and in-situ field validation experiments are used in a qualitative framework that identifies optimal receptor sites(Draper et al., 2019). The most popular kind of models utilized in ecology, development, evolutionary studies, migration and conservation are species distribution models (SDMs)(Zurell et al., 2020). SDM helps in assessing the risk to biodiversity while learning about the effects of climate change on the biota(El-Barougy et al., 2021). Policymakers involved in conservational activities can use modelling for making important decisions using strong tools(Ali et al., 2014). Distribution modeling used to indicate populations at risk of potential future shifting because of climate change estimations(Conroy et al., 2019). In the recent years, the implementation of SDMs has been significantly aided by the development of ready-to-use software applications and the expansion of the accessibility of digital geographic information systems(Zurell et al., 2020). Developing less complex techniques is necessary to create precise range maps, particularly for large number of species(Palacio et al., 2021).With in fields of ecology and sustainability, methods like the rise of machine learning cognitive computing, theories related to ecosystem, and additionally GIS are widely employed. Species Distribution Models (SDMs) are applied to examine abiotic factors and species occurrence data records in natural habitat interactions(Arshad et al., 2022). The models of biodiversity have seen several changes during the past 20 years, which means that there are currently numerous methodologies available. Regression techniques that are common among most environmentalists. One such approach is MaxEnt. Using the highest scoring techniques, MaxEnt's prediction accuracy is continuously competitive. formally accessible around 2004, the method has been widely utilized to model distribution patterns of species(Elith et al., 2011). Maxent seeks to predict the appropriateness of a specific species' environment(Moua et al., 2020). Due to its ability to be trained using presence-only information and its ability to classify land cover categories similarly to a specific species or habitat, MaxEnt is an alternative to popular "soft" classifiers(Amici et al., 2017). MaxEnt is a comprehensive entropy-based correlating approach that uses to anticipate the distribution of species(Bowler, 2014). This maximum entropy dispersion is used by MaxEnt to generate random background baseline points and to assess the likelihood of a species' existence and predicts where that species would probably be found. Its effectiveness as tools to evaluate habitat constraint in current history has been attributed to their utility for analyzing vegetation distribution with habitat compatibility models(Waheed et al., 2023). The AUC is a statistic commonly used to assess the performance of maxent models. It measures the model's capacity for comparing presences across random points within the region that the model is calibrated over(Radomski et al., 2022).

Azadirachta indica also known as neem is rapidly growing perennial trees which have been utilized for over than four thousand years to cure a variety of illnesses. This plant is native to South and east regions of Asia and West regions of Africa and also thrives on islands off the coast of Iran(Trivedi et al., 2019). Neem tree can acclimatize to a wide range of geographical and climatic circumstances. It does well on soil that is dry, stony, flat, and even contains limestone and clay. Neem tree normally thrives in regions with 450 – 1,200 mm of annual precipitation. But now it's been also applied with success even in those regions with precipitation as declined to 150 to 250 mm. It can thrive in broad temperature range, from 0 to 50 °C. It is incapable of withstanding soggy soils and swampy locations(Mridha & Al-Suhaibani, 2014). Neem tree development requires a pH range between 4 and 10. *Azadirachta indica* have a special capacity to mine calcium, which allows them to mitigate acidic soils(Uzzaman, 2020). Listed below are the precise study goals:

. To recreate and classify the possible range of *Azadirachta indica* in light of both present-day and incoming climate change scenarios of future.

. To determine which climate variables are most important for distribution of *Azadirachta indica*

. determination of most suitable areas for *Azadirachta indica* on the basis of Maxent model

2. Materials and methods

2.1. Occurrence data of the specie (*Azadirachta indica*)

We obtained data on *Azadirachta indica*'s geographical distribution from the Global Biodiversity Information Facility GBIF.org (28 April 2023) GBIF Occurrence Download https://doi.org/10.15468/dl.4gz87e (Fig. 1). Additionally, between 2022 and 2023, we (Fig. 1) conducted a field investigation and tallied around 100 occurrence points from diverse places in the division Bahawalpur, Punjab province of Pakistan. We took most of the occurrence points of *Azadirachta indica* from the area of Islamia university of Bahawalpur Bagdad campus and some presences of A. indica from the IUB Old campus. Beside this we also took our occurrence data from the field survey of the whole Bahawalpur city including the Yazman road area and some areas of Lodhran and Multan Road. We also took some presences of *Azadirachta indica* from Lahore through field survey. These presences were collected from the Raiwind, Lahore. Some occurrence points of *Azadirachta indica* taken from Faisalabad through field investigation. These presences were taken from the areas of Jhang Road Faisalabad, Thikriwala and Sadhar bypass Faisalabad. *Azadirachta indica* was also reported from Fort Abbas city. Occurrence points were taken through the field survey of Fort Abbas city. A species distribution model (SDM), a prediction model, was created using 177 valid presence records (17 from GBIF and 114 from field survey of Bahawalpur, 9 from Faisalabad, 10 from Lahore and 26 from Fort Abbas).

2.2. Environmental data

The official WorldClim website (www.worldclim.org, accessed on 3 may 2023) was used to get environmental veriable data. A geographical resolution of 30 seconds per kilometer (1 km) was used to incorporate the 19 bioclimatic variables of Wordclim. The time frame covered 1970–2000, and the data set's version number was 2.1. All these 19 bioclimatic variables have raster data related to different categories of rainfall and temperature. These 19 bioclimatic variables having data of precipitation and temperature were selected as the main environmental variables that has a great influence upon the distribution of species resulted in the formation of the species distribution range. Because rainfall and temperature are the primary ecological traits that account for seasonality, yearly cycles, and species adaptability. The large-scale distribution of species may be explained using these environmental factors. Data sets containing the data of 19 bioclimatic variables taken from WorldClim were downloaded in "tiff" format. These 19 bioclimatic variables then processed in Arcgis10.8 software and converted into ASCII format(Lah et al., 2021). This was done by using Raster-conversion tool – raster to ASCII(*asc) file format for usage in MaxEnt because Maxent do not process raster files.

2.3. Future climatic data

We used future climatic data taken by worldclim website (www.worldclim.org, accessed on 5 may 2023) to forecast *Azadirachta indica*'s future niche modeling. Future climate projections that have been downscaled by CMIP5 are included in this data. With WorldClim version 2.1 as the reference climate, the process of downscaling and calibration were completed. For GCMs and four RCPS like RCP26, RCP45, RCP70, and RCP85, monthly data of minimal temperatures, maximum temperatures, and rainfall were processed. The information on worldclim was averages across 20-year time intervals. To evaluate the likely acceptable ecological distributions of *Azadirachta indica* and sufficient changes in the environment in future climate patterns, estimated bioclimatic features for the time periods of 2050 were gathered between the lowest to maximum representative concentration Pathway scenarios which are RCP4.5 and RCP8.5. Four common representative concentration pathways (RCPs) were included in the IPCC's5 assessment (IPCC 2014). RCP8.5 scenarios indicated the highest levels emission of greenhouse gases, whereas RCP4.5 projected a moderate level emission. RCP2.6 was a severe mitigation scenario because it limits global warming to around or below 2 degrees centigrade increase that was challenging to carry out, hence Representative concentration pathway4.5 (RCP4.5) was selected. General Circulation Models (GCMs) of bioclimatic variables with 30 second resolution were used to establish the future *Azadirachta indica* suitable ranges using the future climate change models of Representative concentration pathway RCP4.5 and RCP8.5. BCC-CSM1-1 (Beijing Climate Centre-Climate System Model version 1–1; www.worldclim.com) bc data was downloaded with 30 second resolution. This data was in raster format (raster.tiff*). These variables were converted into asci format by using Arcgis10.8 software and by utilizing “conversion tool”- “raster to asci” tool of Arcgis.

2.4. Modeling procedure in Maxent

The potential geographical range of *Azadirachat indica* was determined employing MaxEnt v. 3.4.4 software which is the latest one. We browse our occurrence data in sample file portion of Maxent and environmental variables in the environmental layer portion of Maxent. The settings that we used for our Maxent modeling are, create the response curves option, make the pictures of predictions and do jackknife to calculate each variable importance. We also choose Maxent's quadratic and linear features. We also choose a few more options from the Maxent settings menu, such as the random seed option under the basic settings and random test percentage of 30, the ability to write plot data, add samples to the back ground, extrapolate, do clamping, write plot data and appened summary results to maxent results.csv file under the advance tab, and the option to write background predictions show exponent in response curve and fade by clamping under the experimental tap. We use 10,000 background points to run our model. In MaxEnt model, a maximum of 500 iterations were used. We select logistic output format and output file type as asc(Elith et al., 2011). Other parameters of Maxent were set to default values(Tomlinson et al., 2020). *Azadirachta indica* occurrence data were used to develop the MaxEnt model. Based on occurrence data, MaxEnt calculated the likelihood of a species' existence and used the maximum entropy distribution to generate random background points. For future projection we navigate our future data directory to projection tab of maxent software and current data on layer tab with presence data and run the model with the same settings.

3. Results

3.1. Model Validation

Validation guarantees that modeling outcomes are accurate. The Maxent model functioned properly in the given examination, as evidenced by the AUC value (training AUC = 0.942 and test AUC 0.947) during the current examination. Under the current climatic conditions, the distribution of *Azadirachta indica* was greatly influenced by Bio 15 (precipitation seasonality), Bio 13 (precipitation of wettest month), Bio 3 (isothermality), Bio 5 (max temperature of warmest month), Bio 10 (mean temp of warmest quarter), and Bio 17 (precipitation of driest quarter). Additionally, these variables contributed to a larger extent than the remaining other variables.

The MaxEnt modeling can create the Receiver Operating Characteristics (ROC) curve and calculate the AUC score of the model by using its own algorithms, that can subsequently be used as prediction criterion for the model. The AUC-ROC scores given for testing dataset reflect predicted accuracy of the model (Fig. 2) This analysis is conducted using various presence probabilities thresholds among 0 and 1(Fig. 3).

3.2. Important Environmental Variables

Response curves demonstrate the effect of each environmental variable of the interest upon the *Azadirachta indica* suitable habitat. Responsive curves increase our awareness of the environmental domain of a particular specie by demonstrating the statistical connection among environmental factors and their habitat appropriateness. The comparative significance of each explicating factor employed within the maxent modeling was assessed using the jackknife testing technique of maxent. Jackknife testing was employed to assess the importance of explaining factors in predictions. The findings demonstrated that all 19 main variables for regularized training gain, test gain, and AUC for A. indica were evaluated in similar way.

In the jackknife test of single variable contribution rate (Fig. 4), the AUC score of three environmental variables (bio05, bio15, bio8) were all greater than 0.85, indicating that they were the main factors affecting the possible distribution area of *Azadirachta indica*. The environmental variable with highest gain when used in isolation is bio8 (mean temperature of wettest quarter), which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is bio13 (precipitation of wettest month), which therefore appears to have the most information that isn't present in the other variables. Present contribution analysis and jackknife test of Maxent model demonstrate that variables like precipitation seasonality (bio15) and precipitation of wettest month (bio13) contributed about 27.1% and 14.5% correspondingly and these both variables are the main determinants of the distribution of the *Azadirachta indica*. Max temperature of warmest month (bio5), mean temp of warmest quarter (bio10) precipitation of driest quarter (bio17), precipitation of wettest quarter (bio16) and isothermality (bio3) were additional significant environmental factors and their percent contributions were 13.1, 11.8, 7.9, 4.9 and 5.9% respectively.

3.3. Current and Future Habitat Suitability of *Azadirachta indica*

The deserted and somewhat arid parts of Pakistan represent the best places for Azadirachta under the current ecological circumstances that was applied to the model in the form of variables. Southern areas of Sindh, some areas of Punjab province, salt range areas, eastern regions of Balochistan, the KPK areas of Western Zone, Thal and Thar regions, and Rohi Deserts, along with some areas of western zone of Balochistan were among the appropriate places for the habitat of *Azadirachta indica*. Under the light of maxent generated model and its evaluation in Arcgis10.8 software the highly suitable areas for Azadirachta indca are Loralai, Sibi, Gujranwala, Sargodha, Mianwali, Laki Marwat, Dara Ismail khan, Bakhar, Lahore, Jhang, Faisalabad, Kasur, Okara, Toba Tek Singh, Gujrat, Sahiwal, Pakpattan, Khanewal, Vehari, Layyah, Musakhel, Dara Ghazi khan, Muzaffargarh, Bahawalnagar, Bahawalpur etc.

Under the RCP4.5 circumstances of 2050 (Table 1), the Punjab and Sindh areas of Pakistan and north eastern border of Balochistan are the most favourable habitats for the neem tree. This indicates that the climate in these regions is most suited for the development and spread of neem plants. Northern regions of Pakistan like Jammu and Kashmir, Quetta and many other areas of Balochistan, Peshawar, Islamabad, Muree and cold areas of Khyber Pakhtunkhwa have very cold winters and average low temperature of these areas is less than 10°C due to which these areas are unsuitable for *Azadirachta indica*. The spread of neem trees in Pakistan is significantly impacted by the RCP8.5 scenarios (Table 1). The environment might suffer from changes in temperature, patterns of precipitation, and other climatic aspects as a result of this high emission scenario. These modifications may significantly affect the dispersal of plant neem. Neem trees highly suitable area appears to be spread to the lower Punjab and Sindh regions exclusively (Fig. 5).

Table 1
Azadirachta indica suitability area in square kilometers under current and future climate.

Suitability	Current Area	%	RCP 4.5 2050 Area	%	RCP 8.5 2050 Area	%
Unsuitable	585892.6	66.88	573475.7	65.53	584033.3	66.73
Low	146684	16.75	171917.8	19.65	115859.6	13.24
Medium	106415	12.15	92197.09	10.54	120517.6	13.76
High	37045.45	4.23	37634.63	4.29	54850.71	6.27

4. Discussion

The correlation model, MaxEnt, explains the present only species distribution data using multiple regression analysis and predictive modeling approaches(Higgins et al., 2020). The MaxEnt software has been selected due to its benefits like good computational foundation, model's ability to function effectively good even when relatively small sample sizes use, model explanation straightforwardness and model's ability for predicting outcomes with high accuracy and influence(Lah et al., 2021). One of the finest features of Maxent software is that it predicts a suitable range of habitat appropriateness even with gaps and missing data(Yi et al., 2016). Gap analysis is another potential procedure that maxent successfully help. Maxent software helps to predict Higher protection performances as a result of the presence point-based conservation gap evaluation(Bosso et al., 2013). One of the main limiting factors of Maxent is the distributional information quality that influence the habitat predicting ability of model(Tessarolo et al., 2021). The "density" or "evenness" of the algorithm's spatial representation is significantly influenced by one's selection of feature categories and regularization multipliers. The reduction of crossover among the predictive dataset is necessary for identifying the ecological elements that affect range development(Lissovsky & Dudov, 2021). A number of parameters in Maxent influence the model's validity by dictating the kind and degree of dependence upon the environment that Maxent attempts to fit(Phillips & Dudík, 2008). In spite of these drawbacks and presumptions, ecologists rely heavily on SDM to forecast precise maps of species distribution and estimate risk(Mamun et al., 2018) and Maxent approach may prevent clusters phenomena and produce superior results that are more accurate to the real world(Zhang et al., 2020).

The Nineteen bio-climatic factors that taken from the WorldClim database have been utilised in current investigations to estimate the suitability of habitat for *Azadirachta indica*, particularly using statistical MaxEnt approach(Waheed et al., 2023). Using the whole set of presences as well as the regularisation and selection of feature settings that maximise efficiency, we create model in Maxent(Velasquez-Tibata et al., 2019). Based on the projections of *Azadirachta indica*'s distribution models, it is evident that global warming and changing climatic conditions will significantly impact the plant's range(Arshad et al., 2022). It has been shown that environmental change has a significant role in local extirpation, settlement, and shifts in the distribution of plant species(Casazza et al., 2021). models with an AUC > 0.75 are seen to be trustworthy. In our situation, values with an AUC > 0.942 show a particularly powerful ability for prediction; in fact, they are between the best achieved in documented models(Bosso et al., 2013). Selection of cross-selection to evaluate critically the extent to which the models forecast the key data points(Norberg et al., 2019).We conducted a jackknife test to determine the variables that exerted the greatest influence on the model(Waheed et al., 2023). The MaxEnt represents the percentage contributions made by ecological predictors(Lázaro-Lobo et al., 2021). In the present investigation, the relationship between key ecological factors and the likelihood of encountering A. indica was investigated, and associated response curves were created(Waheed et al., 2023). The aggregate of two precipitation-related environmental factors was 27.1% and 14.5%, and the total impact of two temperature-related variables is approximately 41% under current climatic conditions, indicating that for possible geographic range of *A.indica* water requirement was normal but the distribution of *Azadirachta indica* was highly influenced by the precipitation and temperature, which is intrinsically connected to *Azadirachta indica*'s distinctive morphological characteristics. From the Maxent generated model about 290144 km^2 area of Pakistan and almost 33% considered to be suitable for *Azadirachta indica*. Neem trees are known for their ability to tolerate drought conditions. They have the unique ability to survive with minimal water usage, making them highly adaptable to arid environments(Banerjee et al., 2013). This tree can thrive on a number of soil types, including clay-like, sand-based acidic, and soil that is alkaline, but it is unable to develop on land that is waterlogged. *A.indica* can grow on grounds containing stony limestone or mud flats of shallow levels, it may grow because its roots are able to access water beneath the soil(Mridha & Al-Suhaibani, 2014).

To maximize the effectiveness of biodiversity protection, it is crucial to spot changes in acceptable dispersion zones under future changing climate scenarios and to start directed management efforts as soon as possible(Arshad et al., 2022). Numerous additional studies found that all of the investigated future global warming estimates indicated a significant impact in habitat suitability for different species(Waheed et al., 2023). Climate change effects biodiversity by raising atmospheric CO2 levels(Bocksberger et al., 2016). Pakistan's tendency towards a warmer atmosphere might deteriorate in the future as a result of the exponential development in worldwide emissions of greenhouse gases(Arshad et al., 2022). The central and south Punjab and Sindh regions of Pakistan and northern border of Balochistan are the neem tree's suitable habitats under the RCP4.5 conditions of 2050. The total suitable area predicted to be suitable under 2050 RCP 4.5 scenario is 301748 sq kilometers. In the scenario depicted by RCP8.5, climate change and greenhouse gas emissions cause global raise in temperature and neem has good ability to deal with high temperatures due to which neem plants increases its suitability areas it in Pakistan. Neem trees expansion to the lower Punjab and Sindh regions, emphasises how crucial it is to comprehend the possible effects of various climatic scenarios on plant species.

5. Conclusion

In this research, we effectively modelled *Azadirachta indica*'s habitat appropriateness in the prevailing climate. Using MaxEnt model and processing the maxent created files in arcgis software, we successfully predicted a wide variety of areas suited for *Azadirachta indica* growth under current and future climatic conditions which was indicated by red, pink and yellow colours as high, medium, low suitable areas and unsuitable represented by white colour. The findings show that Pakistan's Subtropical and Tropical regions make up a major portion of the appropriate range for *Azadirachta indica*. The distribution of *Azadirachta indica* was shown to be significantly influenced by the variables of mean precipitation of wettest month, precipitation seasonality, mean temperature of wettest quarter, precipitation of driest quarter, and mean temperature of warmest quarter. Our findings demonstrate that under future climatic scenarios the raise in greenhouse gases omission that cause a warming climate will affects the distribution of neem and increases suitability area of Azadirachta, the rise in temperature is possible reason for its increasing suitability. The findings of our research can be applied to future vegetation cultivation foundation, replantation as well as management programmes for this economically significant specie in the Pakistan.

Declarations

Author's contribution: Iqra Aslam; write orignal draft, Muhammad Jamil; supervised,data analysis,Tabinda Maqbool:Data investigation,Sana Rasheed; Data curation,Yasmeen Saleem; editing,conceptualization.

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Figures

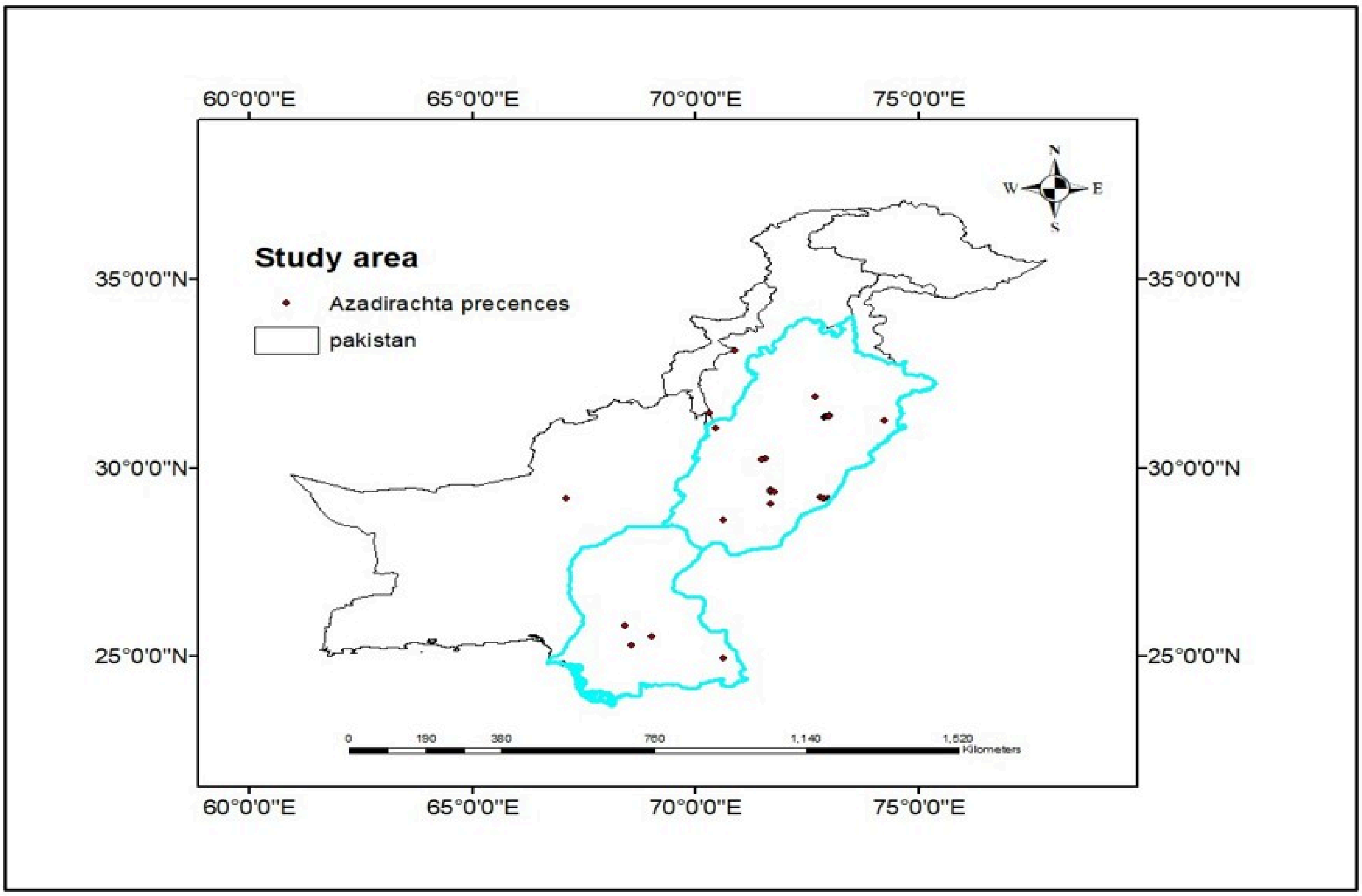

Figure 1

Geographical distribution of presence record of *Azadirachta indica*

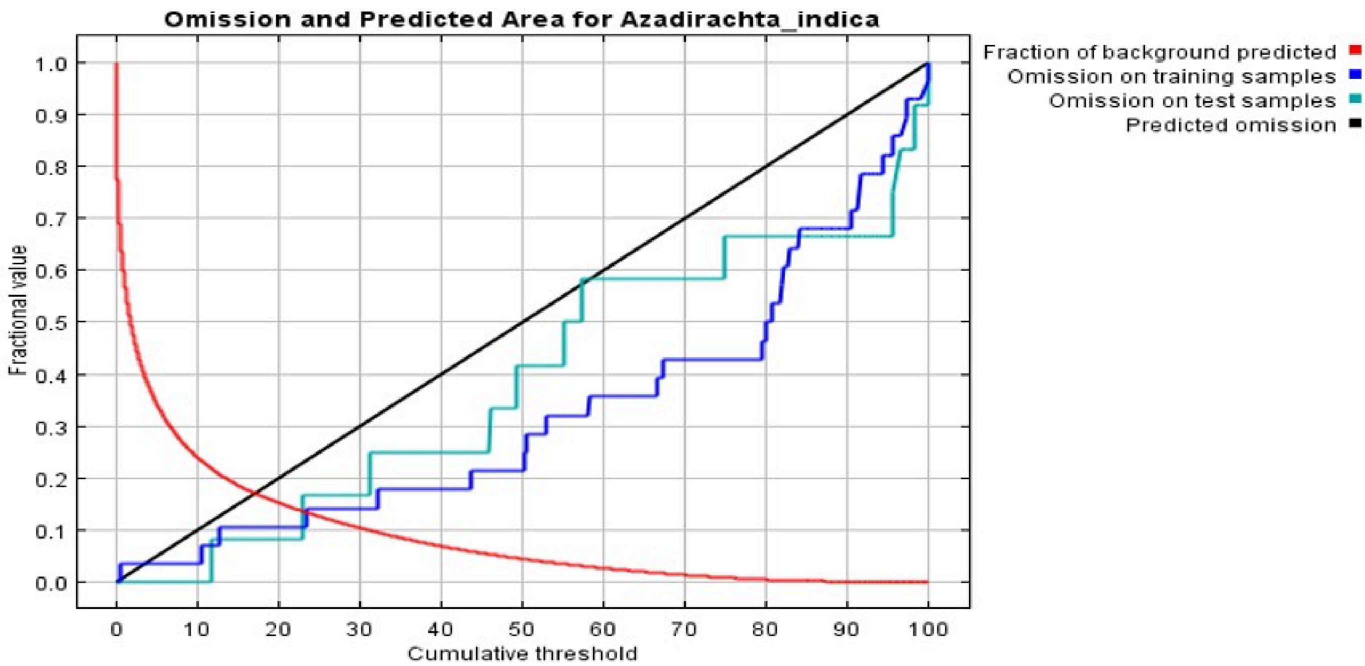

Figure 2

The following picture shows the omission rate and predicted area as a function of the cumulative threshold.

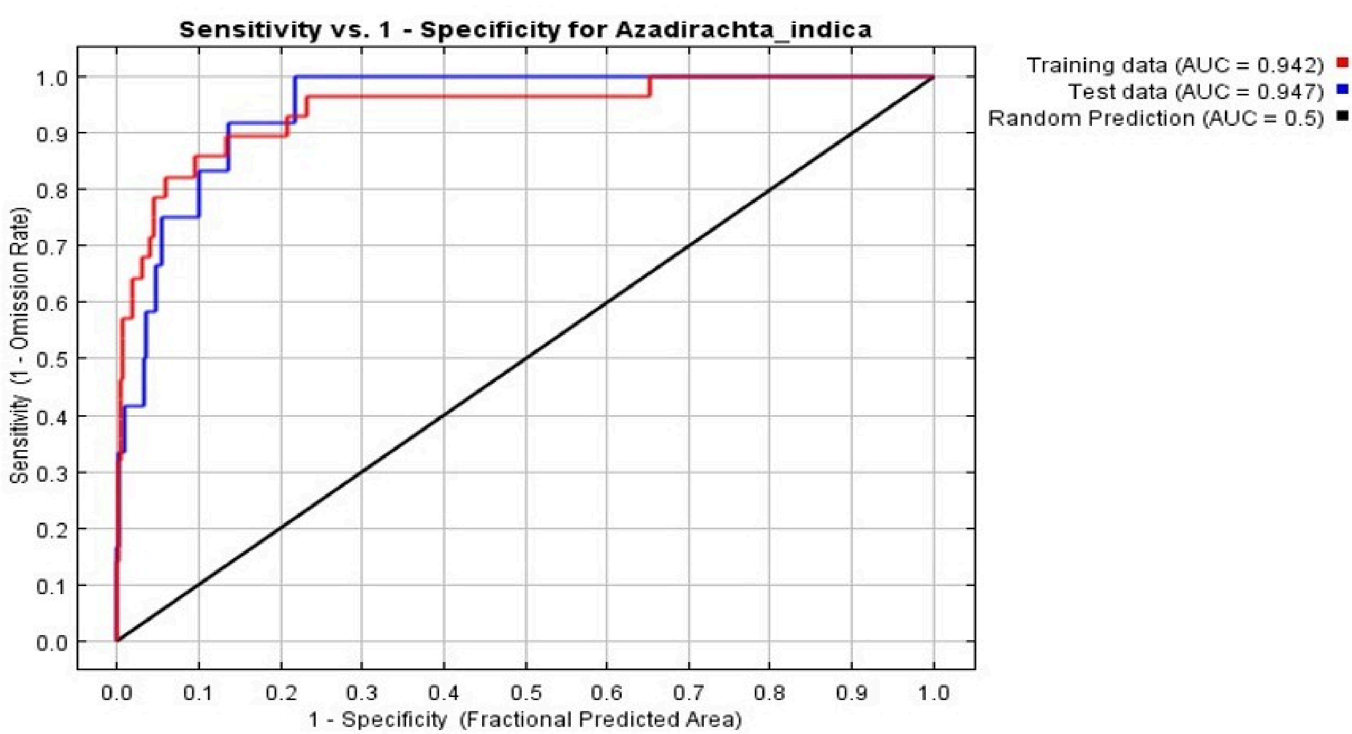

Figure 3

The receiver operating characteristic (ROC) curve for the same data.

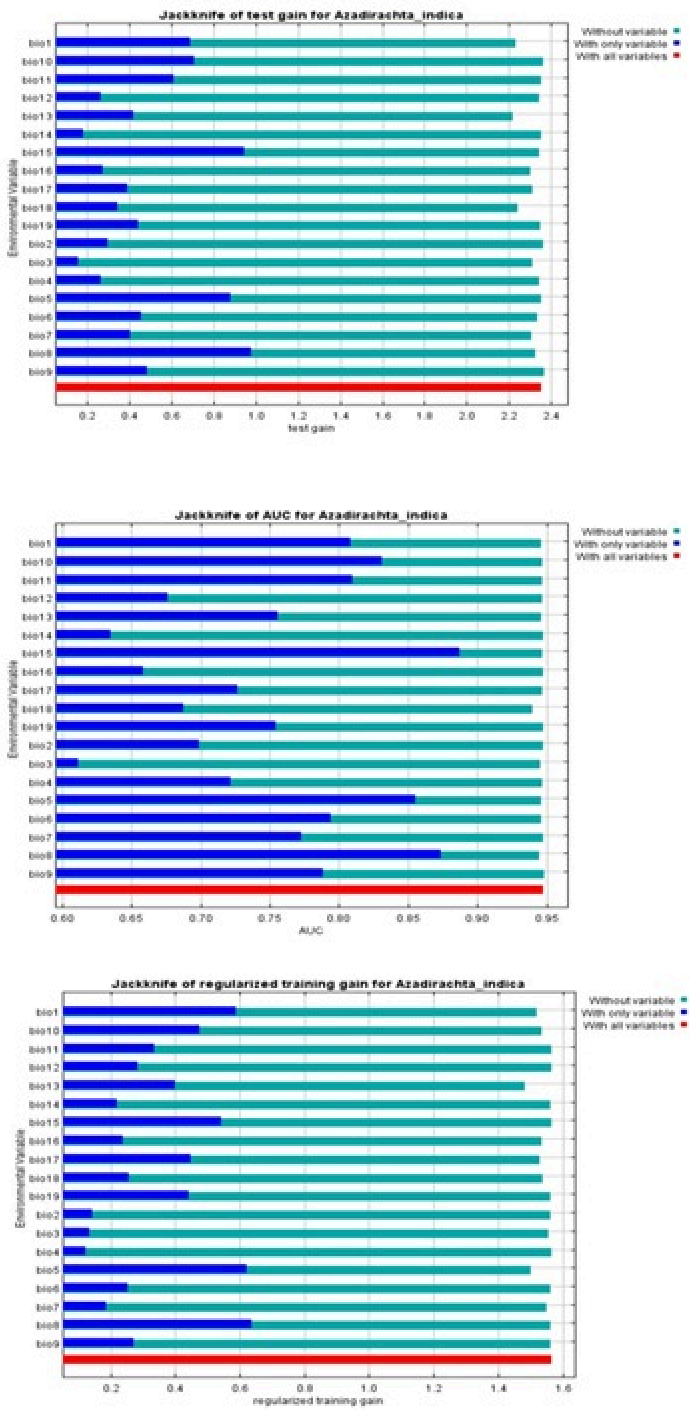

Figure 4

Shows the results of the jackknife test of variable importance for AUC, Test gain and regularized training gain.

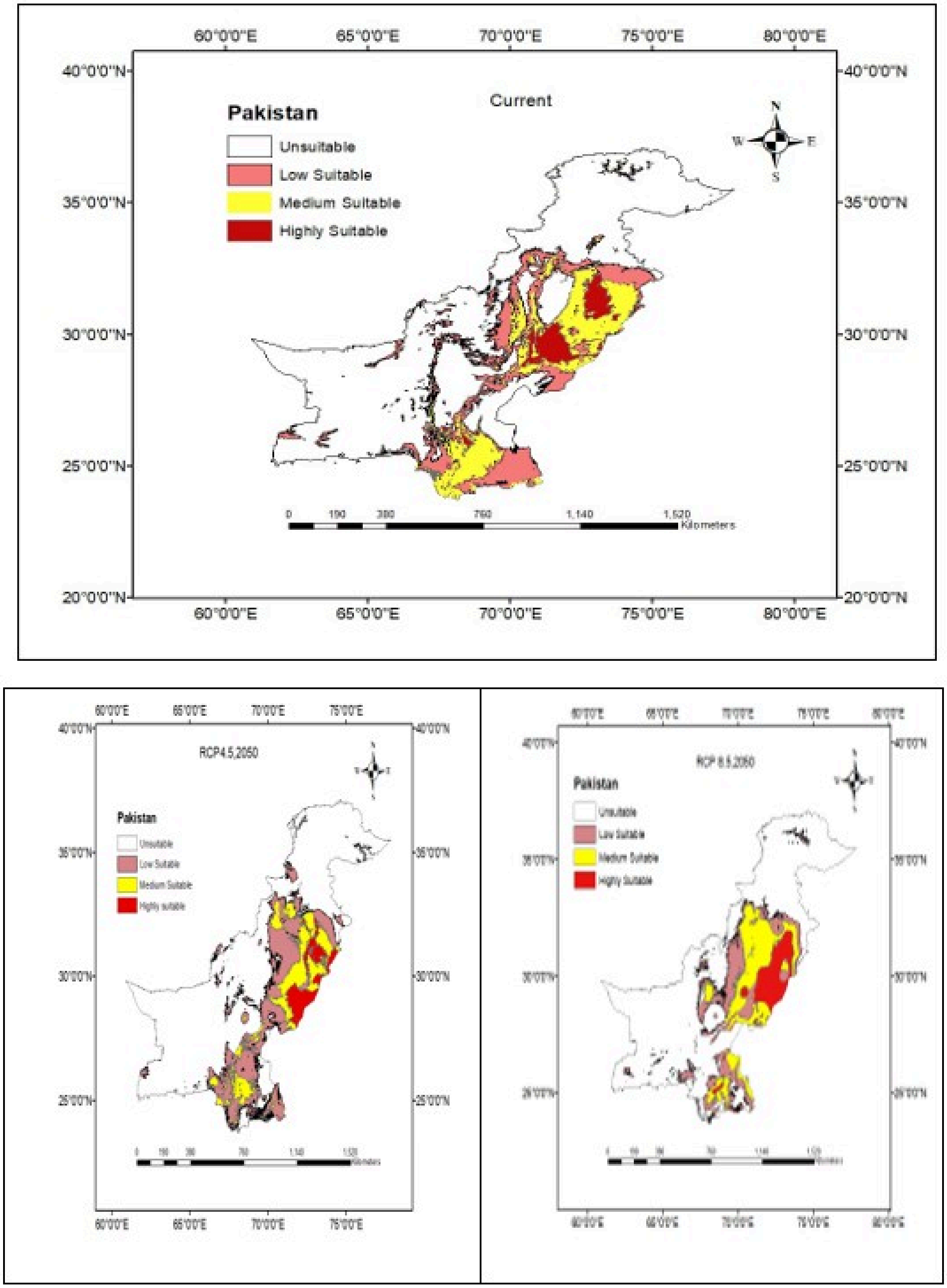

Figure 5

Habitat appropriateness of *Azadirachta indica* in current climatic conditions and future climate scenarios RCP 4.5 and RCP 8.5 ,2050