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Original Article

Modeling the Effect of Climate Change on the Distribution of Main Malaria Vectors in an Endemic Area, Southeastern Iran

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Abstract

Background: Although malaria is endemic in some areas of southeastern Iran, following the successful national malaria elimination plan (NMEP), the local transmission area has been shrunk. This study was aimed to evaluate the effect of climate change on the distribution of main vectors.

Methods: All documents related to research investigations conducted in Kerman Province on malaria vectors published during 2000–2019 were retrieved from scientific databases. Spatial distributions of the main vectors were mapped and modeled using MaxEnt ecological model. The future environmental suitability for main vectors was determined under three climate changes scenarios in the 2030s.

Results: Five malaria vectors are present in Kerman Province. The best ecological niches for these vectors are located in the southern regions of the province under the current climatic condition as well as different climate change scenarios in the 2030s.

Conclusion: Climate change in 2030 will not have a significant impact on the distribution of malaria vectors in the region. Entomological monitoring is advised to update the spatial database of *Anopheles* vectors of malaria in this malaria receptive region.

Keywords: Climate change; Malaria; *Anopheles*, Ecological niche modeling

Introduction

In 2019, an estimated 229 million cases of malaria occurred worldwide, with an estimated 409000 deaths (1). The vision of WHO is to reduce the incidence of malaria and the rate of mortality due to malaria by 90% by 2030 (2). From 25 years ago, more than 35 countries were awarded malaria-free certification, including Sri Lanka, Kyrgyzstan, Paraguay, Uzbekistan, Algeria and Argentina (3). Given that malaria in Iran reported zero indigenous cases from 2018 until 2020, the country is eligible to receive the elimination certificate for malaria (1). In light of the WHO recommendations, countries should have a plan to prevent reintroduction before serious effort is taken to eliminate malaria (4). Areas with higher vulnerability and receptivity for malaria are prone to re-establishment of the disease (5). Considering this definition and previous studies, Iran has both factors, vulnerability and receptivity (6.7). Nevertheless, preventing the re-establishment of the disease is a key concern after the elimination of malaria in Iran (3, 8). In such situations infected visitors and/or migrants play an important role in the risk of resuming local transmission of malaria in areas where *Anopheles* mosquitoes are still present and, climatic/environmental conditions are suitable for both mosquito and parasite (9). Therefore, the National Malaria Elimination Program (NMEP) should identify the areas at risk for the disease transmission, and also consider vector control measures in the at-risk areas (3).

There are seven malaria vectors in Iran, five out of them reported from the southern malarious area of the country (10,11). Earlier studies reported *Anopheles stephensi*, *An. culicifacies* s.l., *An. dthali*, *An. fluviatilis* s.l. and *An. superpictus* s.l. from Kerman Province (10,12,13). Different organisms need special climatic and environmental conditions to survive. This is really the fundamental niche where the organism can occupy if there is no restriction or barrier (14). Progressions in technology can be useful to improve malaria surveillance actions. Geographic information system (GIS) is one of the useful tools to be used during the prevention of malaria re-establishment phase. Predictive models enable all malaria control stakeholders to identify high-risk areas, and to develop an appropriate plan to prevent the re-introduction of malaria (15). Ecological niche models predict ecological space for a given species. The maximum entropy method (MaxEnt) is one of the common models used for predicting the environmental suitability for *Anopheles* mosquitoes across the world (16-18). Independent variables used in this model are bioclimatic and environmental. Therefore, it is possible to use predicted variables under different climate change scenarios and to estimate the at-risk areas for malaria transmission in the future. The global temperature has increased significantly over the past 100 years, with a faster warming trend since the mid-1950s. Global warming will affect the transmission rates of malaria. On the other hand, due to the change in the distribution range of vectors, the disease will enter new regions or will re-emerge in the areas from which the disease was previously eliminated (19-23).

Considering the current climatic conditions and with regard to the importance of climate change and its impact on suitable habitats for vectors, the aim of this study was to find the best ecological niches for malaria vectors in Kerman Province of Iran under the current climate and considering three scenarios of climate change in the 2030s.

Methods

Study area

Kerman Province is the largest province in Iran, located in the south-eastern part of the country with a population of 3,165,000, according to the 2016 national census (24). The climate in the province varies across regions. The north, northwest and central areas experience a dry and moderate climate, whereas in the south and southeast, the weather is warm and relatively humid. There are 23 counties in this province. A major part of the province is largely a steppe or a sandy desert, although there are some oases where dates, oranges and pistachios are cultivated. The southern parts of this province have potential for malaria transmission.

Modeling

In the first stage of this study, all documents related to research investigations conducted in Kerman Province on malaria vectors published during 2000–2019, were retrieved from various sources (Google scholar, PubMed, Scopus, Web of Knowledge, Magiran, IranMedex, Libraries of Iranian Medical Sciences Universities, Iranian Natural Resources Organization, Health Departments of all medical universities of Kerman Province) and reviewed. The obtained data were entered ArcMap10.5 software, and the spatial distribution of the various vectors in Kerman Province was determined on the map. Using MaxEnt ecological model and spatial functions in ArcGIS software, environmental suitability for the vectors was predicted. From these predictions, the most hazardous sites with the potential for the malaria transmission were determined. The MaxEnt model estimates potential species distribution using only presence records of a given species and environmental layers (25). Occurrence data for each species (Fig. 1) was divided into training (80%) and testing (20%) subgroups in random by the model. The area under the receiver operating characteristic (ROC) curve (AUC) was used to evaluate the predictiveness/performance of the model (14). The higher AUC values were considered as better model predictions (25,26,27). The contributions of the environmental variables and bioclimatic variables were tested using Jackknife analysis.

Variable Description

Climatic and environmental variables were downloaded from the worldclim database (28), at a spatial resolution of about one square kilometre. Using the ArcGIS software and the Clip command, the required data were clipped based on the Kerman Province boundary and were converted into an ASCII format for use in the MaxEnt model. A Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory adopted by the Intergovernmental Panel on Climate Change (IPCC) in 2014. Three RCPs (RCP2.6, RCP4.5, and RCP8.5) were selected as representative of three probable climate scenarios (29) in the 2030s. These data were downloaded from the GCM Downscaled Data Portal (http://ccafs-climate.org/data_spatial_downscaling). The same process mentioned above for clipping, converting and finding the correlation of these data was conducted in ArcMap, for use in the MaxEnt model. Band collection statistics analysis in ArcMap was used to find bioclimatic variables with less than 0.8 correlations. Besides, five bioclimatic variables were included in the model as follows: BIO1: Annual mean temperature (°C); BIO6: Min temperature of coldest month (°C); BIO14: Precipitation of driest month (mm); BIO17: Precipitation of driest quarter (mm); BIO18: Precipitation of warmest quarter (mm). Altitude (Elevation above the sea level (m)) layer was also downloaded with the same spatial resolution from the worldclim website and Slope variable (%) was obtained from altitude using spatial analyst of ArcGIS.

Results

Ecological niche modeling

Results of the previous studies conducted in Kerman Province indicate five out of seven malaria vectors of Iran are reported in this area. Therefore, information related to *An. stephensi*, *An. culicifacies* s.l., *An. dthali*, *An. fluviatilis* s.l., and *An. superpictus* s.l. was taken into consideration.

Anopheles stephensi

Current climate

The AUC was 0.855 for training data. The model shows that the most suitable ecological niches for this species are located mostly in the southern regions of the province (Fig. 2). Therefore, these regions can be considered as potentially suitable environments for the breeding of this malaria vector. The results of the Jackknife test show that the environmental variable with highest gain when used in isolation was the minimum temperature of the coldest month (bio6).

2030s horizon

The AUC was 0.860, 0.854 and 0.858 for training data using RCP2.6, RCP4.5 and RCP8.5 climate change scenarios, respectively. The model shows that the most suitable ecological niches for this species are located in the southern half of the province (Fig. 2). There will be no significant difference in the ecological niche of *An. stephensi* in 2030 compared to the present time. However, the maximum environmental suitability will increase from 85% to 88%, 96% and 87% using RCP2.6, RCP 4.5 and RCP 8.5, respectively (Fig.

2). The results of the Jackknife test show that the environmental variable with highest gain when used in isolation was the minimum temperature of the coldest month (bio6) for all scenarios.

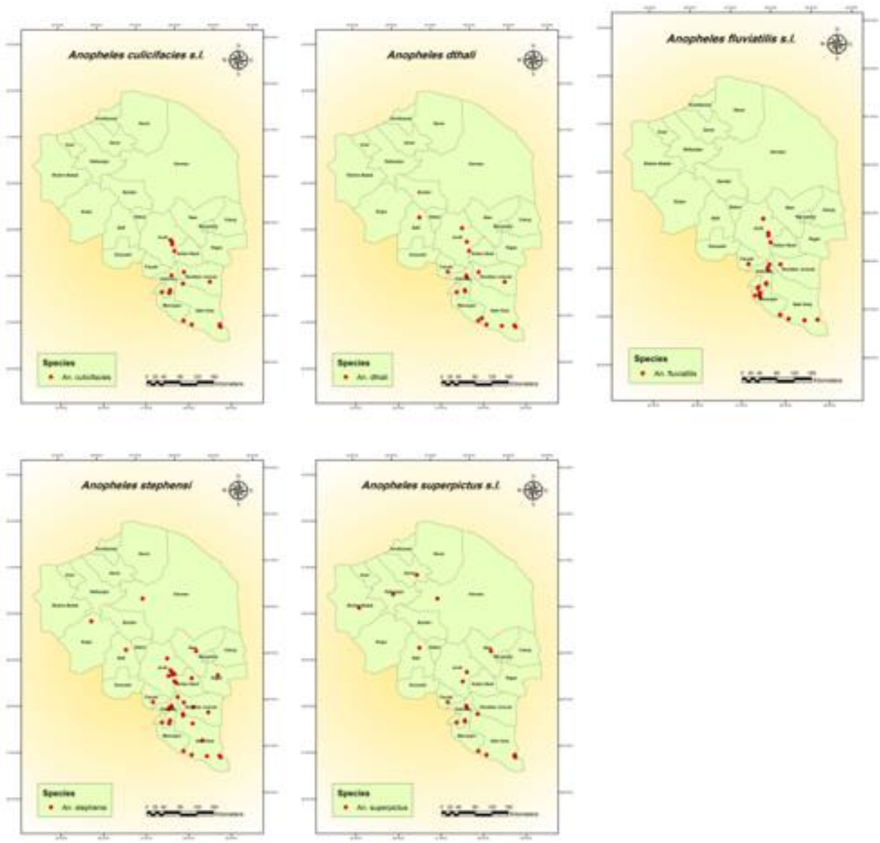

Fig. 1: Presence records for malaria vectors in Kerman Province of Iran, 1990-2019

Anopheles culicifacies **s.l.**
Current climate

The AUC was 0.916 for training data. The model shows that the most suitable ecological niches for this species are located mostly in the southern regions of the province (Fig. 2). Therefore, these regions can be considered as potentially suitable environments for the breeding of this malaria vector. The results of the Jackknife test show that the environmental variable with highest gain when used in isolation was the minimum temperature of the coldest month (bio6).

2030s horizon

The AUC was 0.921, 0.919 and 0.913 for training data, respectively using RCP2.6, RCP4.5 and RCP8.5 climate change scenarios. The most suitable ecological niches for this species are located in the southern and eastern regions of the province (Fig. 2). Comparing to the current situation, the ecological niches of this malaria vector in the future will be almost similar to the current situation. The results of the Jackknife test show that the environmental variable with highest gain when used in isolation was the minimum temperature of the coldest month (bio6) for all scenarios.

Anopheles fluviatilis **s.l.**
Current climate

The AUC was 0.925 for training data. The model shows that the most suitable ecological niches for this species are located mostly in the southern regions of the province (Fig. 2). Therefore, these regions can be considered as potentially suitable environments for the breeding of this malaria vector. The results of the Jackknife test show that the environmental variable with highest gain when used in isolation was the minimum temperature of the coldest month (bio6).

2030s horizon

The AUC was 0.926, 0.925 and 0.926 for training data, respectively, using RCP2.6, RCP4.5 and RCP8.5 climate change scenarios. The model shows that the most suitable ecological niches for this species are located in the southern and south-eastern regions of the province (Fig. 2). The ecological niches of this malaria vector in the future will be almost similar to the current situation, but the worst scenario, RCP8.5, is that the environmental suitability for this species will decrease in some parts of Roodbar Jonoub and Qaleganj counties. The results of the Jackknife test show that the environmental variable with highest gain when used in isolation was the minimum temperature of the coldest month (bio6) for all scenarios.

Anopheles dthali

Current climate

The AUC was 0.889 for training data. The model shows that the most suitable ecological niches for this species are located mostly in the southern regions of the province (Fig. 2). Therefore, these regions can be considered as potentially suitable environments for the breeding of this malaria vector. The results of the Jackknife test show that the environmental variable with highest gain when used in isolation was the minimum temperature of the coldest month (bio6).

2030s horizon

The AUC was 0.885, 0.889 and 0.859 for training data, respectively, using RCP2.6, RCP4.5 and RCP8.5 climate change scenarios. The model shows that the most suitable ecological niches for this species are located in the southern regions of the province. Moreover, comparing to other species, it seems that the environment of Kerman Province is more suitable for *An. dthali* (Fig. 2). The ecological niches of this malaria vector in the future will be almost similar to the current situation, although under RCP8.5 scenario the environmental condition will provide a better situation for breeding and living this malaria vector. The results of the Jackknife test show that the environmental variable with highest gain when used in isolation was the minimum temperature of the coldest month (bio6) for all scenarios.

Anopheles superpictus s.l.

Current climate

The AUC was 0.850 for training data. The model shows that the most suitable ecological niches for this species are located mostly in southern regions of the province, but there are some ecological niches for this species in some other parts of Kerman Province as well (Fig. 2). Therefore, these regions can be considered as potentially suitable environments for the breeding of this malaria vector. The results of the Jackknife test show that the environmental variable with highest gain when used in isolation was precipitation of the warmest quarter (bio18).

2030s horizon

The AUC was 0.846, 0.848 and 0.857 for training data, respectively, using RCP2.6, RCP4.5 and RCP8.5 climate change scenarios. The model shows that the most suitable ecological niches for this species are located in the southern half of the province (Fig. 2). The ecological niches of this malaria vector in the future will be almost similar to the current situation, although under RCP8.5 scenario the environmental condition will not be suitable for breeding and living this malaria vector in some parts of Roodbar Jonoub and Qaleganj counties.

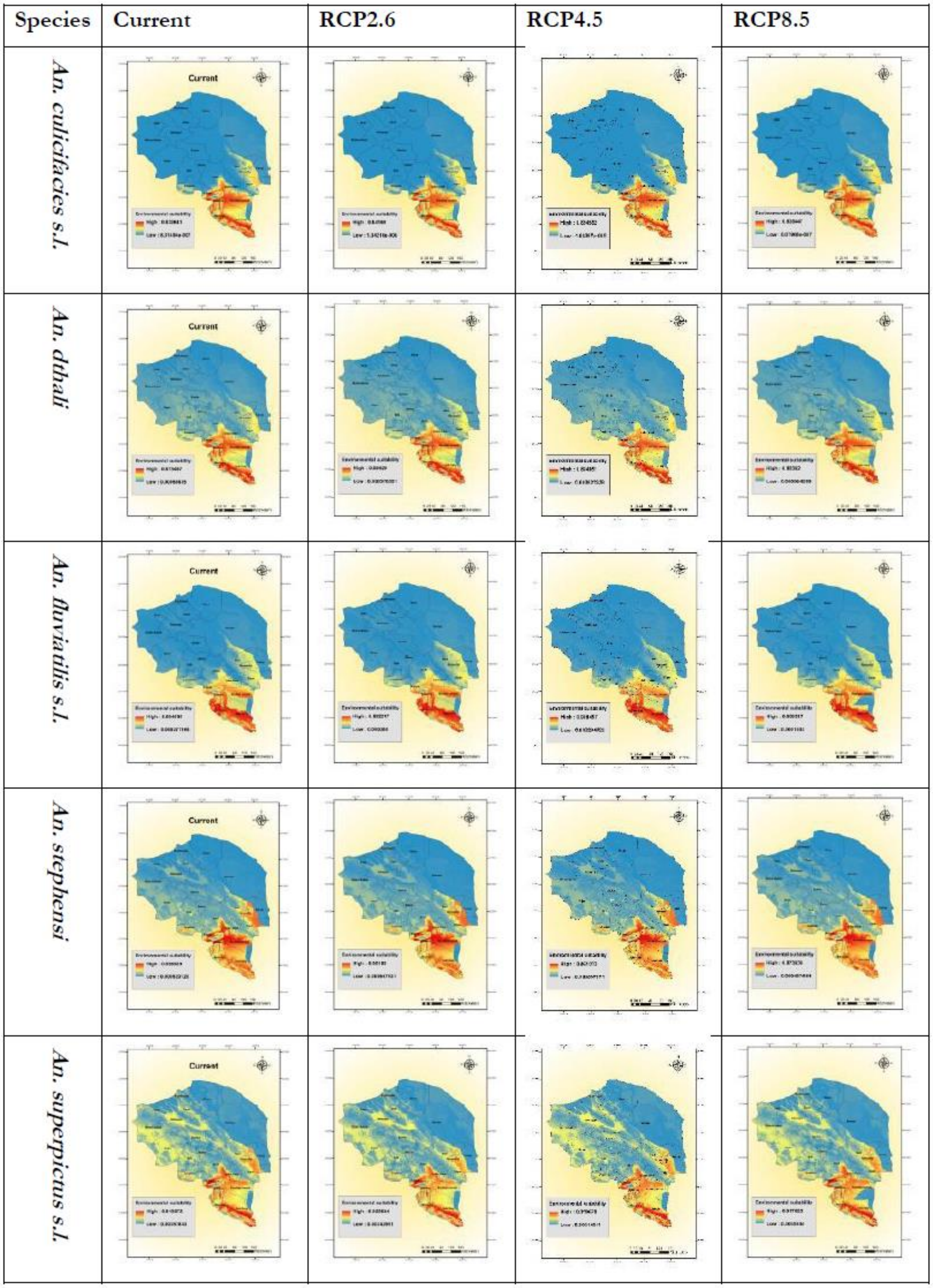

Fig. 2: Environmental suitability for malaria vectors under different climate change scenarios in Kerman Province of Iran, Current climate comparing 2030s

The results of the Jackknife test show that the environmental variable with highest gain when used in isolation was precipitation of warmest quarter (bio18) for current climate and RCP2.6 in 2030, while minimum temperature of coldest month (bio6) was the best predictive variable for two remaining scenarios in 2030s, i.e., RCP 4.5 and RCP 8.5.

Figure 3 presents the environmental suitability for co-occurrence of malaria vectors in the study area. Southern regions of Kerman Province have the best conditions for the occurrence of malaria vectors and therefore the higher risk of human-mosquito contact. RCP 4.5 scenario will provide a better condition for the activity of malaria vectors with clear hot spots in southern areas. This map can be considered as the potential risk of malaria transmission as well.

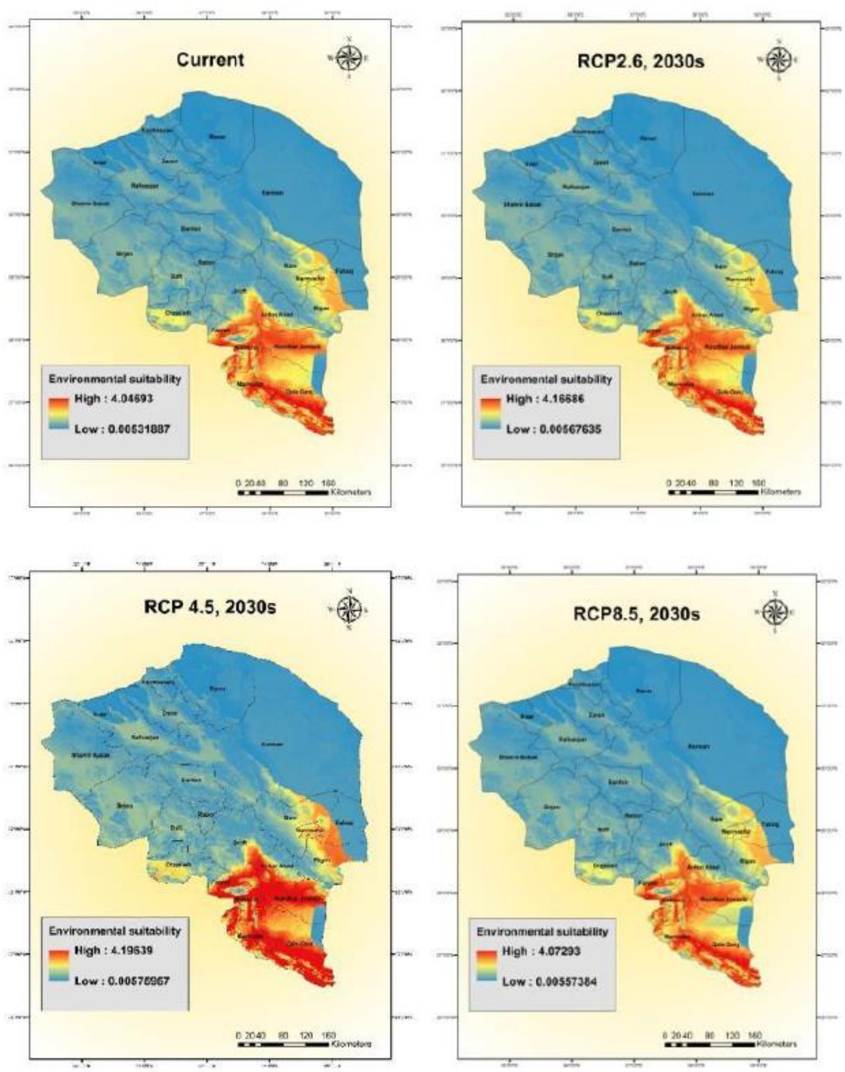

Fig. 3: Potential of malaria transmission in Kerman Province of Iran, considering all malaria vectors and different climate conditions

Discussion

With the intrinsic potential for malaria in Iran, modeling studies show that Hormozgan, Bushehr, Khuzestan, the Southern part of Sistan and Baluchistan provinces, all in the south of Iran, as well as Mazandaran and Gilan provinces in the northern part of the country have the highest risk (30-32). Temperature, humidity and rainfall have long been related to the population dynamics of mosquitoes, which directly affects malaria transmission (33). Temperature was a significantly effective variable in predicting the ecological niches of malaria vectors (34,35). Given our findings, the most effective environmental variable on the model was bio6 (the minimum temperature of the coldest month) among all vectors; therefore, a change in the spatial patterns of bio6 variable may differently affect the spatial distribution of the vectors.

The highest incidence rate of malaria infection was in the south and southeast of Iran, an area with high vulnerability, including traffic and the residence of Pakistani nationals. This package can increase the risk of malaria transmission (6,7).

The way forward for such vulnerable areas requires a plan of the prevention of re-establishment. This study has shown the best ecological niches for malaria vectors in Kerman Province under the current climate and considering three scenarios of climate change in the 2030s. The AUC value was between 0.84-0.92. In agreement with our outputs, previous studies considered AUC>0.75 as a good value for a suitable niche for *Anopheles* species (27,35,36). Those studies indicated the widespread distribution of malaria vectors in southern Iran. Our major finding was that the most suitable ecological niches for five important malaria vectors are located mostly in the southern regions of Kerman Province under the current climatic condition as well as different climate change scenarios in the 2030s. The most obvious finding to emerge from this study was that the ecological niches of malaria vectors in the future would be almost similar to the current situation, although trivial changes are predicted in some species. Therefore, these regions can be considered as potentially suitable environments for the breeding of malaria vectors. More activities be done in these areas, such as prevention of imported cases due to the human reservoir; in addition, identifying asymptomatic individuals. This will reduce vulnerability and receptivity, which will ultimately prevent the re-establishment of malaria (37). In comparison with our study and contrary to our results, the most recent study conducted on modelling the distribution of main malaria vectors of Iran under different climate change scenarios predicted the vulnerable areas for malaria transmission. The total high-risk area for almost all studied species was expected to decrease, but the risky areas might change spatially to newly populated areas (32). Moreover, in Iran, the suitable areas for almost all the studied species would decrease in the future (34,35). The prediction studies in Iran clearly show that the pattern of distribution of *Anopheles* species will change depending on climatic condition. The situation of *Anopheles* species in the world shows expansions of malaria vectors in China and Central America in the future decades (38,39). In contrast, some studies have predicted a decrease in suitable habitats for the activity of malaria vectors in Africa and South America (27,40). Therefore, sufficient information about the current and future distributions of malaria vectors is vital for efficient and evidence-based planning for vector control activities and, both national and local malaria programs should identify the areas at risk for the malaria transmission.

Conclusion

Although Iran has taken great steps to eliminate malaria, but it is more difficult to keep disease cases at zero. Although climate change can influence vector distribution and spread of diseases in Kerman Province, the environmental suitability for all malaria vectors in the 2030s will be more or less the same as current situation.

Journalism Ethical considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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Conflict of interest

The authors declare that there is no conflict of interest.

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