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Risk mapping of malaria in Iran from 2009 to 2018: A GIS-Based survey

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***Abstract*---**Background: Since the issues of public health and the spread of diseases are directly related to the region's geography. We aim to determine malaria incidence, spatial distribution, and hot spots in Iran using the GIS for a decade from 2009 to 2018. Methods: GIS was used to analyze the information acquired from the Ministry of Health and Medical Education in Tehran, Iran, and other associated centers between 2009 and 2018. Subsequently, maps of the disease's spatial distribution were constructed and using ArcGIS 10.5 software, the disease's hotspots in Iran were determined .The disease's variables, such as temperature, relative humidity, normalized difference vegetation index (NDVI), and malaria incidence, were correlated using geographically weighted regression (GWR) analysis in ArcGIS 10.5 .Using descriptive statistics and the chi-square test, data were analyzed using Linear Regression Analysis and SPSS 21 software using descriptive statistics. Result: Sistan and Baluchistan, and the Bushehr provinces were hot spots for Malaria. The geographically weighted regression analysis results showed that in Sistan and Baluchistan and Bushehr, Hormozgan, Fars, Qom, Yazd, Kohgiluyeh and Boyer-Ahmad provinces, the highest correlation between temperature, humidity, vegetation density, and the incidence of Malaria was observed (p-value = 0.019). Conclusion: Using maps can offer accurate estimates of populations at risk. The probability of malaria was influenced more by temperature, humidity, and NDVI than by any other environmental condition. These indicators can act as a predictor of the occurrence of disease. Malaria is linked to environmental and climatic conditions.

Keywords*---Malaria; Incidence; Environmental variables; Geographical information system; Iran.*

Introduction

WHO reports indicate that malaria is the most significant parasitic disease in the world. (1)Approximately 3.3 billion people (half of the world's population) now reside in malaria-prone regions, and almost 660,000 people die annually due to this disease. (1, 2) Plasmodium parasites and anopheles mosquitoes require special climatic conditions for growth, multiplication, and completion of their developmental stages, which influence the frequency and prevalence of malaria.

(3).Based on malaria's oversensitivity to environmental and climatic conditions, the World Health Organization (WHO) focuses on preventing the disease. WHO has continuously worked on tools and techniques to detect, track, evaluate, and control environmental variables and cognitive climates that influence the occurrence of this disease(4).Geographic Information Systems (GIS) is a method for evaluating spatial and non-spatial information and is assumed to be a very effective method for tracking and evaluating environmental variables that influence how diseases appear and spread.(5) These systems can demonstrate risk zoning maps, perform spatial analysis and monitoring of environmental variables that influence how diseases spread, and model disease risk.Malaria control programs on a global scale can now use the spatial distribution of the disease and the factors that affect its spread as a reliable tool. (6) In Iran, malaria is an important public health problem; the weather and geography suit this disease in the south and southeast. More critically than that, Afghanistan, Pakistan, and Iraq are close by, and people freely move from these countries. Before the anti-malaria program began in Iran, this disease affected 4-5 million people every year, and 30–40% of them died. (7, 8).

We aim to use GIS to evaluate the spatial distribution, incidence, and hotspots of malaria from 2009 to 2018 in Iran.

Methods

Data on malaria-related information for all Iranian provinces from 2009 to 2018 was gathered from the Ministry of Health (Disease Management Center), Tehran, Iran. Also, articles published about this disease in Iran were used. Visits to several related regional health centers were also conducted. Searching for conference and dissertation abstracts was an additional source of information. Information regarding the country's population was acquired from the Statistics Center of Iran. (9, 10) The National Meteorological Organization provided us with 10 years of meteorological data from climatological stations in 31 provinces for yearly temperature and relative humidity from 2009 to 2018. The average yearly temperature and humidity were computed for all meteorological stations within a province; the average of the total stations for each province was calculated, and the resulting temperature and humidity values were used for analysis. Next, we used Google Earth Engine software to acquire the NDVI layer based on the Iranian border for the months of May from 2009 to 2018 at a spatial resolution of one square kilometer per pixel. The layers were clipped in ArcMap, according to the provincial borders of the country. The average NDVI value for several years in each province was determined. Using ArcMap 10.5 , the collected numbers were utilized for spatially weighted regression. Data were analyzed to calculate the incidence rate in 100 000 people of the population of the provinces; the following formula was used: Incidence rate = (new disease cases) / (risk in the population) ×(100,000).

Spatial analysis was done using the disease spatial database including cases, age groups of patients, location, gender, and mortality in different age groups in ArcMap. Using spatial analysis in ArcGIS 10.5 and the Hot Spot Analysis tool, disease hot spots in Iran's provinces were identified. Hot Spot Analysis is a feature within the ArcGIS software that identifies provinces that differ from others in terms of illness occurrence. This database analysis based on disease provides positive and negative Z-scores for each province. It indicates which provinces are notably disease hotspots and which are cold areas. The higher the positive value of Z-scores, the more critical the points, whereas the higher the negative value, the more noncritical the points. After doing the analysis, the points are typically split into three groups of hot and cold points at three degrees of confidence: 90%, 95%, and 99%, with each category having its own Z-value. (11). From 2009 to 2018, spatial analysis of geographically weighted regression in ArcGIS10.5 was used to examine the association between environmental variables influencing the disease, such as temperature, relative humidity, NDVI density, and the incidence of Malaria. The regionally variable associations between the incidence of malaria throughout the study period as the dependent variable and average annual temperature, average annual relative humidity, and the NDVI as independent variables, were modeled using geographically weighted regression (GWR) analysis.(9, 12). Using descriptive statistics and the chi-square test, data were analyzed statistically using linear regression analyses using SPSS 21 software (Chicago, IL, USA).

Results

During the studied years, 5,163 Malaria cases were recorded across the country. The malaria incidence rate is depicted in (Figure 1). Malaria had the highest rate in the provinces of Sistan & Baluchistan, Bushehr, Hormozgan, Fars, Qom, Yazd, Kohgiluyeh, and Boyer Ahmad throughout a 10-year period (Figure 2). Sistan & Baluchistan and Bushehr were the provinces with the highest rate of Malaria incidence, considered disease hotspots. (Figure 3). The provinces of Sistan and Baluchistan, Bushehr, Hormozgan, Fars, Qom, Yazd, Kohgiluyeh, and Boyer Ahmad demonstrated the highest association between humidity (Figure. 3), temperature (Figure. 4), and NDVI (Figure. 5). the prevalence of the disease over these years, were determined by GWR analysis.

Data analysis revealed that in 2018, there were 602 new cases of Malaria. The incidence of Malaria was 0.8 per 100,000 patients on average (1.2 men and 0.2 women). According to these statistics, males had the highest incidence. Men accounted for 517 of the 602 new cases of Malaria, while women accounted for 85. The association between the incidence of Malaria in 100,000 patients and NDVI, relative humidity (RH), and mean temperature (TM) was investigated using linear regression analysis (Table 1). The analysis revealed a substantial correlation between temperature and the incidence of Malaria. In fact, a one-degree Celsius increase in temperature has led to a 0.088% increase in the prevalence of malaria ($P = 0.019$). (Table 2).

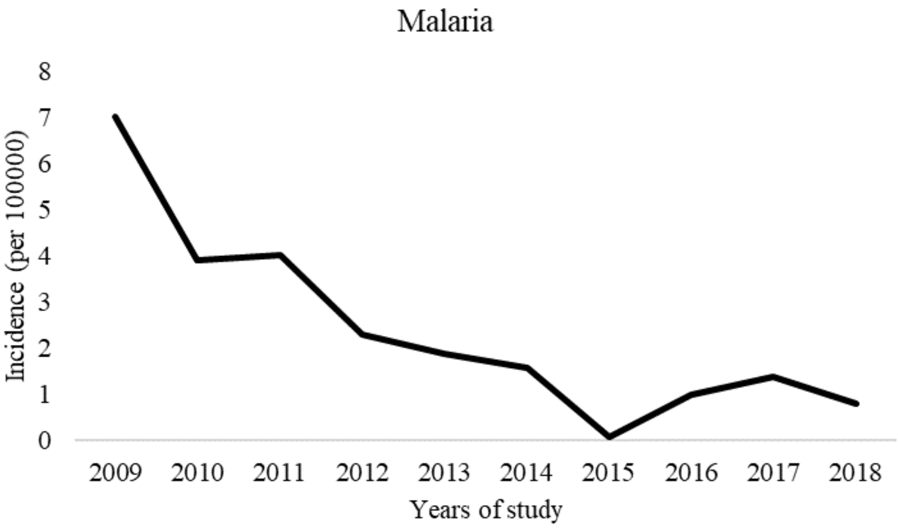

Fig. 1: The trend of Malaria during the years 2009-2018 in Iran

Fig. 2: The incidence of Malaria in different provinces of Iran, 2009-2018

Fig. 3: The results of geographically weighted regression analysis of the correlation between the relative humidity and the incidence of Malaria in Iran, 2009-2018

Fig. 4: The results of geographically weighted regression analysis of temperature correlation and incidence of Malaria in Iran, 2009-2018

Fig. 5: The results of geographically weighted regression analysis of the correlation between NDVI and the incidence of Malaria in Iran, 2009-2018

Table 1: Relationship between environmental variables and the incidence of Malaria in Iran, 2009-2018

province	TM	NDVI	RH	Incidence/100000
Alborz	16.40039214	0.226	36	0.27
Ardebil	9.268608143	0.386	69.3	0.01
AzarbayjanGharbi	13.45255068	0.351	58	0.03
AzarbayjanSharghi	12.74801269	0.325	51.1	0.02
Bushehr	25.58515797	0.107	63.8	6.41
ChaharmahalVa Bakhtiari	12.47099015	0.266	44.5	0.2
Esfahan	14.02026325	0.115	37.15	0.72
Fars	17.68660851	0.154	39	1.96
Gilan	15.83153861	0.564	77.5	0.08
Golestan	18.53809255	0.404	69	0.05
Hamedan	10.10541655	0.31	48.15	0.06
Hormozgan	24.68627044	0.083	62.7	11.85
Ilam	20.31200242	0.16	40.75	0
Kerman	24.0960181	0.099	33.1	1.63
Kermanshah	15.59402365	0.335	40.4	0.01
Khorasan Razavi	15.07798998	0.145	48.75	0.14
Khuzestan	25.06462137	0.139	43.95	0.15
Kordestan	12.84783848	0.374	47.75	0.04
Markazi	12.21402871	0.223	43.45	0.18
Mazandaran	16.21690237	0.472	76.05	0.06
North Khorasan	14.71020272	0.215	58.15	0.06
Qazvin	15.22403958	0.282	52.55	0.3
Qom	16.56578786	0.104	46.5	1.89
Semnan	15.29186281	0.08	37.45	0.15
Sistan Va Baluchestan	23.32389757	0.071	30	47.82
South Khorasan	18.50197443	0.08	33.2	0.13
Tehran	15.81778573	0.161	36	0.4
Yazd	17.43841887	0.082	28.75	0.06
Zanjan	12.75088759	0.278	54.45	0.02

TM: Mean annual temperature, RH: Average of annual relative humidity, NDVI: Normalized difference vegetation index

Table 2: Results of the univariate and multiple linear regression model for Malaria

variable	univariate		multiple	
	Beta(SE)	P-value	Beta(SE)	P-value
TM	0.886(0.355)	0.019	0.845(0.460)	0.078
RH	-0.132(0.125)	0.301	-0.024(21.39)	0.999
NDVI	-21.30(12.37)	0.096	-0.094(0.180)	0.607

TM: Temperature, RH: Average of annual relative humidity,NDVI:

Vegetation density

Discussion

GIS can be a valuable tool for public health, especially malaria because it provides spatial patterns and disease distribution (13) This study estimated the hot foci of malaria using spatial analysis .During 2009–2018, cold foci of the disease, i.e., provinces in which the incidence of the disease was significantly low, were not observed. Furthermore, GWR was employed to establish correlations between the variables influencing the disease. The results of the current study are similar to those in Kenya and Iran.(14, 15) In this study, geographically weighted regression analysis was utilized. The analysis revealed an association between temperature, relative humidity, NDVI, and malaria incidence in the provinces of Sistan and Baluchistan, Bushehr, Hormozgan, Fars, Qom, Yazd, Kohgiluyeh Ahmad, and Boyer Ahmad. Similar to prior studies, the highest correlation was found between temperature, relative humidity, NDVI, and malaria incidence. (1, 15-17)) . The results of Hanafi et al al. study showed the application of GIS in the study of malaria infections is beneficial and shows a better understanding of parasite transmission. It showed that environmental factors such as temperature, humidity and altitude have an effect on the distribution and dispersion of malaria.

The results of the present study indicated that these provinces have the most favorable climatic conditions (annual mean temperature, relative humidity, and density of vegetation), which create an outstanding potential for the activity and reproduction of the Anopheles mosquito and the survival of the malaria parasite.

Consequently, the incidence of malaria is higher in these regions.Environmental . The climatic factors significantly impact the Anopheles mosquito's activity, distribution, and reproduction, temperature, relative humidity, and vegetation density are the most significant climatic influences on malaria prevalence.(18).Temperature and humidity influence the growth and reproduction of the anopheles mosquito as well as the activity of malaria parasites. (18). The majority of Plasmodium's life cycle stages are influenced by temperature.(18) Consequently, as the temperature rises, the number of eggs laid by the Anopheles mosquito increases. (19) According to the researchers, the minimum temperature for Plasmodium parasite activity ranges between 14 and 19 degrees Celsius. The threshold for P. vivax species is lower than that of P. falciparum species, whereas the lowest temperature threshold for anopheles mosquito activity is between 8 and 10 degrees Celsius. The optimal temperature range for growth and activity of the Anopheles mosquito and the Plasmodium parasite is between 25 and 27 degrees Celsius and 21 and 21 degrees Celsius, respectively.(20, 21).

In temperatures around 40 degrees Celsius, mosquitoes and parasites become less active, which may be one of the causes of the decline in relative humidity.(22)

Humidity has no impact on the Plasmodium parasite. However, it does affect the Anopheles mosquito's life cycle. (19). The development of the Plasmodium parasite is influenced by activity and temperature, but humidity seems to have no direct effect on its life cycle. Satellite photos with high spatial resolution can identify temporary water bodies and vegetation as breeding and resting places for mosquitoes.(15) Based on geographic weighted regression analysis in Iran, Sistan and Baluchestan, Bushehr and Hormozgan provinces have the most favorable climatic conditions (temperature, humidity, and density of vegetation simultaneously) for the activity and breeding of the Anopheles mosquito. The provinces of Qom, Kohgiluyeh, and Boyer-Ahmad belong to the second category in terms of climate conditions conducive to the activity and reproduction of the Anopheles mosquito. Furthermore, in the third category are Yazd and Fars provinces.

Sistan and Baluchistan, which has a long frontier with Pakistan, have the highest prevalence of malaria in the country. also, imported malaria cases from neighboring countries have grown in three provinces over the past few years: Hormozgan, Sistan & Baluchistan, and Kerman. (23, 24) Intensive control initiatives in Iran, led to a significant fall in the number of malaria cases from 2008 to 2016; the incidence rate fell from 11,460 to 705 cases (25) Appropriate (active and passive) monitoring, spraying, accurate diagnostic tools, a comprehensive disease reporting system, worldwide financial collaborations, and the expansion of border patrol stations appear to have played a crucial role in minimizing this participation.(26-28) Furthermore, people in rural areas in southern Iran have an acceptable level of malaria awareness and attitude, which can contribute to enhanced protection against anopheles bites. (29) Considering malaria is an environmentally dependent disease, combining this data with the community's socioeconomic, cultural, and health status enables the establishment of an early warning system for epidemics.(15) Geographical Information System (GIS) graphically identifies the relationship between malaria incidence and the epidemiological data of malaria hotspots, assisting malarialogists and authorities in their efforts to eliminate, control, manage, and monitor malaria.(30-32) .Limitations of this study may be considered missing data during data collection.

Conclusion

GIS mapping can be used in malaria control strategies. It can provide researchers with instant information updates and the identification of problem points at the village level within the region, which is usually the lowest unit equipped with computer facilities. Furthermore, more importantly, the information can be instantly delivered to the government and policymakers for focused and cost-effective formulation.

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