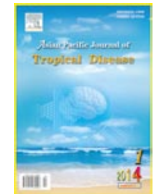
Contents lists available at ScienceDirect

Asian Pacific Journal of Tropical Disease

journal homepage: www.elsevier.com/locate/apjtd



Document heading doi: 10.1016/S2222-1808(14)60434-5

Modelling spatial relationship between climatic conditions and annual parasite incidence of malaria in southern part of Sistan&Balouchistan Province of Iran using spatial statistic models

Mansour Halimi[1*], Manuchehr Farajzadeh[2], Mahdi Delavari[3], Ashraf Takhtardeshir[4], Abbas Moradi[5]

[1]*Department of Climatology, Tarbiat Modsres University, Tehran, Iran*

[2]*Department of Remote Sensing, and GIS, Tarbiat Modsres University, Tehran, Iran*

[3]*Department of Medical Parasitology, Faculty of Medicine, Kashan University of Medical Science, Kashan, Iran*

[4]*Department of Climatology, Tehran University, Tehran, Iran*

[5]*Department of Mathematic, Shiraz University, Iran*

PEER REVIEW

Peer reviewer
Dr. Yahya Maarofi, Associated Professor of Medical Parasitology, Medical University of Zabol, Iran.
Tel: +98-9183755825
E-mail: Y.Maroufi@modares.ac.ir

Comments
This is a good study in which the authors developed a climate-based pre-warning model based on spatial regression for predicting malaria outbreak in southern part of Sistan&Baluchestan where included more than 0.65 of malaria infection yearly. Such studies can be very helpful in the anti-malaria campaign in malaria endemic area.
Details on Page S172

ABSTRACT

Objective: To model spatial relationship between climatic conditions and annual parasite incidence (API) of malaria in southern part of Sistan&Balouchistan Province of Iran using spatial statistic models.

Methods: A geographical weighted regression model was applied for predicting API by 3 climatic factors in order to model the spatial API of malaria in Sistan&Baluchistan Province of Iran.

Results: The results indicated that most important climatic factor for explaining API in Sistan&Baluchistan was annual rainfall being of more importance in southern part of study area such as Chabahar, and Nikshar. The temperature and relative humidity are of the second and third priority respectively. The importance of these two climatic factors is higher in northern part of the studied region. The spatial autocorrelation (Moran's I) for standard residual of applied geographical weighted regression model is –0.022 which indicated no spatial patterns.

Conclusions: This model explained only 0.51 of API spatial variation (R^2=0.51). Thus, the non-climatic factors such as socioeconomic, lifestyle and the neighborhood position of this province with Afghanistan, and Pakistan also should be considered in epidemiological survey of malaria in Sistan&Baluchistan.

KEYWORDS
Annual parasite incidence, Geographical weighted regression, Iran, Malaria, Sistan&Baluchistan, Spatial modelling

1. Introduction

Before any anti-malaria campaign in Iran, about 60% of people were living in endemic areas, and 4 to 5 million people were infected with malaria each year. While 30% to 40% of total mortality in these regions was due to this disease[1]. The first malaria-training course for preliminary operations of anti-malaria campaign started in Iran in 1945. Anti-malarial campaign including drug prophylaxis, treatment, anti-mosquito spraying with DDT and some anti-larval control measurements were carried out during 1948-1956. Malaria infection rate was decreased considerably in most endemic areas. In 1957, malaria eradication program started in Iran and malaria transmission was almost

*Corresponding author: Mansour Halimi, Department of Climatology Tarbiat Modsres University, Tehran, Iran.
Tel: +989384845389
E-mail: m.halimi@modares.ac.ir

Article history:
Received 19 Nov 2013
Received in revised form 24 Nov, 2nd revised form 2 Dec, 3rd revised form 9 Dec 2013
Accepted 16 Dec 2013
Available online 28 Jan 2014

interrupted up to 1980 in the north parts of the country. However, although the infection rate considerably decreased in the south parts, malaria transmission was not interrupted due to some technical and operational problems. Therefore, the malaria eradication program shifted to malaria control program in 1980 which had been continuing up to present[2]. Beginning anti-malaria campaign in Iran, number of infected cases have declined year by year in such a way that the number of infected people with this disease was less than 3000 cases in 2010. Most cases of malaria in Iran occur mainly in three southern provinces of Sistan&Baluchestan, Hormozgan, and Kerman. According to the Iran's Ministry of Health and Medical Education, about 65% of malaria cases infected have been reported in the Sistan&Baluchestan Province in 2010[1]. Environmental and climatic factors also play an important role in prevalence of malaria disease in Sistan&Baluchestan. Since the mosquitoes of anopheles transmit the genus plasmodium parasite, the spatiotemporal distribution of malaria largely depends upon climatic and environmental factors that affect the survival and multiplication of the anopheles mosquitoes and plasmodium parasite as well. The climatic factors such as temperature, relative humidity, rainfall, magnitude and direction of winds and also spatiotemporal distribution of these climatic factors influence the prevalence of malaria. Identification and elucidating the influence of climatic factors on prevalence of malaria disease, climate-based pre-warning system can be designed which is able to predict malaria based on the temporal and spatial characteristics of climatic factors change during the outbreak and prevalence of disease. In this research, the role of each climatic factor was identified as the independent variable in prevalence of malaria in Sistan&Baluchestan by using Geographically Weighted Regression (GWR) model. In addition, the spatial role of each climatic factors in geographical distribution of malaria was investigated.

2. Materials and methods

2.1. Area of study

Sistan&Baluchestan Province (bearing an area equal to 181471 km^2) is the vastest province in Iran and 11.5% of the country's area is devoted to this province. As depicted in Figure 1, this southeastern province of Iran is located between latitudes 25°3' to 31°27' N of equator and longitudes 58°50' to 63°21' E of the Greenwich meridian. Sistan&Baluchistan Province has a 1265 kilometer common borderline with Pakistan and Afghanistan. The Sistan&Baluchistan is formed of 2 main parts: the northern part is Sistan in neighboring Afghanistan and southern part is Baluchistan in neighboring Pakistan and also Oman Sea in south. The average of annual rainfall in this semi-arid province is about 110 to 140 mm and average of annual temperature is about 23 °C. This province has the highest ratio of malaria incidence in Iran and about 65% of cases of malaria infected have been reported in Sistan&Baluchestan Province in 2010 according to the Iran's Ministry of Health, and Medical Education.

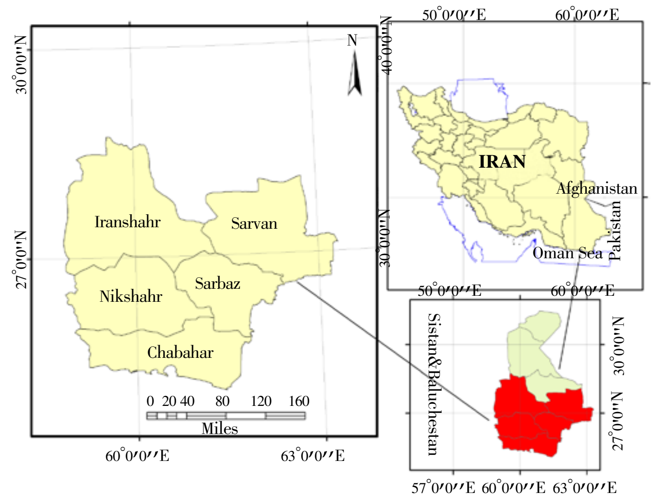


Figure1. Map of Sistan&Baluchestan Province (study area).

2.2. Data source

In this study, we used 2 types of data: climatic data and annual parasite incidence (API) data as malaria prevalence index.

2.2.1. Climatic data

Climatic data include 20-year average (1985-2005) of mixed ratio of humidity (MRH). Colinearity statistics are reporterelative humidity, annual precipitation and mean monthly temperature of 11 synoptic and climatology stations located in the province of Sistan&Baluchestan. The climatic data have been obtained from data processing department of Iran meteorological organization and have been applied to develop a GWR model for spatial prediction of API in this province after preprocessing and quality control.

2.2.2. API data

In this work, we used API data as a malaria prevalence index:

$$\text{API}=\frac{\text{confirmed cases during 1 year}}{\text{population under surveillance}}\times 1000$$

We gave this data for 11 cities of the province and used them as a spatial dependent variable (Table 1).

Table 1
API data for 11 districts of province (2010).

City	API
Fanouj	15
Sarbaz	10
Chabahar	6
Nikshahr	4
Kenarak	4
Sarbaz	2
Dalagan	2
Zaboli	1
Soran	1
Iranshahr	1

2.3. GWR

GWR is a fairly recent contribution to modelling spatially heterogeneous processes[3]. The underlying idea of GWR is that the parameters may be estimated anywhere in the study area given a dependent variable and a set of one or more mentioned independent variables which have been measured at places where their location are known.

2.4. Data pre-possessing

The Jarque-Bera (JB) normality test as a goodness-of-fit test of whether sample data have the skewness, and kurtosis matching a normal distribution or not[4]. Also, we used variance inflation factor(VIF) and tolerance as indices to detect the colinearity between independent variables[5].

2.5. Model post-possessing

In the next step, we run the Moran spatial autocorrelation as an analysing pattern tool to validate the fitted spatial model[6]. The Moran run on standard residuals of fitted GWR model to elucidate whether there is any significant pattern in standard residuals of model or not.

3. Results

The first step to develop any model is awareness of the suitability of data and variables that contribute in modelling and prediction. The GWR, like all regression models, is based on basic assumption in which variables have to pass them such as following normality distribution and having no significant linear relation between independent and explanatory variables (colinearity). To detect the colinearity problem between the explanatory variables, we used indices that are based on predicted variance of modelling (VIF and tolerance). We observed that the relative humidity as one of the climatic explanatory variables was highly collinear with other independent variables (VIF=6), and the GWR model is not executable. Thus, we removed this variable from modelling, and instead we executed GWR using the MRH. Colinearity statistics are reported in Table 2.

Table 2
Colinearity statistic.

Statistic	MRH	*P*	*T*
R^2	0.489	0.078	0.406
Tolerance	0.561	0.922	0.664
VIF	1.770	1.085	1.404

We applied JB normality test to understand the distribution of the variables which are reported in Table 3. As showed in Table 3, all variables follow the normal distribution. The Q-Q plot for three climatic factors is presented in Figure 2 to visualize how much the distribution of this factor matches normal distribution.

Table 3
JB normality test.

Variable	MRH	P	T	API
JB (Observed value)	1.717	0.272	0.638	3
JB (Critical value)	5.991	5.991	5.991	5.991
P-value	0.424	0.873	0.727	0.210
Alpha	0.050	0.050	0.050	0.050

The spatial association of climatic factors, and malaria incidence are depicted in Figure 3, is presented in Table 4. The pixel by pixel correlation of spatial distribution of climatic factor versus API in study area indicated that the precipitation has largest correlation with API (0.53). The coefficient of spatial correlation for temperature, and MRH is 0.40 and 0.35, respectively.

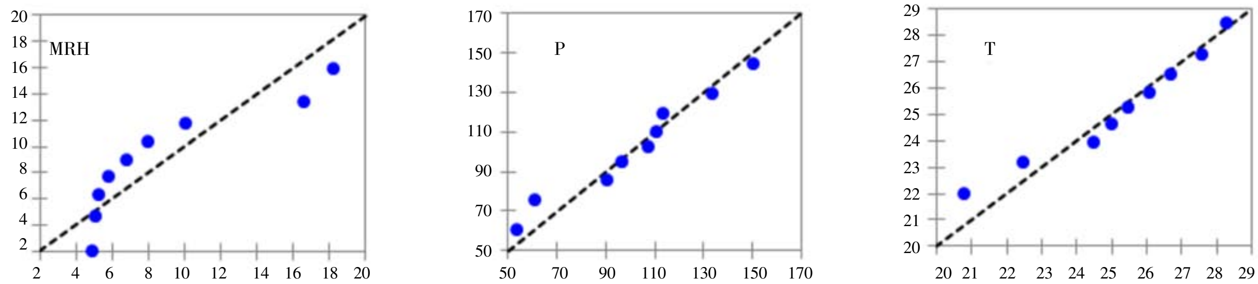


Figure 2. The Q-Q plot for three climatic factors.

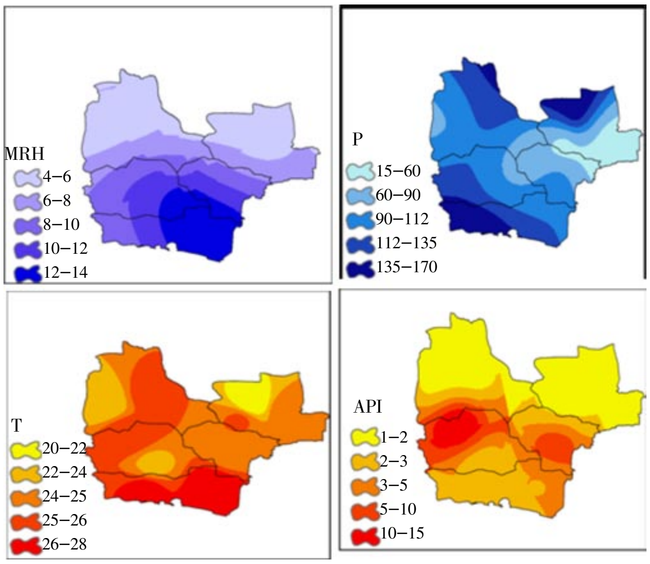


Figure 3. Spatial distribution of climatic factor, and API in study area.

Table 4

20 years average of 3 malaria effective climatic factor.

City	MRH	T	P
Fanouj	8.20	26.00	111.00
Sarbaz	10.09	24.11	97.00
Chabahar	15.30	27.60	110.00
Nikshahr	13.60	23.32	107.30
Kenarak	4.90	26.70	150.50
Sarbaz	5.30	24.49	61.00
Dalagan	8.00	22.49	91.00
Zabol	6.84	25.01	54.00
Soran	7.00	20.78	134.00
Iranshahr	5.77	25.50	120.00

Developing GWR model can not only prioritize the climatic factor in terms of importance to influence on malaria prevalence but also explain the spatial role of each climatic agent in spatial transmission, and prevalence of this mosquito borne disease. We applied this by mapping the spatial coefficient of each explanatory variable.

3.1. Tempreture

The average annual temperature of study area is about 22 °C which spatial range between southern and northern part of region is about 9 °C. The spatial distribution of average annual temperature is shown in Figure 4. As this map indicated that temperature in the southern part of this province like Chabahar is about 26 to 28 °C higher. While monthly, and seasonal fluctuation of temperature in this part of region is lower than northern part. The lowest monthly temperature during the year belongs to January which is about 9 °C. The average of monthly temperature in all months is greater than 8 °C (the minimum temperature for mosquito development) and therefore the ecological cycle of anophel is not interrupted in any month of the year. The difference between monthly highest and lowest temperature during the year is about 20 °C (January 9 °C, and July 29 °C).

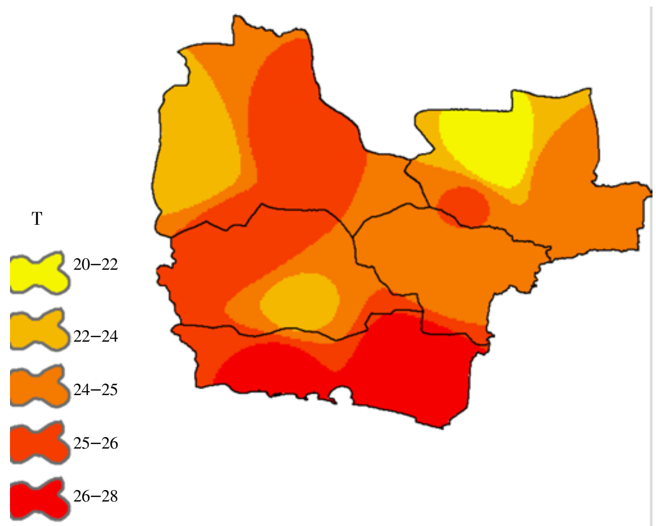


Figure 4. Spatial distribution of average annual tempreture (°C) in study area.

Spatial role of annual temperature in malaria incidence rate can be visualized by mapping its coefficient which is the output of developed GWR model presented in Figure 5. As seen in this figure, the temperature as an effective climatic factor in malaria incidence has greatest spatial influence in northwest of study region like Iranshahr, and toward the southeast, like east of Chabahar and Sarbaz. Its spatial effectiveness was dwindled in API. The spatial influences of temperature is about 0.008 to 0.010 in south eastern parts and is increased toward north western part of province about 0.13 to 0.50. It means that, in northwest parts, the variations of temperature has stronger importance on malaria incidence compared to south or east parts of study area.

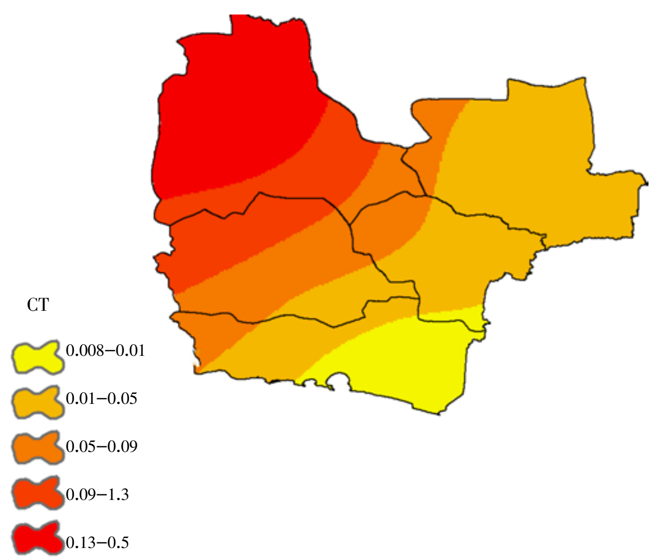


Figure 5. Coefficient of tempreture (CT) in study area.

3.2. Precipitation

The 20 years' average (1985–2005) of sum monthly precipitation of study area was considered as another spatial independent variable. Its distribution is presented in Figure 6. As can be seen, the southern parts of province have highest rainfall while the precipitation is decreased toward the central part. The largest amount of rainfall occurs in December to March. The average of annual precipitation of region is about 130 mm.

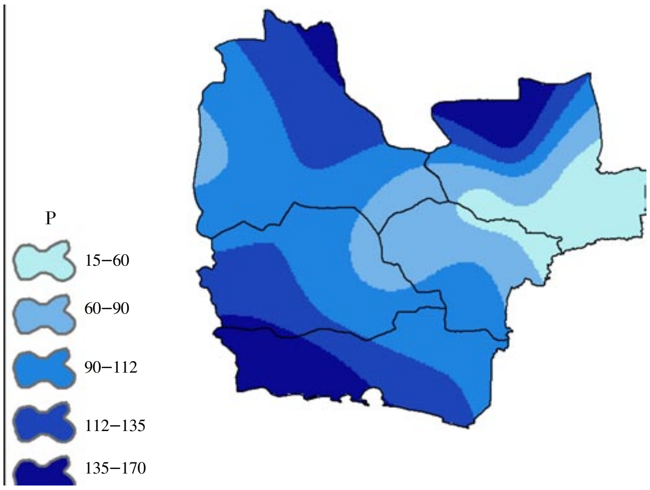


Figure 6. Spatial distribution of total annual precipitation (mm) in study area.

Spatial role of annual rainfall in malaria incidence rate can be visualized by mapping its coefficient which is output of developed GWR model presented in Figure 7. As seen in this figure, the precipitation has greatest spatial influence in northwest of study region like Iranshahr while its spatial effectiveness dwindled in API toward the southeast parts like east of Chabahar and Sarbaz. The spatial influences of rainfall is about 0.002 to 0.009 in south eastern parts and is increased toward north western part of province about 0.04 to 0.05. It means that, in northwest parts, the temperature variation is more important in malaria transmission compared to south or east parts of study area.

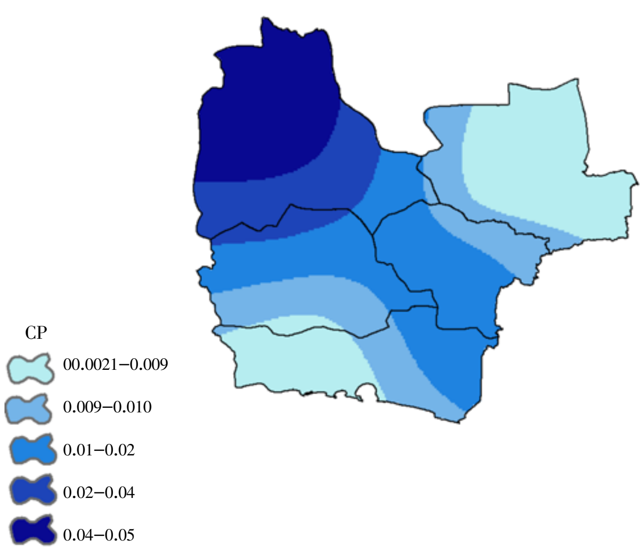


Figure 7. Coefficient of precipitation (CP) in study area.

3.3. MRH

The spatial distribution of MRH is presented in Figure 8. As can be seen, the maximum concentration of MRH is located in south and southeastern of study regions like Chabahar which is near Oman Sea. The spatial role of this climatic factor is more important in northern study region while its effectiveness in malaria transmission is decreased in southern parts.

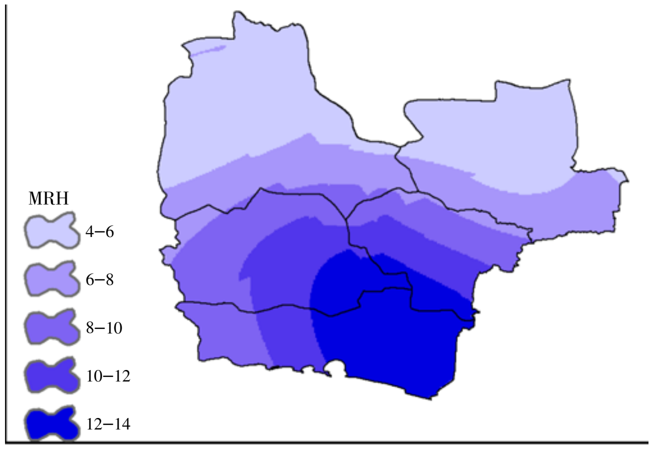


Figure 8. Spatial distribution of total annual mixed ratio of humidity (g/kg) in study area.

Coefficient of determination of applied model was 0.51 which indicates that climatic factors can explain 51% of the spatial variation of API in Sistan&Baluchistan Province (Figure 9). Therefore, non-climatic factors such as socioeconomic, cultural, lifestyle and the neighborhood position of this province with Afghanistan and Pakistan should also be considered in anti-malarial campaign and epidemiological survey of malaria in Sistan&Baluchistan.

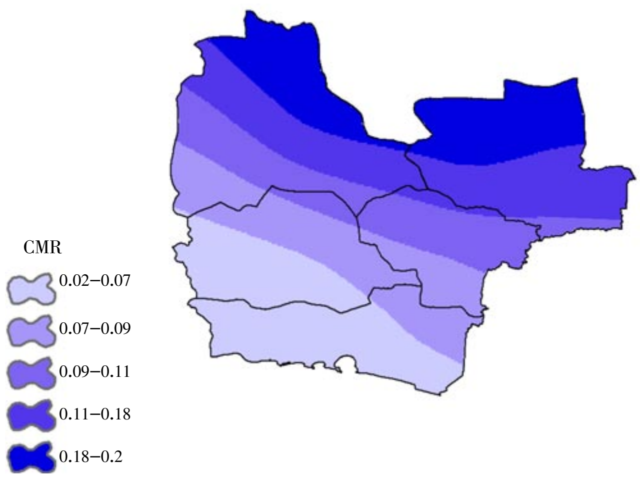


Figure 9. Coefficient of mixed ratio of humidity (CMR) in study area.

Having validated the results by developed GWR model, spatial standard residuals of model were tested through Moran spatial autocorrelation. The value of mentioned index for standard residuals of applied GWR model was 0.022 that indicates the absence of significant spatial autocorrelation (Figure 10).

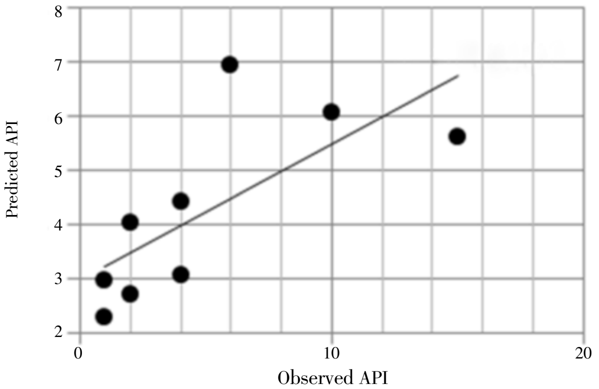


Figure 10. Observed API versus predicted API.

4. Discussion

In this paper, we developed a spatial climate–based model which can clarify the spatial role of climatic factor in malaria transmition. It's noteworthy to mention that, this climate–based model can explaine only 0.51 of the spatial variation of API in Sistan&Baluchistan Province. Thus, non–climatic factors such as socioeconomic, cultural, lifestyle and the neighborhood position of this province with Afghanistanand Pakistan should also be considered in anti–malarial campaign and epidemiological survey of malaria in Sistan&Baluchistan.

Conflict of interest statement

We declare that we have no conflict of interest.

Comments

Background

The background of this research focus on the situation of malaria prevalence In Iran and anti–malaria campaign. Indeed, malaria in Iran is the most important parasitic disease. Therefore, it is important to plan and develop the method based on survey and assessment of the malaria prevalence and its effect in Iran.

Research frontiers

Using spatial statistic for analysis association between spatial variables such as API and climatic factor is good idea. But I suggested to validate this spatial model in compare with classical statistic model such as classic correlation or regression.

Related reports

This is a few studies like Salehi *et al.* (2008) who try to develop a spatial model for predicting malaria incidence in S&B Province of Iran, but they used the variogram and geostatistic model and classic regression for prediction of SIR in S&B.

Innovations & breakthroughs

Using the GWR as a dynamic regression based model to predict malaria prevalence according to climatic and environmental factors which not only assess the effect of climatic factor but also determine the spatiotemporal effectiveness of mentioned factor in malaria prevealence.

Applications

Malaria is the vector–born disease therefore environmental and climatic factors play an important role in its prevalence. Explaining the influence of climatic factors on prevalence of malaria disease could be very helpful and promote anti–malaria campaign.

Peer review

This is a good study in which the authors developed a climate–based pre–warning model based on spatial regression for predicting malaria outbreak in southern part of Sistan&Baluchestan where included more than 0.65 of malaria infection yearly. Such studies can be very helpful in the anti–malaria campaign in malaria endemic area.

References

[1] World Health Organization. Malaria. Geneva: World Health Organization; 2013. [Online] Available from: http://www.afro.who.int/en/clusters–a–programmes/dpc/malaria/mal–publications.html. [Accessed on 21st November, 2013]

[2] Edrissian GH. Malaria in Iran: past, and present situation. *Iranian J Parasitol* 2006; **1**(1): 1–14.

[3] Fotheringham A, Brunsdon C, Charlton M. *Geographically weighted regression: the analysis of spatially varying relationships.* Chichester: Wiley; 2003, p. 282.

[4] O'Sullivan D, Unwin DJ. *Geographic information analysis.* 2nd ed. New York: John Wiley & Sons; 2003, p. 436.

[5] Mantalos, P. *The three different measures of the sample skewness and kurtosis and the effects to the Jarque–Bera test for normality.* Sweden: Jönköping International Business School; 2010, p. 20.

[6] Chen J, Jiang J. Analysis of spatial autocorrelation for point object based on line buffer. Leicester, UK: Accuracy 2010 symposium, July 20–23 .