Original Article

Time Series Analysis on the Appropriate Time for Malaria Residual Spraying Based on Anopheles abundance, Temperature, and Precipitation between 2009-2016 in Kazerun, South of Iran

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Abstract

Background: Malaria is one of the most important vector-borne diseases, a major health problem, and a serious cause of mortality around the world. Indoor Residual Spraying (IRS) together with insecticide-treated nets is among the primary methods used for controlling and reducing the burden of malaria. The present study aimed to determine the appropriate time for malaria management based on entomology, vector abundance, temperature, and precipitation data.

Methods: In this time series study the study data were collected using the entomological data existing in Kazerun's health and treatment network and weather station between 2009 - 2016. The data were analyzed via time series models with monthly time intervals, which included 96 months. The following models were applied: Autoregressive Moving Average (ARMA), Moving Average (MA), Autoregressive (AR), and Autoregressive Integrated Moving Average (ARIMA). Indeed, kriging approach was employed for interpolation of temperature and precipitation in the study points. All analyses were done using Information Technology Service Management (ITSM) software.

Results: Temperature followed a similar trend in the six villages under investigation. It was predicted up to 20 months after the observations using MAmodel. Accordingly, the mean of temperature was 30 °C.The trend of precipitation showed great fluctuations; thus, the results of the precipitation model were not accredited. The trend of *Anopheles* abundance was predicted using ARMA in Jahad-Abad, Hakimbashi, Seyed Hossein, and Dadin and using ARMA in Khesht and Jareh. According to the results, *Anopheles* abundance followed a descending trend in the study regions. Considering the temperature trend and peak of *Anopheles* abundance in the areas under investigation, the best time for residual spraying was two weeks prior to the peak of *Anopheles* abundance within the temperature range of 25-30 °C.

Conclusion: Considering entomology and temperature data, two weeks prior to the peak of *Anopheles* abundance within the temperature range of 25-30°C was found to be the best time for residual spraying in order to prevent and control malaria. Other preventive and control measures, such as active case detection, timely treatment of patients, and public education should also be intensified at this time.

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Keywords: Indoor residual spraying, ARIMA model, Time series analysis, Malaria, Kazerun

Introduction

Since one child dies due to malaria every two minutes, it has been considered to be the most serious vector-borne disease in the world. In 2015, nearly 212 million new malaria cases occurred worldwide, which caused 429 000 deaths including 303 000 children below five years of age. Malaria is also a major cause of malignancy, which was responsible for 63-110 million Disability Adjusted Life Years (DALYs) in 2010.[1] Thus, malaria is one of the most important vector-borne diseases, a major health problem, and themain cause of mortality around the world.[2] Itis also the most important parasitic disease and an important health issue in some regions of Iran.[3] Based on the national reports provided by the malaria care system in 2015, 799 malaria cases were reported, among which 167cases were locally transmitted and 632 were imported.[4] At present, Iran is in the malaria elimination phase, which has been considered to last up to 2025.[5]

Malaria is accompanied with complex problems. Hence, synergistic interventions are considered to be a priority. In this context, insecticide-treated nets and residual spraying, as two cost-effective methods, are used to prevent malaria. These measures were applied to eliminate malaria in endemic countries in the past decade.[6] Climate is also effective in development of mosquitoes and parasites, frequency of blood feeding, and disease transmission. Hence, short-term climatic changes, including temperature, humidity, precipitation, and irregular climatic phenomena, such as El Nino, can play a role in malaria transmission. However, these issues were not taken into account in malaria elimination programs in the past.[7]

Indoor Residual Spraying (IRS) together with insecticide-treated nets is among the primary methods used for controlling and reducing the burden of malaria. IRS requires utilization of insecticides on the walls, ceilings, and other resting places for mosquitoes, which contribute to malaria transmission.[8] The beneficial effects of IRS on prevention of malaria have been reported in endemic areas with high and low prevalence rates of the disease. Accordingly, IRS helped reduce malaria in Latin America, Asia, and Europe.[9] Residual spraying has also been shown to be effective in declining the parasite density and the prevalence of the disease.[10]

Fars province, Iran, is a malaria-endemic area and local transmission occurs in western regions of the province; therefore, larviciding, IRS, and use of insecticide-treated nets have been carried out as a part of the malaria elimination approach in the western regions of the province, including Kazerun as a re-emerged focus of the disease.[2] Based on the data provided by Kazerun's health and treatment network, 14 malaria cases were reported in the malaria epidemic which occurred in 2015. Among these cases, 13 were locally transmitted and one was imported.

The present study aimed to determine the best time for residual spraying based on entomology, vector abundance, temperature, and precipitation data in order to control and prevent malaria. In this way, a critical step can be taken towards malaria control and prevention in Kazerun.

Materials and Methods

Study Region

Kazerun, with an area of 406 000 hectares, is located in western Fars province at 51°35 ″E, 29°35 ″N. It neighbors Shiraz from east and northeast, Firouzabad from southeast, Nour-Abad Mamassani from west and northwest, and Borazjan from the south and southwest (Figure 1).[11]

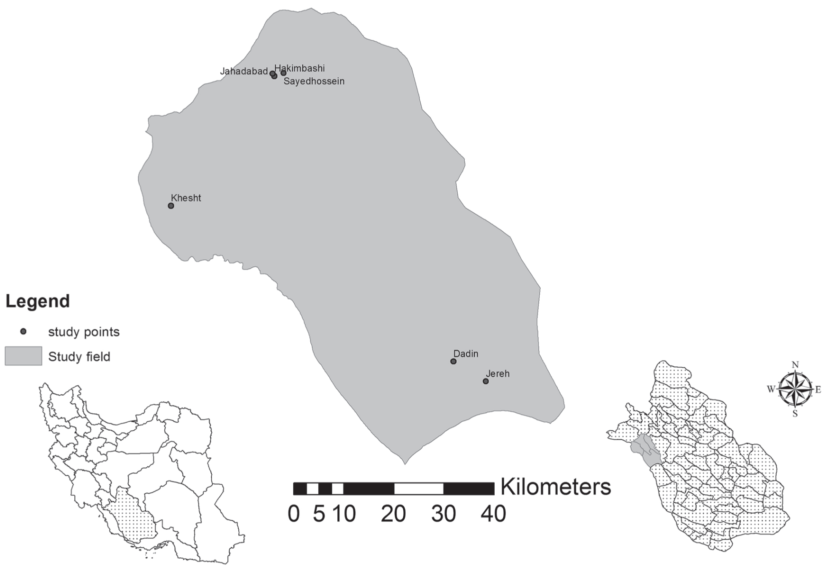

Figure 1: Distribution of the study points in Kazerun (up, middle), Fars province (down, right), and Iran (down, left) in 2017

Data Collection

The data related to the abundance of vectors were gathered from the entomology information existing in Kazerun's health and treatment network. In addition, the climate data including temperature and precipitation from 2009 to 2016 were collected from the county's weather station. Vectors abundance was computed by dividing the number of captured female *Anopheles* by the number of investigated shelters. This was carried out in six regions throughout Kazerun (eight locations in each region) using the entomology program conducted by trained specialists twice a month (due to the fact that the sexual cycle of *Anopheles* lasts for two weeks).

Statistical Analysis

This time series study aimed to predict the appropriate time for malaria residual spraying based on the vectors' abundance, precipitation, and temperature. The data were analyzed using time series models with monthly time intervals, which included 96 months. At first, the data were entered into the EXCEL software where their accuracy was verified and the necessary modifications were applied. Additionally, outliers were omitted or modified using statistical methods. Then, time series models were employed to analyze the data. In doing so, Box-Jenkins, Seasonal Autoregressive Integrated Moving Average (SARIMA), and Autoregressive Integrated Moving Average (ARIMA) models were used.

In case observations are interrelated, model performance has been taken into consideration. The correlation between an observation and a previous case in a specific model provides a more reliable prediction for the seasonal trend of a disease. ARIMA models have been widely used to predict and determine active factors, such as climate, in such diseases as malaria, hepatitis, pneumonia, and dengue fever. Box-Jenkins, SARIMA, and ARIMA models consist of the following stages: preparing a series for modeling, identifying the primary model based on the estimation of the parameters, determining the model parameters accurately, and identifying the appropriate model.[12, 13]

In this study, data analysis was carried out via Information Technology Service Management (ITSM) software. The following time series models were applied: Autoregressive Moving Average (ARMA), Moving Average (MA), Autoregressive (AR), and ARIMA. Indeed, kriging approach was employed for interpolation of temperature and precipitation in the study regions. Since no temperature and precipitation data were available for the areas under investigation, the required information was obtained with the help of the data related to the surrounding regions through interpolation of temperature and precipitation by the kriging approach using ArcGIS software.

Results

This study aimed to analyze the vectors' abundance, temperature, and precipitation in Jahad-Abad, Hakimbashi, Seyed Hossein, Khesht, Jareh, and Dadin using entomology and weather data. In the primary analysis, similar trends were observed in Jahad-Abad, Hakimbashi, Seyed Hossein, and Dadin as subtropical areas and Khesht and Jareh as tropical areas. Therefore, their estimated data were taken as a whole and the statistical analyses were carried out once again.

According to the results, temperature followed a similar trend in the six villages under investigation. The trend of temperature up to 20 months after the observations was predicted using MA(2) model; the results are shown in Figure 2. Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) graphs for model fitness are displayed in Figure 3. The mean of temperature was 30 °C.

The trend of precipitation and its prediction up

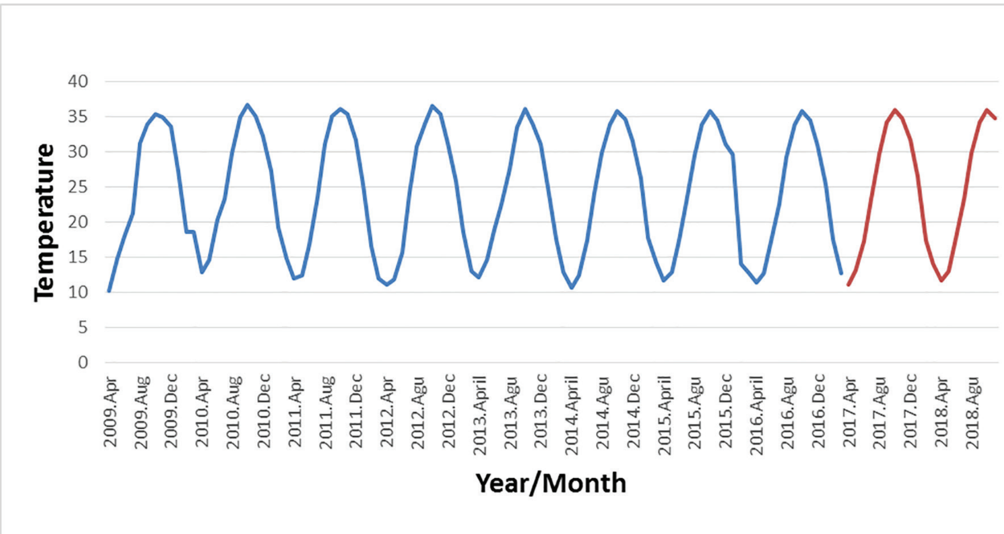

Figure 2: The trend of temperature and its prediction in the six study villages using MA(2) model

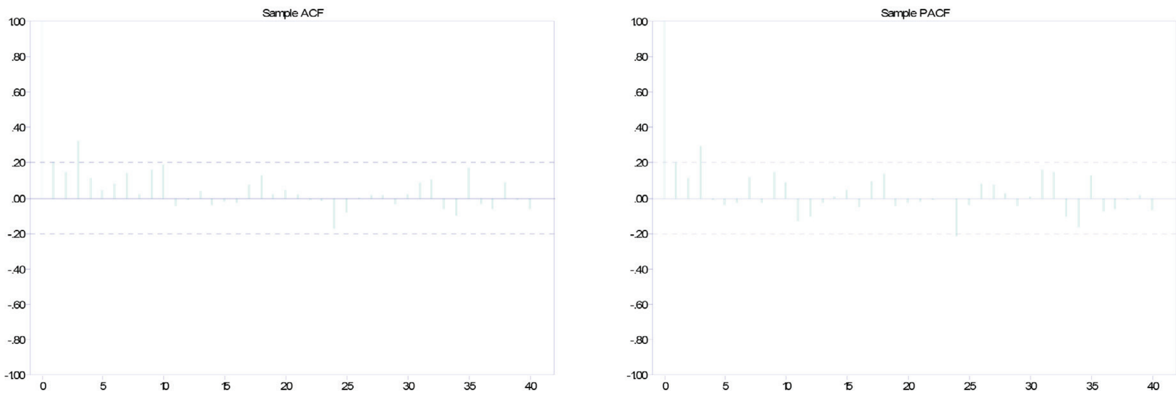

Figure 3: ACF and PACF graphs for determining the appropriateness of the model that fit the data

to 20 months after the observations in Jahad-Abad, Hakimbashi, Seyed Hossein, and Dadin using MA(4) model are shown in Figure 4. ACF and PACF graphs for determining the appropriateness of the model are presented in Figure 5. Considering the great fluctuations in the trend of precipitation, the results of the precipitation model could not be accredited.

The trend of *Anopheles* abundance in Jahad-Abad, Hakimbashi, Seyed Hossein, and Dadin and its prediction up to 20 months after the observations using ARMA(6,2) model are depicted in Figure 6. Accordingly, *Anopheles* abundance followed a descending trend in the above-mentioned villages, which can be justified by droughts, dryness of bogs and stagnant waters, climatic changes, and inappropriate conditions for *Anopheles* growth and development.

The trend of precipitation in Khesht and Jareh and its prediction up to 20 months after the observations using MA(6) model are shown in Figure 7. Due to the great fluctuations in the trend of precipitation in these two villages, the results of the precipitation model could not be trusted.

The trend of *Anopheles* abundance in Khesht and Jareh and its prediction up to 20 months after the observations using ARMA(1,1) model are shown in Figure 8. Accordingly, *Anopheles* abundance followed

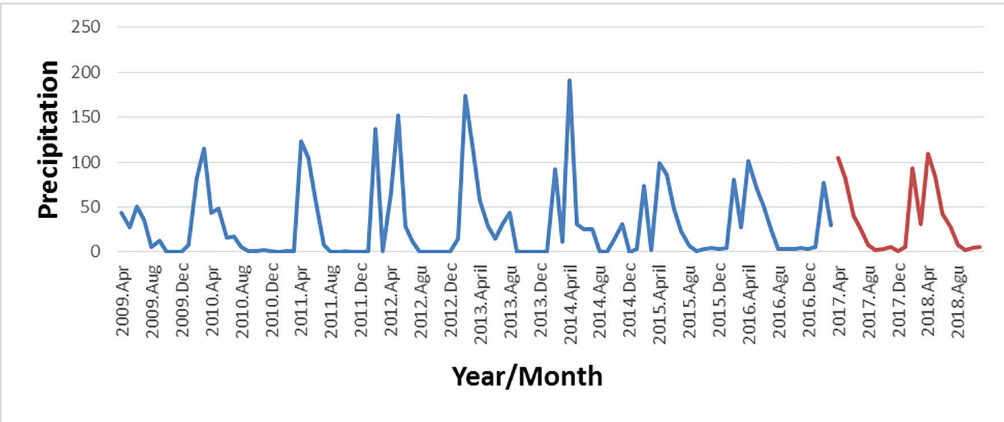

Figure 4: The trend of precipitation and its prediction in Jahad-Abad, Hakimbashi, Seyed Hossein, and Dadin using MA(4) model

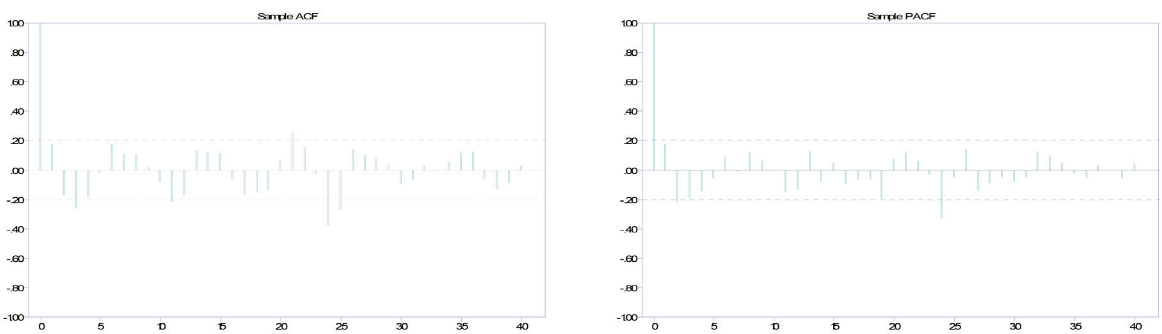

Figure 5: ACF and PACF graphs for determining the appropriateness of the model that fit the data

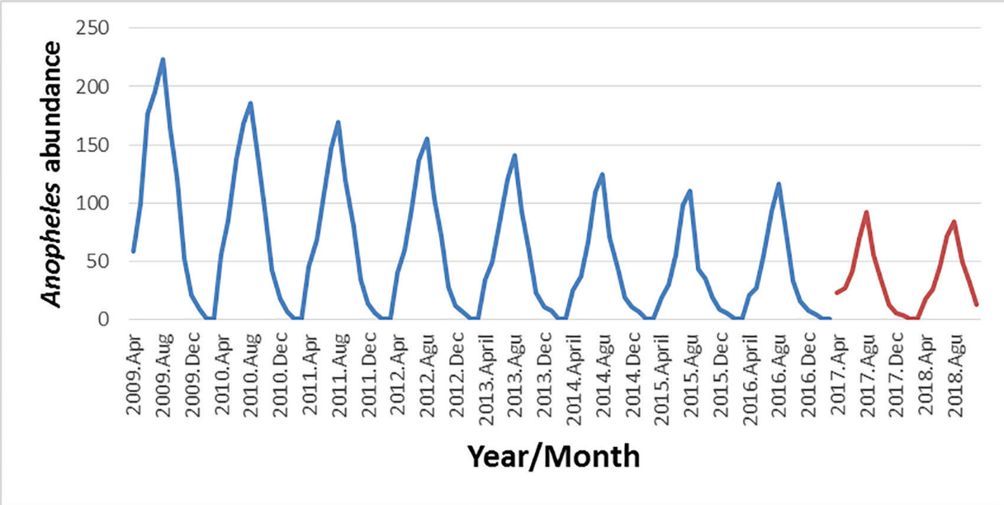

Figure 6: The trend of *Anopheles*abundance and its prediction in Jahad-Abad, Hakimbashi, Seyed Hossein, and Dadin using ARMA(6,2) model

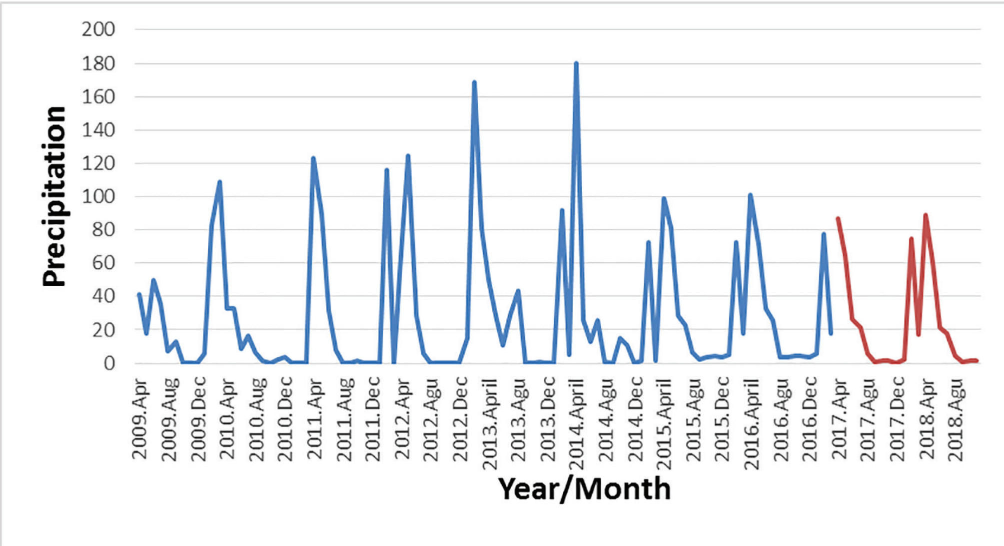

Figure 7: The trend of precipitation and its prediction in Khesht and Jareh using MA(6) model

a descending trend in these two villages, which can be attributed to droughts, dryness of bogs and stagnant waters, climatic changes, and inappropriate conditions for anopheles growth and development.

Discussion

IRS is among the measures taken to control and prevent malaria in Kazerun. Determining the proper time for effective spraying is one of the most important challenges in this regard. The present study was the first one to determine the appropriate time for residual spraying in order to control and prevent malaria in Kazerun using entomology, vector abundance, temperature, and precipitation data. Therefore, the results were compared to those of the studies which focused on the impact of temperature, precipitation, and humidity on the trend of malaria.

This study revealed the trend of precipitation in the villages under investigation and predicted it up to 20 months after the observations. Considering the great fluctuations in the trend of precipitation, the results of the precipitation model were not applied to determine the proper time of residual spraying for controlling and preventing malaria. Kipruto et al. reported that the prevalence of malaria conformed to precipitation alterations.[14] However, Mohammadkhani et al. and Ostovar et al. indicated no significant relationships between precipitation and the incidence of malaria in the modified model.[5, 15] This might be attributed to the recent droughts all over Iran, which have caused fluctuations in the trend of precipitation. Hence, the results obtained from the precipitation model could not be reliable.

In the present study, the trend of temperature was assessed and predicted up to 20 months after the observations. Based on the results, the mean of temperature was 30 °C. ACF and PACF graphs also confirmed the appropriateness of the model. In the research by Hajison et al., the number of malaria cases

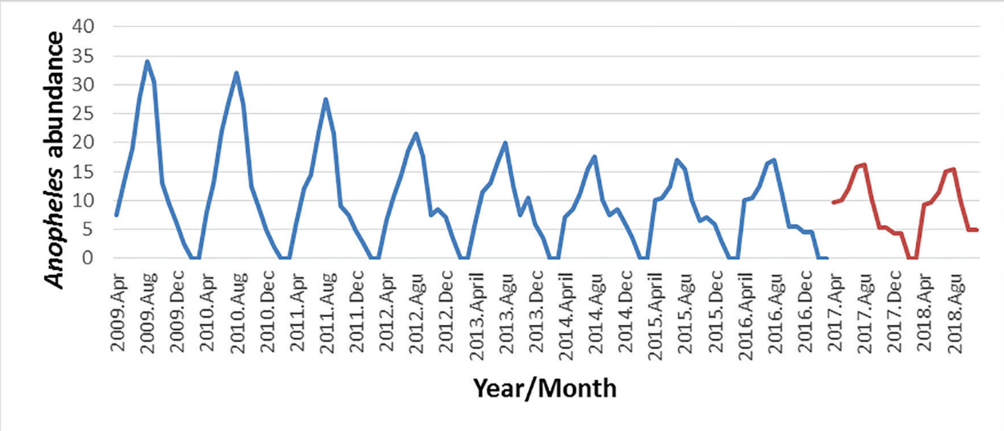

Figure 8: The trend of *Anopheles* abundance and its prediction in Khesht and Jareh using ARMA(1,1) model

increased with the increase in temperature. Indeed, the peak of malaria cases was detected at 24 °C.[16] Nath et al. also demonstrated a significant relationship between temperature and incidence of malaria.[17] Similar results were also obtained by Kiprutoet al. and Mohammadkhani et al., representing temperature as a constant determinant of malaria incidence.

Malaria is sensitive to climatic conditions. On the other hand, biological transmission of the disease is complexly associated with environmental conditions. In this context, the main restriction is the minimum temperature. Low temperatures prevent the development of parasites causing malaria and the *Anopheles* carrying them. The lowest threshold temperatures for survival of *Plasmodium Vivax* and *P. Falciparum* have been reported to be 18 and 15 °C, respectively.[18] In the current study, *Anopheles* abundance followed a descending trend in all study regions, which can be justified by droughts, dryness of bogs and stagnant waters, climatic changes, and inappropriate conditions for *Anopheles* growth and development. Generally, vector abundance is a key factor in the disease risk and is used in disease transmission modeling. Additionally, the risk of mosquito-borne diseases depends on the number of vectors per host. In this context, temperature plays a pivotal role in the rate of development of immature to mature mosquitoes.[19] Since the sexual cycle of *Anopheles* lasts for two weeks, residual spraying should be done two weeks prior to the peak *Anopheles* abundance.

Strong Points and Limitations of the Study

As the strength of the present study, it investigated the appropriate time for residual spraying for the first time. The study data were collected by trained specialists using the entomology program. However, the limitation of this study was the unavailability of the temperature and precipitation data for the study areas. Thus, interpolation of the temperature and precipitation at the study regions was done via kriging approach using ArcGIS software.

Conclusion

The study results indicated that based on temperature and entomology data, the best time to start residual spraying for controlling and preventing malaria was two weeks prior to the peak of *Anopheles* abundance at 25-30°C.Therefore,residual spraying should be started at this temperature range at any time of the year including March, April, May, and June. At this time, other control and prevention measures such as active case detection, timely treatment of patients, and public education should be intensified as well.

Suggestions

Climatic conditions are effective in development of mosquitoes, frequency of blood feeding, and disease transmission. Indeed, short-term climatic changes, such as temperature, humidity, and precipitation play important roles in malaria transmission.[7] Therefore, such information has to be recorded precisely in malaria endemic areas. Moreover, considering all climatic variables in prediction of the disease trend and determination of the time for initial control measures, such as residual spraying, in future studies will help achieve more reliable results. This study can be a guide for regions with similar conditions to determine the best time for residual spraying and apply more focus on the areas prone to malaria transmission.

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Conflict of Interest: None declared.

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