Climate and Health Journal

İklim ve Sağlık Dergisi / Climate and Health
Climatehealth 2021; 1(3):126-140

E-ISSN: 2757-8607
Başvuru / Received: 30.11.2021
Kabul / Acccepted: 10.12.2021

ARAŞTIRMA / RESEARCH ARTICLE

Prediction of Monthly Malaria Outbreaks in Districts of Odisha, India with Meteorological Parameters using Statistical and Artificial Neural Network Techniques

Pulak Guhathakurta[1] **Ram Ratan**[1] **Rajib Chattopadhyay**[1] **Deepa Kulkarni**[1] **Lalit S. Bile**[1] **Ashwini Prasad**[1]

1 Office of The Head, Climate Research & Services, India Meteorological Department, Pune, India, PUNE- 411005

Abstract

Malaria is a vector-borne disease spread by female Anopheles mosquitoes. This study provides the relationship between malaria and meteorological parameters over 10 districts in Odisha for the period 2012-2016. The complete life cycle of Plasmodium is dependent primarily on meteorological variables like rainfall, temperature, humidity. Rainfall increases the survival chances of mosquitoes by providing a habitat for the different development stages of mosquito larvae. Temperature and humidity affect the survival of Plasmodium and mosquitoes. Malaria cases peak in the monsoon season and decrease thereafter. The malaria cases have almost doubled over Odisha in 2014-2016 in comparison to 2012-2013. Minimum temperature (Tmin), Rainfall, and RH at noon show a significant maximum positive correlation with the malaria cases while the diurnal variations of temperature (DTR) and relative humidity are negatively correlated with the malaria cases. Almost all the peak occurrences of malaria are associated with the Tmin >20o C range. DTR of 6-8o C is associated with all of the peak malaria cases. The combination of all these meteorological variables decides the transmission of malaria at any place condition on the presence of Plasmodium in the vector mosquitoes. The malaria forecast models for different districts of Odisha are prepared using the relationship between meteorological parameters and malaria occurrence. The simple multiple linear regression and Artificial Neural Network (ANN) methods are applied for this purpose. The performance of ANN method is quite well compared to the multiple linear regression for almost all times. The RMSE range for Angul, Kandhamal, Mayurbhanj and Keonjhar for ANN methods is almost half compared to the Multiple linear regression methods. The lowest and highest RMSE in ANN method is 152 in Keonjhar and 268 in Mayurbhanj, while the multiple linear regression method, is 339 for Ganjam and 776 in Mayurbhanj. Also, the R-Square value is improved in ANN method compared to the Multiple linear regression methods. Plasmodium.

Keywords: Malaria Outbreaks, Climate Relationship, Prediction, Artificial Neural Network.

Bu makaleden şu şekilde alıntı yapınız / Cite this article as: *Guhathakurta P, Ratan R, Chattopadhyay R, Kulkarni D, Bile LS, Prasad A. Prediction of monthly malaria outbreaks in districts of Odisha, India with meteorological parameters using statistical and artificial neural network techniques. Climatehealth. 2021;1(3):126-140*

Sorumlu Yazar / Corresponding Author:
Pulak Guhathakurta , Office of The Head, Climate Research & Services,
India Meteorological Department, Pune, India, PUNE- 411005
E-mail:

1. INTRODUCTION

Malaria is a life-threatening disease which is prevalent in Africa and southeast Asia. Africa contributes 90 % of the total global malaria cases and the rest is carried by southeast Asian countries. India contributes to 88% of malaria cases and 86 % of deaths in the South-East Asia region in 2019 (World Malaria Report, 2020). India reports a significant decline in Malaria cases from 20 million in 2000 to 5.6 million in 2019 (World Malaria Report, 2020). Jharkhand, Odisha, West Bengal, Andhra Pradesh states are severely affected by Malaria in India (NCMH report 2005).

Malaria was called a rural disease because it was mostly present in rural parts of India where cleanliness and hygiene are not maintained Malaria is caused by protozoan parasites *Plasmodium*, which has 5 main species worldwide, *Plasmodium vivax*, *P. falciparum, P. malariae, P. ovale and P. knowlesi*. Malaria parasite completes its life cycle in two hosts, first part in mosquito and second part in human. Only female mosquito bites and male mosquitoes usually survive on flowers. The female mosquitoes require blood during the development stage of their eggs. The *Plasmodium*-infected, female Anopheles mosquitoes transfer these parasites into the human body by biting a human. In Africa, 99% of malaria cases are caused by *P. falciparum but* in India *P. falciparum* and *P. Vivax* are almost equally responsible for Malaria transmission (World Malaria Report, 2020). *Anopheles culicifacies* is primarily accountable for transmission of malaria in rural parts and *An. stephensi* in urban parts while *An. fluviatilis* for hilly and foothills region in India (Kumar et. al.,2007). The female *Anopheles* mosquito lays its eggs in clean water, collected primarily by rain or other sources. The climate relationship with malaria outbreaks has already been studied by many researchers. Lingala (2018), Lingala et al. (2020) have established a statistical relationship with rainfall for Plasmodium falciparum malaria outbreaks in India.

1.1. Study Area

Vector born disease like malaria, dengue is a major concern for many of the states in India. Odisha is also worst affected by malaria and it's was also called the "Malaria Capital" of India because of the frequent outbreaks of Malaria. Odisha state is situated on the Eastern coast of India at the latitudinal and longitudinal location between 17.49'N and 22.34'N and 81.27'E and 87.29'E (2,3). It constitutes an area of 155,707 km^2 which accounts for 4.87% of total Indian land with a population of 41,974,218. Odisha has total of 30 districts, which contain 4 meteorological subdivisions. Eastern parts of Odisha are situated on the Bay of Bengal Coast The neighboring states of Odisha are Jharkhand and West Bengal towards the north, Chhattisgarh to West and Andhra Pradesh to the south. Based on topographical and morphological characteristics Odisha is divided into 5 major zones namely, coastal plains on the Eastern side, middle mountains and high land region, which covers three fourth part of the state, the central plateau region, the western rolling hills and the flood plain. Odisha has 10 major rivers system like Mahanadi, Brahmani, Baitarani, Subarnarekha, Budhabalanga etc. Many of these rivers have catchments inside Odisha (Budhabalanga, the Baitarani) and many originate outside Odisha like Subarnarekha, the Brahmani and the Mahanadi, etc. Odisha receives maximum rainfall in the monsoon season June through September. More details about Odisha can be obtained from http://magazines.odisha.gov.in/orissaannualreference/2014/ORA-2014.htm.

Many parts of Odisha are endemic to malaria. Malaria causes a major burden on the state because the economically productive population is worst affected by this disease. It reduces the effective working hours of the working population (Kumar et. al.,2007). Children and pregnant women are worst affected by Malaria. It causes anemia, low birth rate, abortion in pregnant women and children below age 5 has high mortality due to malaria. The percentage of death below 5 years is 67% in 2019, all over the world (World Malaria Report, 2020). It also affects the economic aspects of daily wage workers. Shivlal (1996), reported that every 1 rupee spend in malaria control yields 19.70 rupees in return profit.

This study primarily focuses on the malaria outbreak over Odisha and the relationship between malaria transmission and meteorological variables. The aim and scope of this report are to quantify the relationship between meteorological parameters and malaria occurrences and thereby use these relationships for the development of monthly forecast models of malaria outbreaks using meteorological parameters and present month malaria cases for the coming months. The ten districts of Odisha considered for the study are shown in fig. 3.

2. DATA DESCRIPTION AND METHODOLOGY

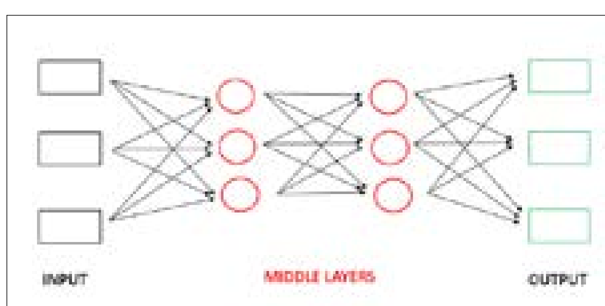
The malaria disease data used in this study is obtained from the health department, Government of Odisha. This data reports the monthly occurrences of malaria cases over Odisha for the period 2012-2016, i.e., for 5 years. We have considered 10 districts out of 30 total districts over Odisha viz. Angul, Kandhamal, Ganjam, Mayurbhanj, Keonjhar, Balasore, Bhadrak, Cuttack, Khurda and Puri. However, this data didn't provide the information regarding individual cases that occurred by *P. falciparum and P. vivax*.

Since India Meteorological Department is already generating a monthly forecast of meteorological parameters with reasonable accuracy, these meteorological forecast data can be used to generate real-time malaria outbreak monthly forecasts. These different meteorological variables like temperature, Relative Humidity (RH) and rainfall are compared with the reported Malaria cases over Odisha. The observed meteorological data is obtained from the India Meteorological Department over these 10 districts. The meteorological variables used in the study are temperature, relative humidity, rainfall, mean temperature (Tmean), mean relative humidity (RHmean), diurnal variabilities of RH (DRH) and temperature (DTR). Daily 03:00 and 12:00 hours UTC observations data of RH and temperature are used for computation of Tmean and RHmean by taking the average of Tmin and daily maximum temperature (Tmax) values and RH at 03:00 and 12:00 hrs for daily for both these variables. The Diurnal Variability of Temperature, DTR is calculated by taking the difference between Tmax and Tmin. Diurnal Variability of Relative Humidity, DRH is calculated using the difference between RH 03:00 and RH 12:00 hrs. The relative humidity is highest at 03:00 hrs. and it is lowest at 12:00 hrs. because high temperature in the afternoon hours expands the air and reduces the RH. Since malaria data is on a monthly scale, we have also converted all the meteorological variables into a monthly scale for easy comparison.

The spatial pattern of malaria occurrences for monthly and yearly scales is looked upon using the malaria occurrence data. Pearson correlation between meteorological variables like temperature, RH, precipitation and malaria occurrences for each district separately as well as combined for all districts is also looked upon. The Bivariate histogram between meteorological variables and malaria occurrences is also analyzed for these variables separately. The only variables having a significant relationship with the malaria occurrences are used as a predictor for the malaria forecast. After carefully investigating the relationship using the above-mentioned methods, a Malaria forecast for these districts of Odisha is prepared.

We apply two methods, viz. simple Multiple linear regression and Artificial Neural Network to forecast of malaria. The predicted malaria cases from both these methods i.e., Multiple linear regression and Artificial Neural Networks methods are compared to see the differences. Multiple linear regression is used to establish the relationship between independent variables and one dependent variable. In this case, the meteorological variables are independent variables and malaria cases are the dependent variable. The artificial Neural Network method has one input layer and one output layer in-between the middle or hidden layer/ layers which is sandwiched between input and output layers as reported in figure 1. The input layer receives the input, the middle layer does the processing work and the output layer provides the output results. More details about the ANN can be obtained from Hornik et al., 1988, Fisher et al, 1994, Guhathakurta et al., 2008, Guhathakurta, 2013. The training algorithm used is Output Weight Optimization - Hidden Weight Optimization (Guhathakurta, 2013). The Output Weight Optimization - Hidden Weight Optimization (OWO-HWO) method was introduced by Chen et al. (1999) and then modified by Yu and Manry (2002) to train the neural network. They have shown that the OWO-HWO method is superior in terms of convergence to standard OWO-BP (output weight optimization-back propagation) which uses OWO to update output weights and backpropagation to update hidden weights.

Figure 1: Graphical representation of Artificial Neural Network model with 2 hidden units (middle layer).



3. RESULTS AND DISCUSSION

The spread of malaria is determined by many factors like climatic, seasonal, ecological, environmental, social and economic factors. The combination of these factors determines the transmission and intensity of malaria at any location. Population immunity, household conditions, mosquito control measures and topography also play important role in the malaria outbreak. The female mosquito life span is usually one month but it does not live longer than 1-2 weeks. In the optimum climatic condition's malaria transmission increases and it turns out to be a malaria outbreak

3.1 Spatial pattern of Malaria over Odisha

Figure 2 represents the spatial pattern of monthly occurrences of malaria cases for all 10 districts over Odisha. It also shows the geographical locations of all these 10 districts over Odisha. Coastal districts have fewer malaria cases throughout the year compared to the central districts. Kandhamal. Angul, Mayurbhanj and Keonjhar are the four worst-affected districts by malaria in Odisha among the 10 districts considered. Malaria cases are low in the starting months from January to April, and it increases in the monsoon season. The highest cases come from the month of July and it decreases thereafter till December. The occurrence of malaria cases also depends upon the presence of *Plasmodium* in vectors, mosquitoes biting frequency etc.

Figure 2: Monthly Mean Malaria cases in different district over Odisha for the period 2012-2016. (Higher number of cases can be clearly noticed in June through September in Monsoon months in compare to pre and post monsoon months).

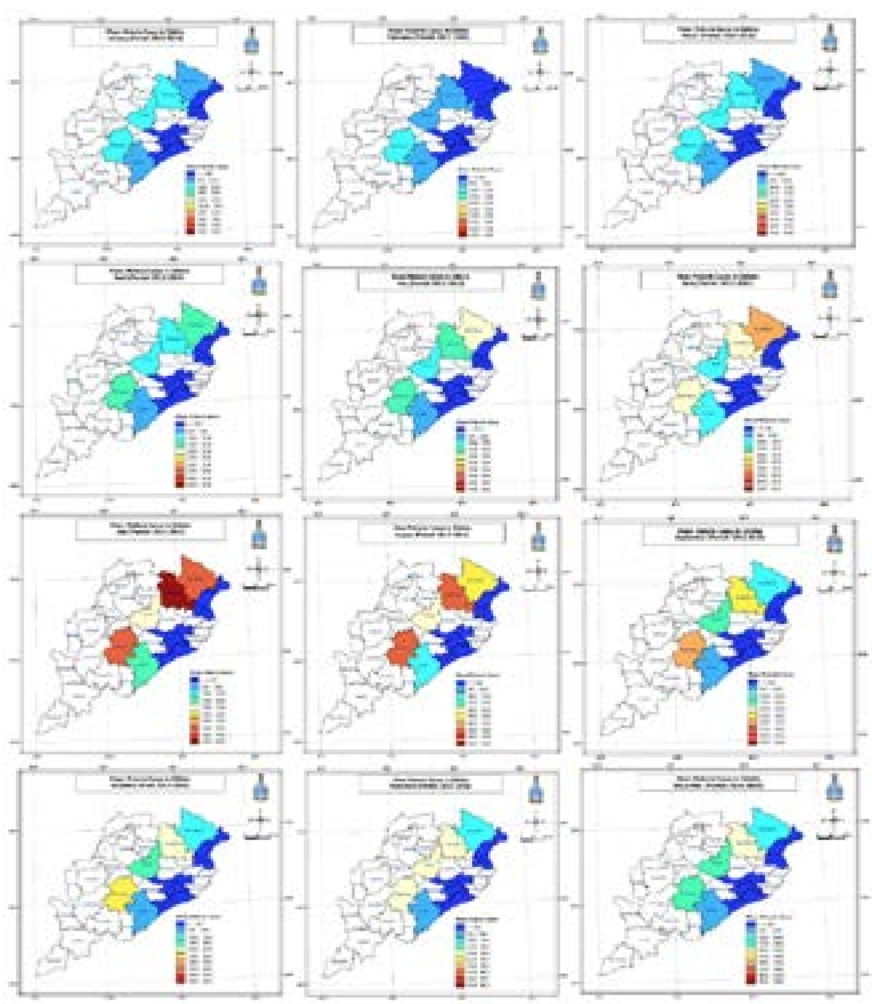
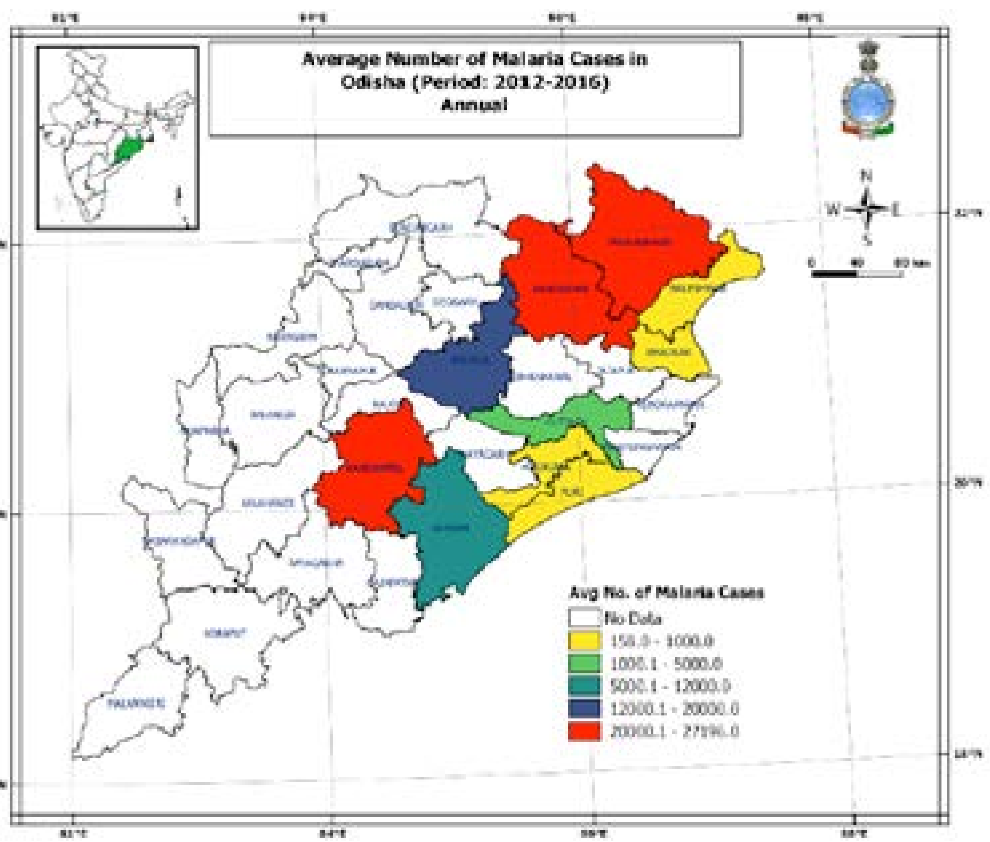


Figure 3 shows the spatial pattern of mean annual malaria cases for the period of 2012-2016. It provides the yearly number of malaria cases over Odisha for the combined five years period. The maximum number of malaria cases reported primarily comes from Kandhamal, Angul, Mayurbhanj and Keonjhar which is consistent with figure 2.

Figure 3: Mean yearly occurrences of malaria cases reported over different districts over Odisha for the period 2012-2016, with highlighting the location of Odisha in India (in green) at the top left corner.



3.2 Temporal Pattern of Malaria Occurrences over Odisha

The time series of malaria cases for all 10 districts combined is shown in figure 4. Firstly, the spike in malaria cases can be noticed in the monsoon season over all the years, which clearly indicates that the number of malaria cases is always high for the monsoon months for all these years. Also, Malaria cases have increased in the later years especially 2014 to 2016 compared to previous years. In the later years (2014-2016), around 15000-20000 cases/year can be noticed in each month of monsoon season. It gives a strong linkage between monsoon season and malaria occurrence. The separate time series for each district's malaria occurrences are also analyzed and reported in figure 5. The inter-annual variability of the malaria occurrences varies from district to district, depending on the availability of parasites and climatic conditions. We have pooled these districts into two groups firstly where the yearly number of malaria cases is < 5000 and other where malaria cases are > 5000. Those districts where malaria cases are relatively high are pooled into figure 5a and the remaining districts into another pool in figure 5b. The peak in malaria cases in the monsoon months is still evident in each of the panels. Also noticed that the higher number of malaria cases in figure 4 in the later year (2014-2016) comes from the increased number of cases in figure 5a, i.e., from Angul, Kandhamal, Ganjam, Mayurbhanj and Keonjhar districts. Because there is very little increase in malaria cases from other districts in figure 5b. Also noticed that the order of the magnitude of the Y scale in figure 5a is several times high compare to figure 5b. The black dotted line in Figures 5a and 5b is the mean of the curve for all the districts in each panel.

Figure 4: Timeseries of occurrences of malaria cases for all 10 districts combined for the period 2012-2016.

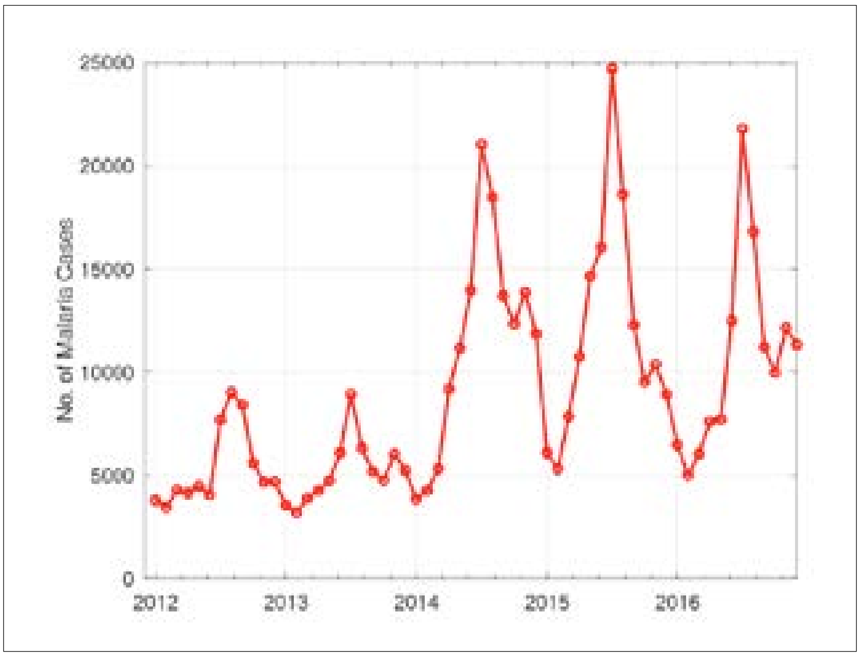
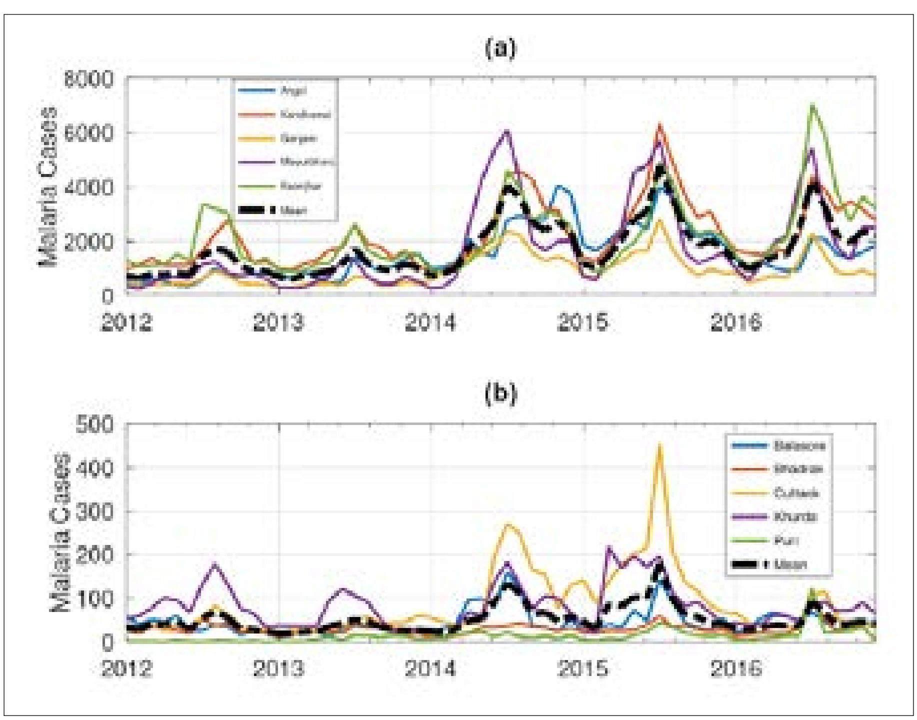


Figure 5: Timeseries of monthly occurrences of malaria cases for each district separately for the period 2012-2016 (a) District with higher number of malaria cases and (b) Districts with lower number of malaria cases. The black solid line is the mean of all curves in the panel.

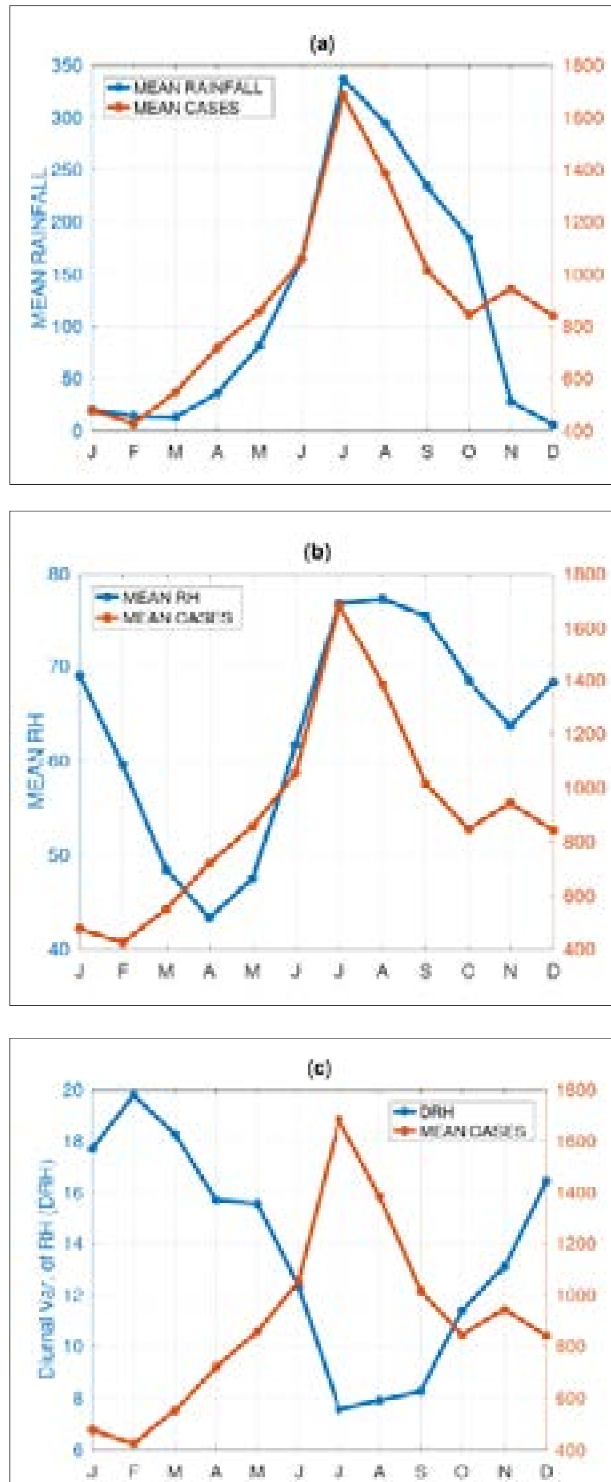


3.3 Relationship between malaria and meteorological parameters

Three important meteorological parameters which affect the malaria outbreak are rainfall, temperature and relative humidity. The combination of these three parameters defines the malaria dynamics at any place. Rainfall provides enough freshwater supply which gives an ideal breeding place for mosquitoes and the growth of mosquitoes larvae. The rainfall increases the relative humidity which gives the optimum environment for the development of *Plasmodium* parasite into mosquito's body and also increases the mosquito survival chances. Heavy rain sometimes destroys the breeding places of mosquitoes and flushes out the mosquitoes. Temperature predominantly affects the life cycle of parasites and mosquitoes by changing the survival rate of both parasites and mosquitoes. An increase in temperature increases the digestion process of blood meal in mosquitoes and also increases the biting rate of mosquitoes. The increase in mosquito biting rate increases the malaria transmission speed. 90% of mosquito survival range is between the temperature range of 16° - 36° Celsius. Above and below this range the mosquito survival decreases. 60% RH with a temperature range of 20° -30° C is optimum for the survival of mosquitoes (Bruce-Chwatt, 1980).

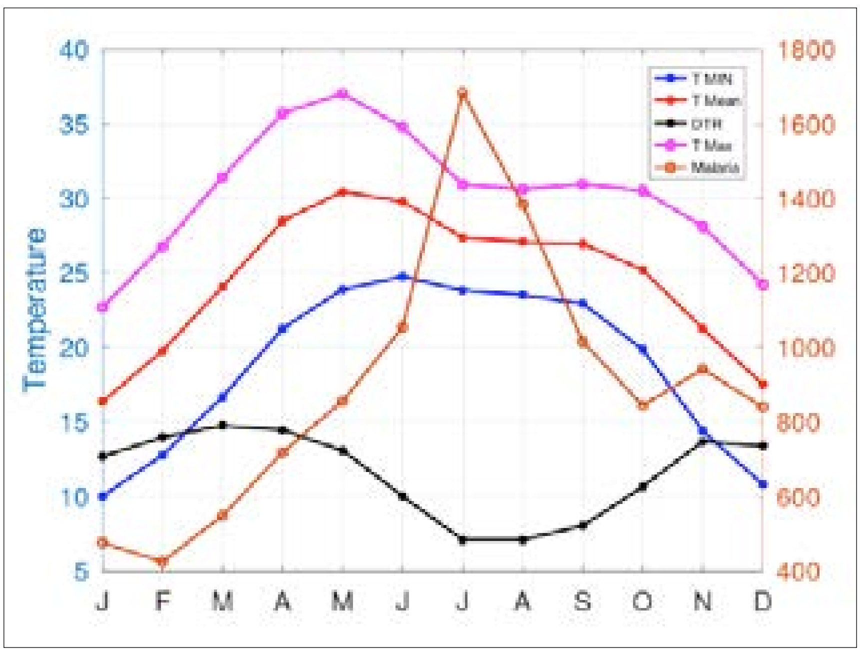
The positive relationship between (i) mean rainfall and malaria cases and (ii) mean RH and malaria cases can be clearly depicted in Figures 6(a) and (b). The monthly mean rainfall and monthly mean RH is calculated using monthly rain and monthly RH values overall 10 districts. The number of malaria cases increases with the increase in the mean rainfall as well as the increase in mean RH. In the pre-monsoon months when mean rainfall and mean RH is less the number of malaria cases is low. The malaria cases start increasing with the start of monsoon season and it peaks in July and then starts decreasing thereafter (see figure 6a and b). The Pearson correlation between mean rainfall and mean RH with malaria cases is 0.87 and 0.57 respectively with 95 % confidence level. The Diurnal Variation of RH (DRH) shows an interesting pattern as reported in figure 6(c) and it is always in the opposite phase with the number of malaria cases. DRH starts decreasing from January and lowest in July for the whole of the monsoon season and then increases thereafter. The malaria cases are opposite of DRH and increase till July and then decrease thereafter.

Figure 6: Relationship between different Meteorological variables and number of Malaria Cases for (a) Monthly mean Rainfall and number of malaria case (b) Mean RH and Mean number of Cases (b) between DRH (Diurnal Variation of RH) and Mean number of malaria case.



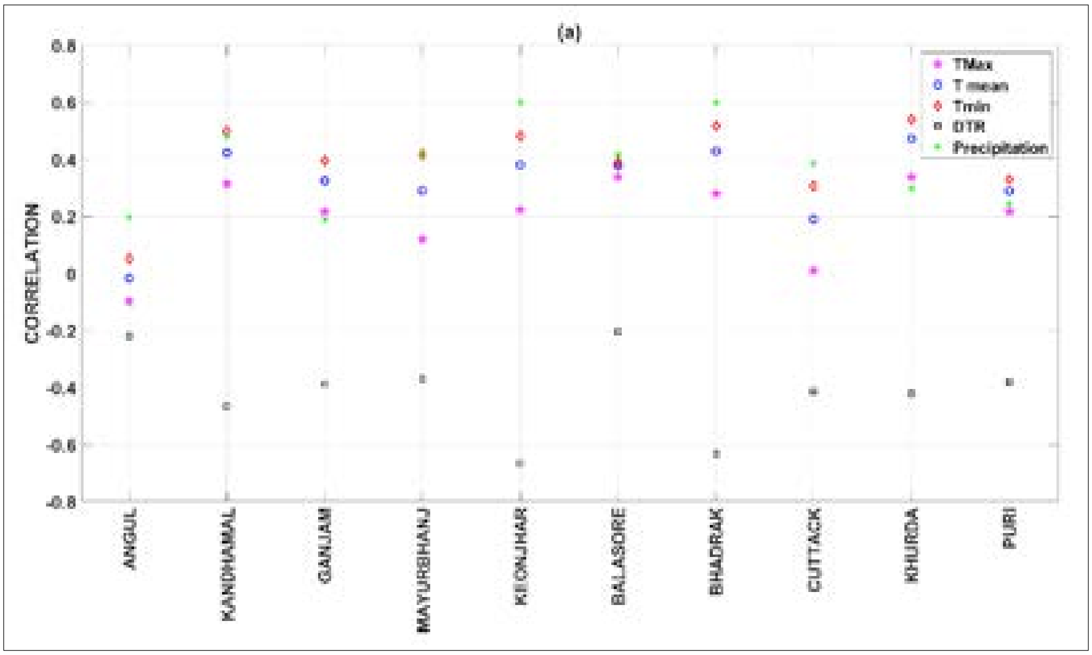
The Relationship between temperature-related variables like Tmin, Tmax, Tmean and DTR, with malaria cases is also analyzed as reported in figure 7. All the variables are on monthly scale as reported in the previous discussion in figure 6. Tmax, Tmin and Tmean increase till June and then decrease thereafter till December. It clearly shows that as the monsoon progresses the difference between Tmax and Tmin i.e., DTR reduces and it is lowest in the JJAS season because frequent rainfall episode reduces the difference between Tmax and Tmin. Interestingly the DTR and malaria cases are in opposite phases so, as the monsoon progresses the DTR goes down and malaria cases increase till the end of monsoon. The Pearson correlation between DTR and malaria cases is -0.89. The relationship between malaria occurrences with RH and temperature is also analyzed by various other studies (Paaijmans et. al., 2010, Lingla 2018). They also reported higher positive dependence of Tmin and rainfall with Malaria transmission.

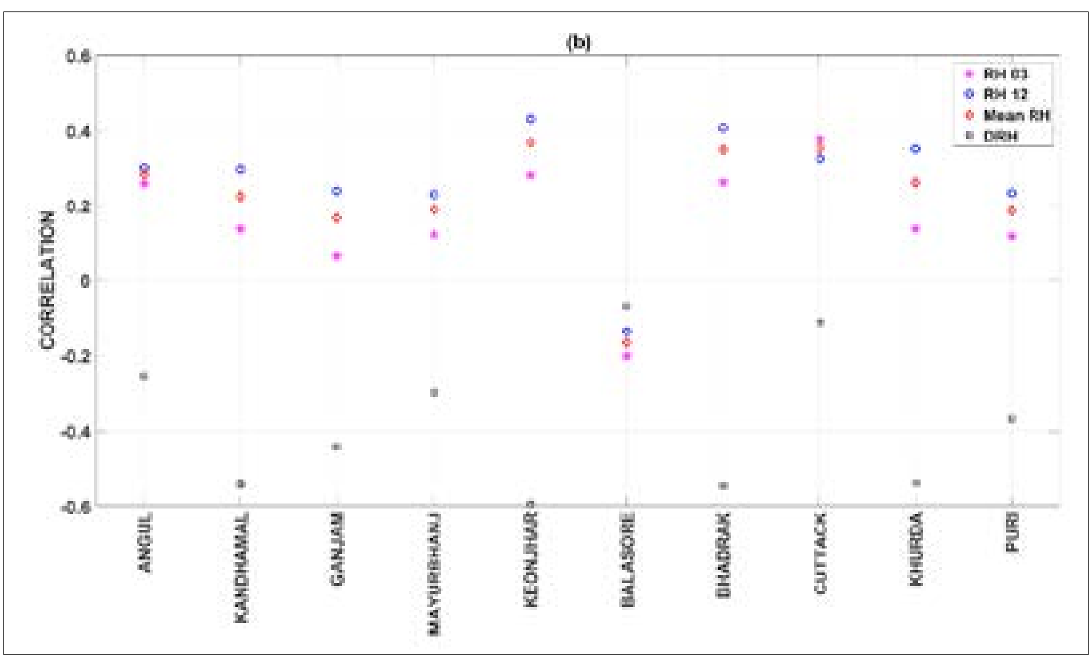
Figure 7: Monthly variation of Temperature (Tmax, Tmin, Tmean and Diurnal Temperature) with the Number of Malaria Cases.



So far, the analysis of meteorological variables and malaria cases is combined for all 10 districts of Odisha. The variation of these variables for each of the districts is also looked for the temperature-related variables (Tmin, Tmax, Tmean, DTR) and rainfall with malaria occurrences as shown in figure 8(a) and RH variables (RH at 03:00 UTC (RH03), RH at 12:00 UTC (RH12), Mean RH and DRH) with the number of malaria cases in figure 8(b). Tmin, Rainfall and RH12 show maximum and positive correlation with the malaria cases for all the districts as shown in figure 8(a) and (b). All these correlation values are significant with 95% confidence.

Figure 8: Correlation between different meteorological variables and the number of malaria cases for different districts over Odisha for (a) Temperature (Tmax, Tmin, Tmean and Diurnal Temperature) and precipitation vs malaria cases and (b) Relative humidity (at 03:00, 1200, mean RH and DRH) with malaria cases.

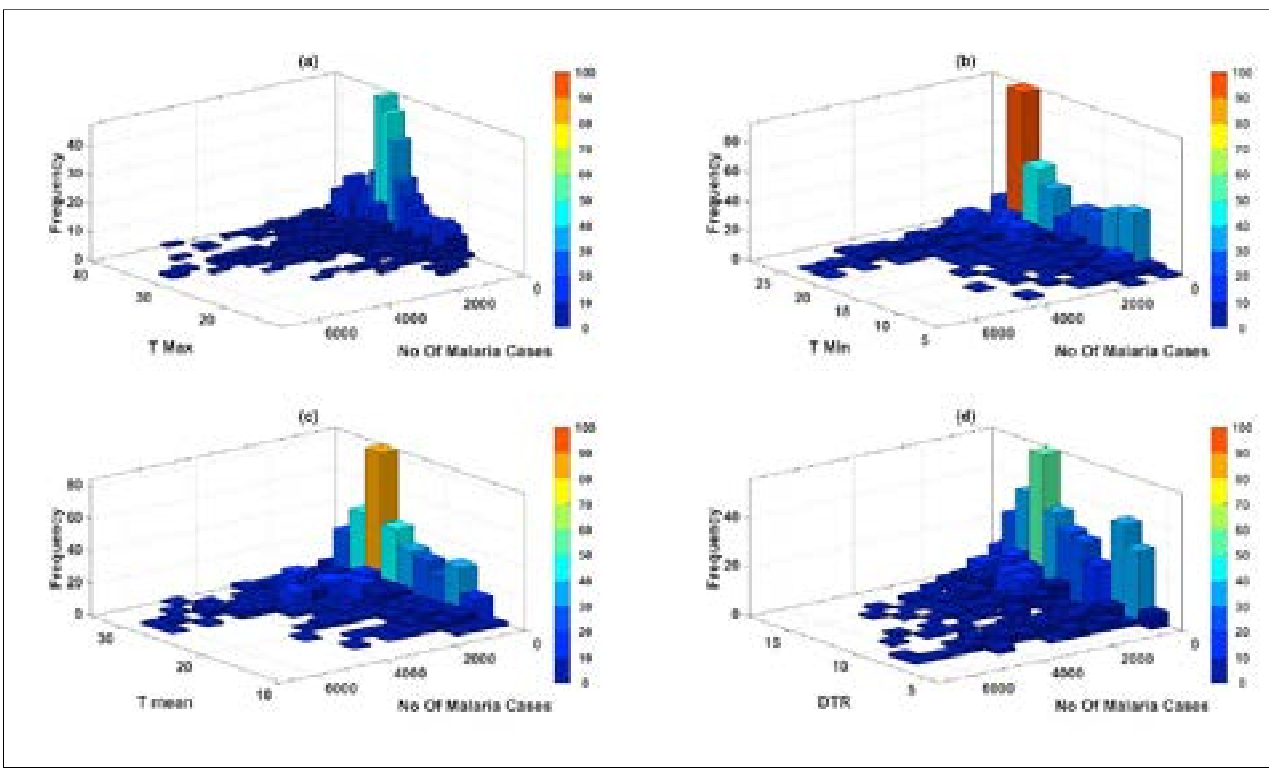




The positive relationship between rainfall and Malaria occurrences is already established. As expected, rainfall episodes lower the DTR and DRH. Since these quantities are negatively correlated with the rainfall and are in the opposite phase with rainfall. So DTR and DTH are also negatively correlated with the number of malaria cases.

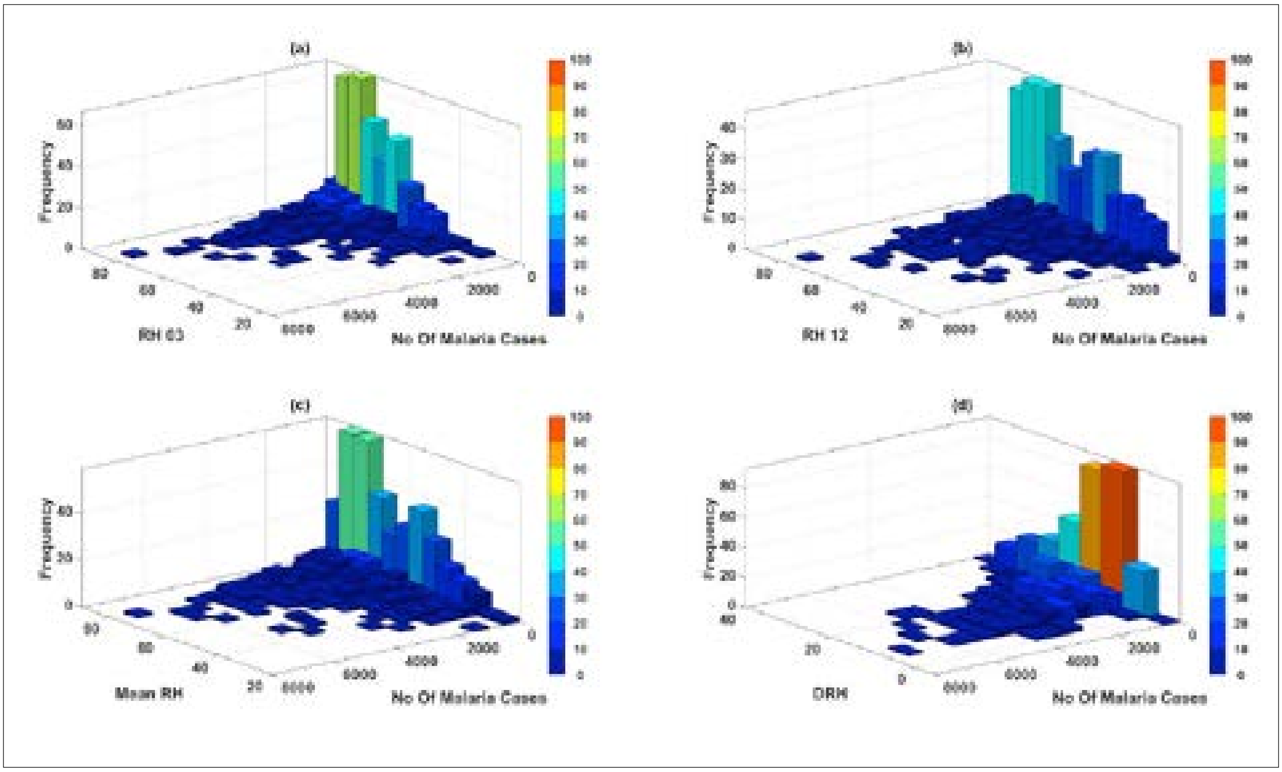
Figure 9 depicts the Bivariate histogram of different temperature variables like Tmax, Tmin, Tmean and DTR with the malaria cases. These are 3d histogram where X and Y planes show the two variables distributed in different bin size and Z axis show the frequency. The probability of transmission of malaria with different ranges of Tmax and Tmin is clearly visible here. The peak malaria cases also coincide with a higher limit of Tmax, in the optimum temperature range of 20^{o}-25^{o} C as shown in figure 9a. All the peak malaria cases (>4000) are associated with Tmin >20^{o} and as Tmin crosses the 20^{o} C limit malaria cases jump up to the range of 4000 to 8000 cases as shown in figure 9b. There are no >4000 malaria cases below the Tmin 20^{o} C threshold. Peak malaria cases with low frequency are also very severe because 3 frequency of 7000 malaria cases will give 21000 cases, which is very high in magnitude. The Bivariate histogram of Tmean and malaria cases also follow the same pattern as Tmin, with peak cases associated with the Tmean range of >25^{o} C as reported in figure 9c. The range of The Bivariate histogram of DTR vs malaria occurrences shows that the maximum occurrences of malaria cases are associated with the low DTR range between 5-15^{o} C. All Peak malaria cases are primarily associated with the lower value of DTR in the range of 6-8^{o} C, these lower range of DTR are mainly caused by frequent rainfall episodes.

Figure 9: Bivariate Histogram between (a) Tmax. (b) Tmin. (c) Mean Temp.(d) DTR i.e., Diurnal variations of temperature with the number of malaria cases for the period 2012-2016.



The Bivariate histogram of malaria cases and Relative Humidity variables like RH03, RH12, Mean RH and DRH are also looked upon and shown in figure 9. The comparison between RH03 and RH12 shows that the malaria occurrences have higher preferences for higher RH03 values but opposite in RH12, where preferences shifted toward lower values of RH12 as reported in figure 9a and b. Malaria occurrences have a higher correlation with the RH12 than compared to RH03 as reported in the discussion in figure 8. Mean RH and RH03 show similar behavior with the malaria occurrences. The behavior of DRH is similar to DTR with maximum occurrences of malaria associated with the lower value of DRH and DTR.

Figure 10: Bivariate Histogram between (a) RH03 (b) RH12 (c) Mean RH and (d) DRH i.e., Diurnal variations of RH with the number of malaria cases for the period 2012-2016.



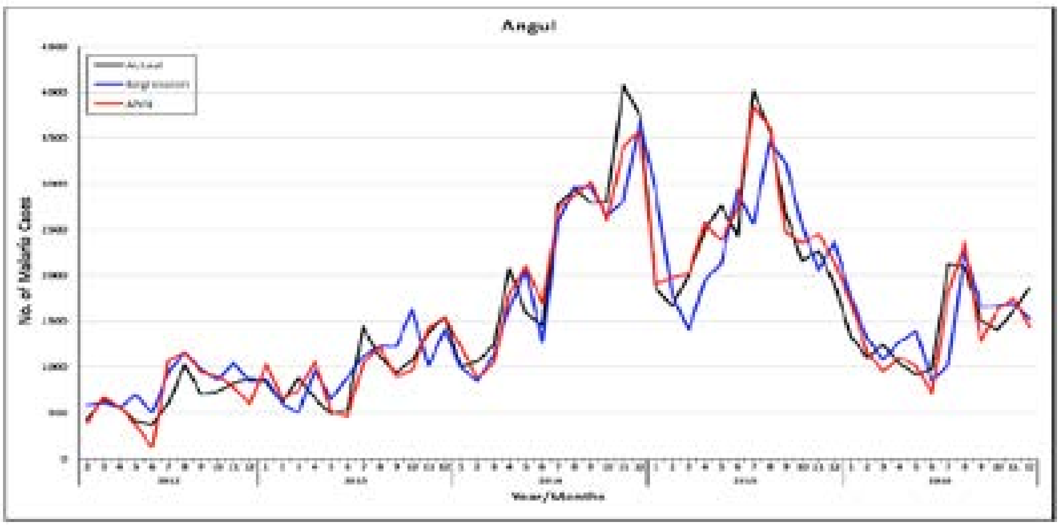
3.4 Prediction of Malaria outbreaks over Odisha

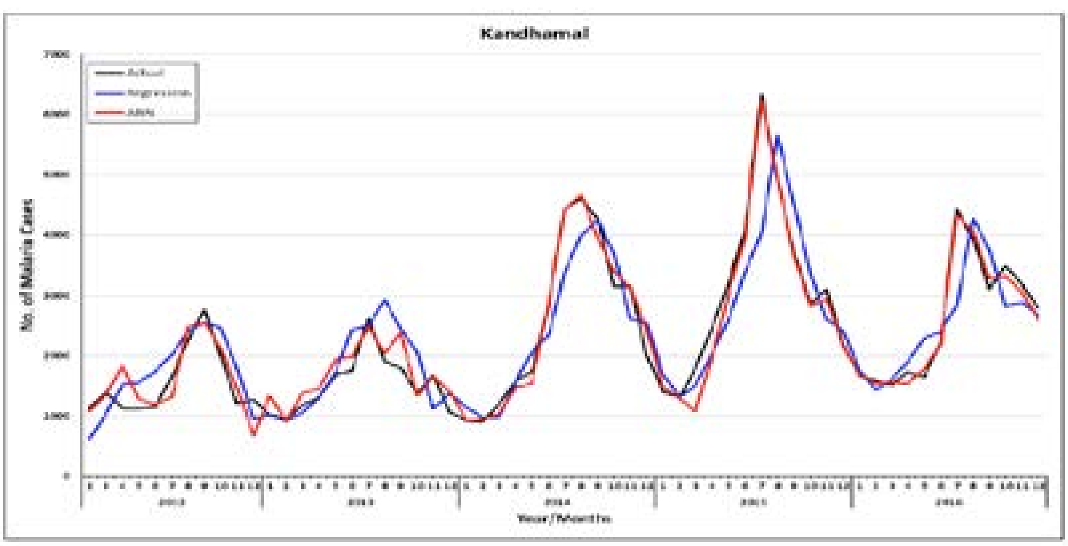
Based on preliminary analysis, it is found that the occurrence of malaria cases shows higher dependency on many meteorological variables. As already mentioned malaria has a high significant correlation with precipitation, Tmin, RH12, DTR, DRH etc. Based on this information total of 7 predictors are selected and used to forecast the malaria cases over different districts over Odisha. These selected predictors are as follows

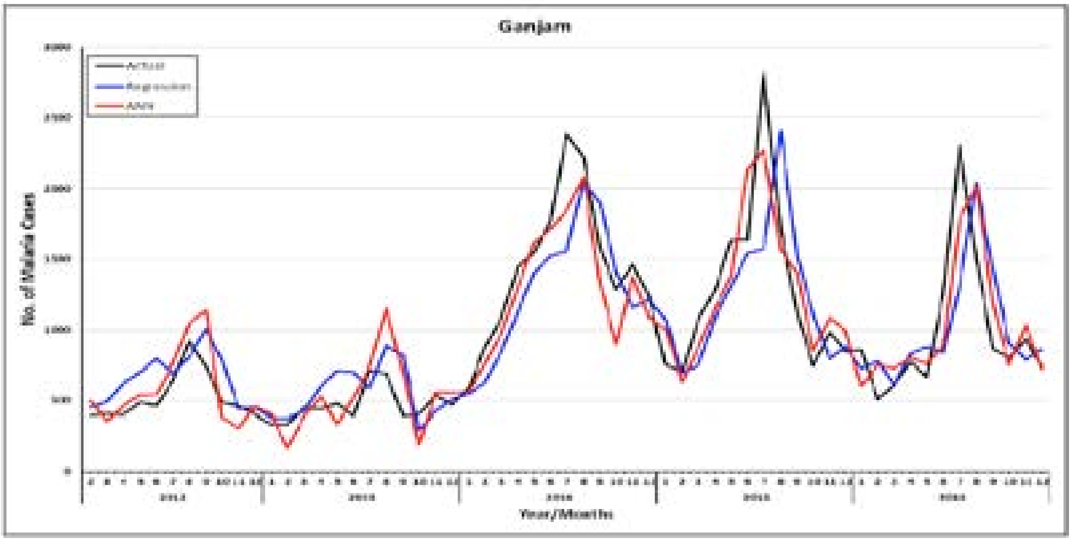
1. Tmin,
2. Rainfall,
3. Diurnal variation of temperature (DTR),
4. RH 12:00 hrs,
5. Diurnal variation of RH (DRH),
6. Previous month rainfall,
7. Previous month malaria cases,

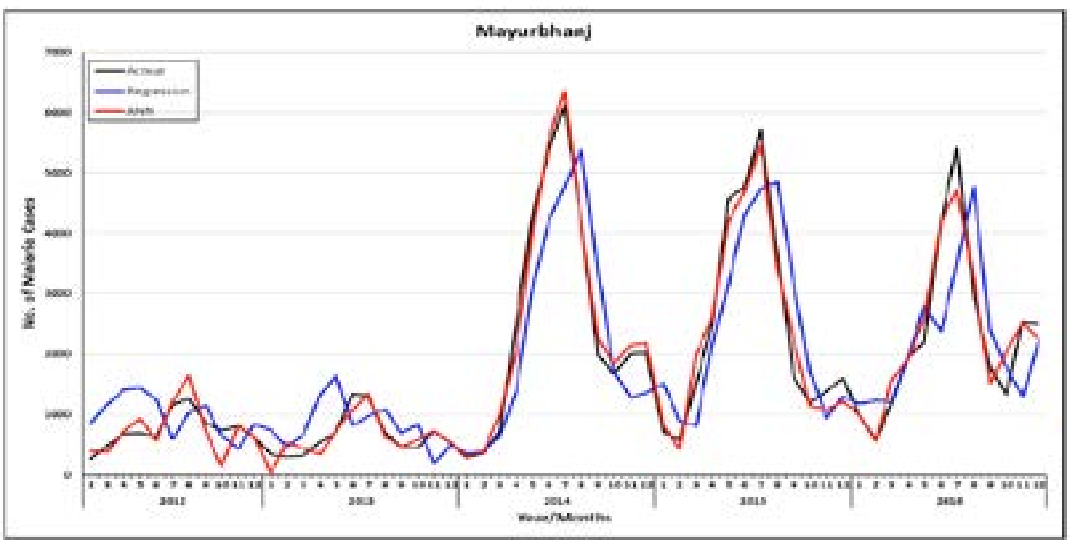
Peng et al, (2003) also reported monthly Tmin and monthly rainfall with one-month lag are significantly correlated for malaria transmission in Shuchan region in China. Nizamuddin et. al., (2013), used NOAA/ AVHRR satellite to construct weather data to forecast malaria epidemics over Tripura. Sudheer et al., (2014) used the support vector machine method to forecast the malaria cases over Jodhpur and Bikaner region. Simple multiple linear regression and Artificial Neural Network methods are used to forecast the malaria cases over the different districts of Odisha. In simple multiple linear regression, all 7 selected meteorological variables are used as predictors for the malaria forecast. The simple multiple linear regression model shows a good relationship to forecast malaria occurrences. The Artificial Neural Network method performs quite well for the malaria forecast. The district-level malaria forecast using Multiple linear regression and ANN methods is shown for 5 districts of Odisha in Figure 11. The peaks of malaria are very well captured by both these methods. The ANN forecast time series is very close to observations compared to the Multiple linear regression method. Root Mean Square Error Value and R Square value associated with both these methods are reported in Table 1. Table 2 gives the Artificial Neural Network Architectures for the forecast of Malaria occurrences over different districts over Odisha. ANN models are using fewer predictors than the multiple regression models. Table 1 indicates that the performance of ANN method is better than multiple linear regression methods. Root Mean Square Errors for all the districts are less than the standard deviation of the malaria cases in both multiple regression and ANN models and in ANN it is even less than half of the standard deviation. The Artificial Neural Network method can be quite effectively used to forecast the malaria case over different districts of Odisha.

Figure 11: Predicted values of Malaria cases for using multiple linear regression and Artificial Neural Network methods over (1) Angul and (2) Kandhamal (3) Ganjam, (4) Mayurbhanj and (5) Keonjhar districts of Odisha for the period 2012-2016.






Ganjam
Actual
Regression
ANN
No. of Malaria Cases
Year/Months


Mayurbhanj
Actual
Regression
ANN
No. of Malaria Cases

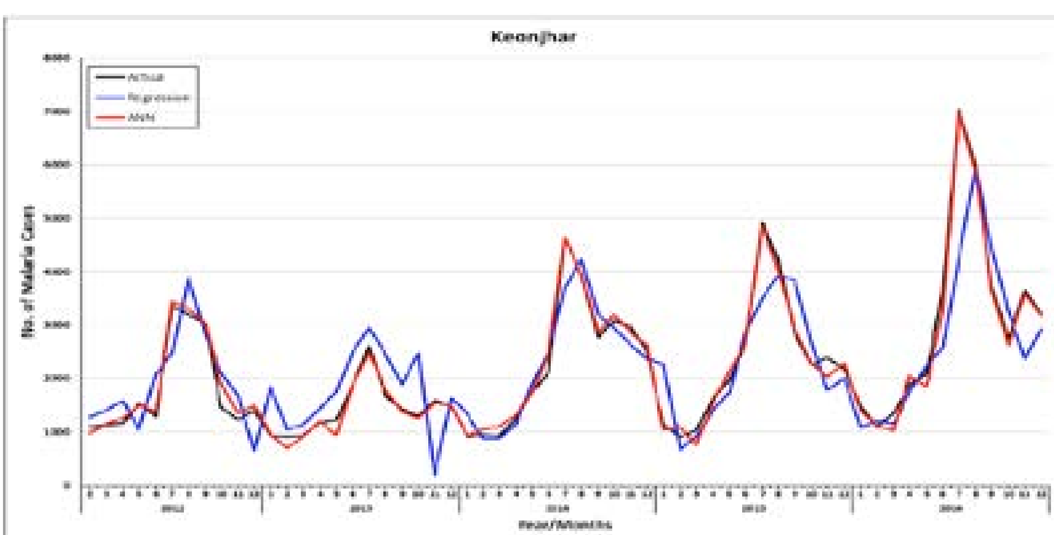

Keonjhar
Actual
Regression
ANN
No. of Malaria Cases

Table 1. Root Mean Square Error (RMSE) and R-Square value for Multiple Linear Regression and Artificial Neural Network models over different district over Odisha for the period 2012-2016.

Name of the District	RMSE (Normal Multiple linear regression)	RMSE (ANN)	R- Square (NORMAL)	R-Square (ANN)
Angul	430	237	0,79	0,93
Kandhamal	580	240	0,76	0,95
Ganjam	339	230	0,65	0,83
Mayurbhanj	802	268	0,73	0,97
Keonjhar	689	152	0,72	0,98

Table 2. Artificial Neural Network Architecture for the forecast of Malaria occurrences over different districts over Odisha.

S. No	Name of the District	Predictor Used	Number of Hidden Layers
1	Angul	Previous month Malaria cases, Previous Month Rainfall, Tmin, Rainfall, TDR, RH12, DRH	3
2	Kandhamal	Previous month Malaria cases, Tmin, Rainfall, TDR, RH12, DRH	4
3	Ganjam	Previous month Malaria cases, Tmin, Rainfall, TDR, RH12, DRH	6
4	Mayurbhanj	Previous month Malaria cases, Tmin, Rainfall, TDR, DRH, previous month rainfall	6
5	Keonjhar	Previous month Malaria cases, Tmin, Rainfall, TDR, RH12, DRH	6

4. CONCLUSIONS

Odisha is worst affected by malaria for a long time and the maximum load of malaria cases in India comes from Odisha state. The climatic, seasonal, ecological, environmental, social, and economic factors also regulate the transmission of malaria at a place. In this study, five years of malaria cases over 10 districts of Odisha for the period 2012-2016 is used to analyze and compare the relationship between meteorological variables and malaria cases. Meteorological parameters like temperature, precipitation and RH are used to quantify the relationship between malaria occurrences and meteorological variables. It is found that Kandhamal, Keonjhar and Mayurbhanj are the worst affected districts of Odisha, where more than 1 lac malaria cases are reported in a year. Malaria cases peaks in the monsoon months because monsoon seasonal provide enough water and moisture, which provide an ideal environment for the growth of mosquitoes as well as *Plasmodium* parasite. Mosquitoes transfer the *Plasmodium* parasite into the human body when it bites for a blood meal. *P. falciparum* and *P. vivax* are the main species responsible for the spread of malaria in Odisha. The relationship between meteorological variables like temperature, humidity, rainfall and malaria occurrence is looked upon. The temperature shows a good relationship with the malaria cases. Tmin is having a significant positive correlation with the malaria occurrences for all the districts in Odisha. The monthly malaria occurrences also show a good relationship with temperature and DTR . Mean rainfall and mean RH both show significantly positively correlated with malaria cases. DTR and DRH both are in the opposite phase of malaria cases and are significantly negatively correlated with the malaria cases. In the monsoon season when the diurnal range of temperature, humidity i.e., DTR and DRH is lower, the number of malaria cases is highest. DTR, rainfall, RH12 and DRH also shows a significant correlation with malaria cases. Bivariate histogram and normalized frequency of different range of temperature and RH is also analyzed. All peak malaria cases are associated with the range of Tmin >20^{o} C. Based on the preliminary analysis it is found that malaria occurrences are highly dependent on Tmin, RH12, Precipitation, DTR, DRH. Finally, a total of seven predictors are selected to forecast the malaria cases over these ten districts of Odisha. Simple multiple linear regression and ANN is used for the forecasting of malaria cases for these districts of Odisha. The ANN performs a very good forecast compared to the multiple linear regression method. Based on this analysis and results and using these forecast parameters, we hope to correctly forecast the malaria occurrences over Odisha.

The future scope of this work is in terms of using sub-monthly malaria cases. Since, the temporal resolution of occurrences of malaria cases is on a monthly scale, which is quite high compares to *Plasmodium* life cycle in the mosquito's body, which is usually less than 15 days. Malaria dynamics can be altered very significantly in the sub-monthly scale or weekly time scale because of the variability of meteorological parameters in a sub-monthly scale. So, it is very beneficial to have malaria occurrence data on a daily/weekly scale to carefully look into the behavior of malaria cases using meteorological variables.

Acknowledgments

The authors acknowledge the suggestions and encouragements of DGM, IMD. The authors are also thankful to all the officers and staff of Climate Application & User Interface Group, IMD Pune for their help and cooperation.

REFERENCES

1. Kumar A, Valecha N., Jain T, and Dash, AP. Burden of Malaria in India: Retrospective and Prospective View, Am. J. Trop. Med. Hyg., 2007, 77, pp. 69–78.
2. Bruce-Chwatt LJ. Epidemiology of malaria. In Essential Malariology. London: William Heinemann, Medical Books Ltd, 1980. pp. 129-168.
3. Burden of Disease in India. A report by National Commission on Macroeconomics and Health. Ministry of Health & Family Welfare, Government of India, New Delhi, 2005
4. Yu C, Manry MT. (2002), A modified hidden weight optimization algorithm for feedforward neural networks, Thirty-Sixth Annual Asilomar Conference on Signals, Systems and Computers, 2002, pp. 1034-1038, Pacific Grove, CA, 3-6.
5. Chen HH, Manry MT and Chandrasekaran H. A neural network training algorithm utilizing multiple sets of linear equations, Neurocomputing, 1999, 25, 1-3, 55-72.
6. Fischer MM and Gopal S. Artificial neural networks: A new approach to modeling interregional telecommunication flows, 1994, J. Reg. Sci., 34, 503-527.
7. Hornik K, Stinchcombe M and White H. 1989, "Multilayer feedforward networks are universal approximators", 1989, Neural Networks, 2, 359-366.
8. Lingala MA, Climatic variables and malaria transmission, Chapter 5, in Vector-borne diseases and treatment. 2018; Vol 2: 1-12.
9. Lingala MA, Singh P, Verma P, Dhiman RC. Determining the cutoff of rainfall for Plasmodium falciparum malaria outbreaks in India. J Infect Public Health. 2020 Jul;13(7):1034-1041. doi: 10.1016/j.jiph.2019.11.017. Epub 2019 Dec 11. PMID: 31837999.
10. Nizamuddin M, Kogan F, Dhiman R, Guo, W, & Roytman L. Modeling and forecasting malaria in Tripura, India using NOAA/AVHRR-based vegetation health indices. International Journal of Remote Sensing, 2013, 3(3), 108–116.
11. Paaijmans KP, Blanford S, Bell AS, Blanford JI, Read AF, Thomas MB. Influence of climate on malaria transmission depends on daily temperature variation PNAS, 2010, 107 (34) 15135-15139; DOI: 10.1073/pnas.1006422107.
12. Guhathakurta P. Long lead monsoon rainfall prediction for meteorological sub-divisions of India using deterministic artificial neural network model, Meteorology and Atmospheric Physics, 2008,101, pp 93–108.
13. Guhathakurta P, Tyagi A, Mukhopadhyay B. Climatology at any point: A neural network solution, Mausam, 2013, Vol-64, 2, pp. 231-250.
14. Peng B, Tong S, Donald K, Parton KA. and Ni J. Climatic variables and transmission of malaria: A 12 year data analysis in Shuchen county China. Public health report, 2003, Vol-18: 65-71.
15. Sharma VP. Malaria: cost to India and future trends. Southeast Asian J Trop Med Public Health, 1996, 4-14. PMID: 9031392.
16. Sudheer C, Sohani, SK, Kumar D, Malik A, Chahar BR., Nema AK, Panigrahi BK., Dhiman, RC. A Support Vector Machine-Firefly Algorithm based forecasting model to determine malaria transmission Neurocomputing, 2014, 129, pp. 279-288. doi: 10.1016/j.neucom.2013.09.030
17. World malaria report 2020. 20 years of global progress and challenges. Geneva: World Health Organization; 2020. Licence: CC BY-NC-SA 3.0 IGO.