A pilot study on assessing the effect of climate on the incidence of vector borne disease at Pune and Pimpri-Chinchwad area, Maharashtra

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(*Received 15 March 2019, Accepted 24 October 2020*)

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सार – पुणे नगर निगम (PMC) और पिंपरी-चिंचवाड़ नगर निगम (PCMC), पुणे महाराष्ट्र के अधिकार क्षेत्र में कुछ वेक्टर जनित रोगों (VBD) जैसे डेंगू और मलेरिया पर जलवायु की भूमिका को समझने का प्रयास किया गया है। इसके लिए 2010-2018 के दौरान उपर्युक्त दो नगर निगमों के स्वास्थ्य विभाग से उपलब्ध VBD के मासिक संख्या के मामलों और इन वर्षों के जलवायु अनुसंधान एवं सेवाएँ, भारत मौसम विज्ञान विभाग के कार्यालय से उपलब्ध मासिक जलवायु आँकड़ों का उपयोग किया गया है। इस प्रायोगिक अध्ययन से, निम्नलिखित प्रारंभिक परिणाम मिले हैं:

(*i*) मोटे तौर पर, सभी महीनों में मलेरिया के मामलों में कमी आई है और 2017 तक सभी महीनों में डेंगू के मामलों में वृद्धि हुई है।

(*ii*) मलेरिया के लिए हॉटस्पॉट 70-82% RH और माध्य तापमान 25-30 °C के बीच देखे गए। 24-26 °C के Tmean, DTR 6-8 °C पर मलेरिया के हॉटस्पॉट पाए गए।

(*iii*) डेंगू की घटनाओं के हॉटस्पॉट तब पाए गए जब मासिक Tmean, 20-25 °C के भीतर था और मासिक माध्य RH 55-70% के भीतर तथा जब मासिक Tmean 25-30 °C के भीतर था और मासिक माध्य आरएच 75-80% के भीतर है। जब माध्य तापमान 24 °C से नीचे होता है, तो अधिकतम डेंगू के मामले DTR में 16-18 °C के बीच होते हैं, जब माध्य तापमान 24 और 26 °C के बीच होता है, तब DTR 8-12 °C पर हॉट स्पॉट पाए जाते हैं। 26 °C से ऊपर, जैसे माध्य तापमान में वृद्धि होती है, डेंगू के मामले कम हो जाते हैं।

(*iv*) मलेरिया और डेंगू दोनों के लिए, पुणे और पिंपरी-चिंचवाड़ नगर निगम क्षेत्र में होने वाली उनकी मासिक संख्या का न्यूनतम मासिक तापमान, दैनिक औसत तापमान, मासिक माध्य DTR, मासिक कुल वर्षा और मासिक माध्य RH के साथ महत्वपूर्ण समवर्ती और संगामी सहसंबंध है।

(*v*) इस अध्ययन की एक सीमा यह रही कि 2010-2018 तक मलेरिया के मामलों में लगातार कमी के कारण इस विश्लेषण पर प्रभाव पड़ा।

ABSTRACT. An attempt has been made to understand the role of climate on some Vector borne diseases (VBD), like Dengue and malaria over the region under the jurisdiction of Pune Municipal Corporation (PMC) and Pimpri-Chinchwad Municipal Corporation (PCMC), Pune Maharashtra. For that monthly number of cases of occurrence of these VBDs during 2010-2018, available from Heath Department of above two Municipal corporations and Monthly Climate data of these years, available from the office of Climate Research and Services, India Meteorological department have been used. From this pilot study, following preliminary results have been found:

(*i*) Broadly, there is a decrease in the malaria cases for all months and there is an increase in the dengue cases for all months till 2017.

(*ii*) Hotspot for Malaria were observed to be associated with RH between 70-82% and Mean temp 25-30 °C. At a *T*mean of 24-26 °C, Malaria hotspots were found at DTR 6-8 °C.

(*iii*) Hotspots of occurrences of Dengue were found when monthly *T*mean was within 20-25 °C & monthly Mean RH is within 55-70% and when monthly *T*mean was within 25-30 °C & monthly Mean RH is within 75-80%. When mean temp is below 24 °C, then maximum Dengue cases occur at DTR between 16-18 °C, when mean temp is between 24 & 26 °C, then hot spots are found at DTR 8-12 °C. Above 26 °C, as mean temp increases, dengue occurrence decreases.

(*iv*) For both Malaria and Dengue, their monthly number of occurrences in Pune & Pimpri - Chinchwad municipal corporation area have significant concurrent and lagged correlation with Mean monthly minimum temperature, daily mean temperature, monthly mean DTR, monthly total rainfall and monthly mean RH.

(*v*) One limitation of the study is that gradual reduction in cases of malaria from 2010-2018 might have affected the analysis.

1.   Introduction

Vector borne diseases (VBD) constitute an important cause of death, disease burden and health inequity, a brake on socioeconomic development and a strain on health services (Cambell *et al*., 2015). Vector-borne diseases are among the most well studied of the diseases associated with climate change, owing to their large disease burden, widespread occurrence and high sensitivity to climatic factors. In contrast to some other climate-sensitive health risks, such as heat-stress, or exposure to storms and floods, the influence of meteorological factors are less direct and more diverse, both within and between individual diseases (Smith *et al*., 2014). The simplest pathways are through temperature, affecting the biting, survival and reproductive rates of the vectors, extrinsic incubation period (EIP) and the survival and development rates of the pathogens that they carry. Precipitation also exerts a very strong influence, most obviously in the case of diseases transmitted by vectors that have aquatic developmental stages (such as mosquitoes), but also, via humidity, on diseases transmitted by vectors without such stages, such as ticks or sand-flies. Spatial and temporal distribution of vector-borne diseases like malaria, dengue and chikungunya are likely to be affected the most as the mosquitoes which transmit the diseases are cold blooded (Singh & Dhiman, 2012). Their life cycle and development of pathogen in their body are likely to be affected at varying temperature and relative humidity. Studies undertaken in India with A2 scenario on malaria reveal that the transmission window in Punjab, Haryana, Jammu & Kashmir and north-eastern states are likely to extend temporally by 2-3 months and in Odisha, Andhra Pradesh and Tamil Nadu there may be reduction in transmission windows. Studies undertaken in India on malaria in the context of climate change impact reveal that transmission windows in Punjab, Haryana, Jammu and Kashmir and north-eastern states are likely to extend temporally by 2-3 months and in Orissa, Andhra Pradesh and Tamil Nadu there may be reduction in transmission windows and Orissa, West Bengal and southern parts of Assam will still remain malarious and transmission windows will open up in Himachal Pradesh and north-eastern states etc. (Dhiman *et al*., 2010).

For most Anopheles vector species of malaria, the optimal temperature range for their development lies within 20 °C to 30 °C. However, transmission of *P. vivax* requires a minimum average temperature of 15 °C and transmission by *P. falciparum*, requires a minimum temperature of 19 °C. The transmission window in terms of the temperature range should extend over a period of time for completion of the sporogeny. Malarial survival is also dependent on the time of the year, *i.e*., the wet or dry season. However, no clear relationship has been observed between the positive malaria cases and the annual precipitation. Some actually contend that the amount of rainfall may be secondary in its effects on malaria to the number of rainy days or the degree of wetness that exists after a rain event. Also, if the average monthly relative humidity is below 55 per cent and above 80 per cent the life span of the mosquito gets so shortened that the scope of malaria transmission diminishes (Bhattacharya *et al*., 2006). Paaijmans *et al*. (2010) while studying the dependence of Malaria transmission on daily temperature fluctuation found that, compared with rates at equivalent constant mean temperatures, temperature fluctuation around low mean temperatures acts to speed up rate processes, whereas fluctuation around high mean temperatures acts to slow processes down.

Impact of climate change on dengue also reveals increase in transmission with 2 °C rise in temperature in northern India. Although there is an established transmission window with respect to maximum temperature, minimum temperature and relative humidity for Malaria virus, similar information for Dengue virus with respect to all these climate parameters is not known.
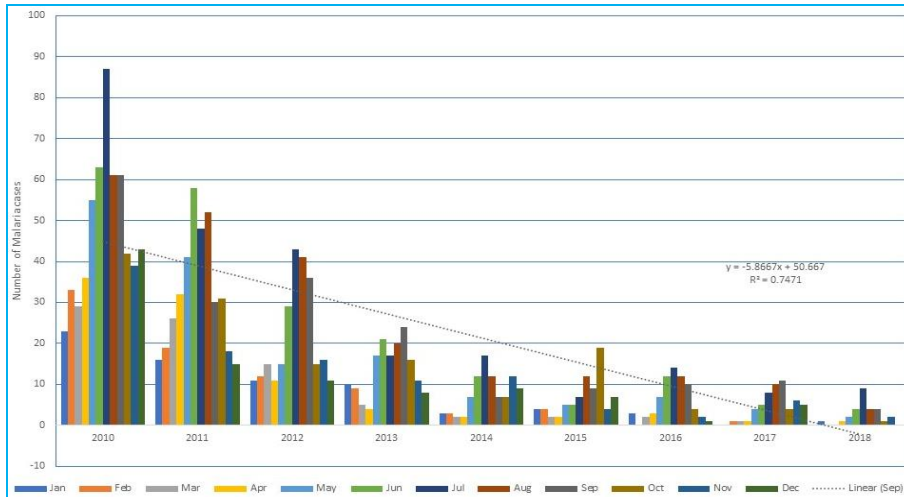
Fig. 1(a). Year wise distribution of monthly number of Malaria cases over Pune (based on PMC & PCMC data) during 2010-2018
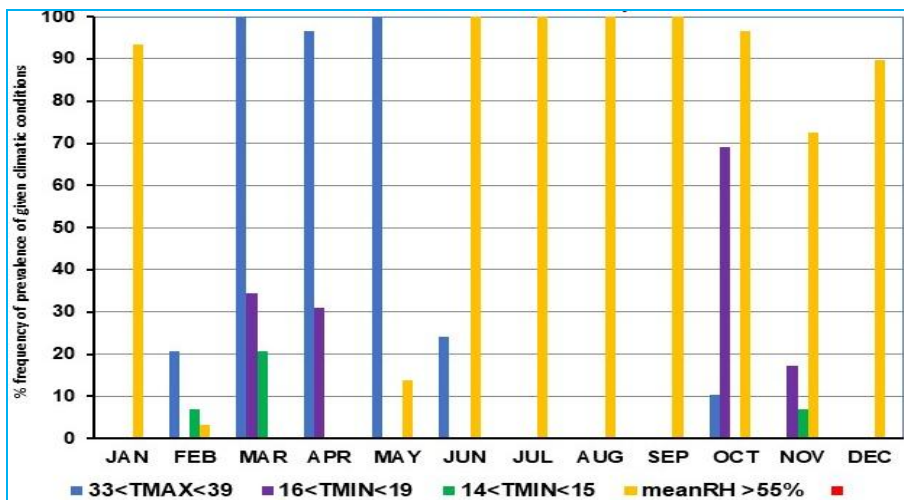

Fig. 1(b). Climatology of threshold values of meteorological parameters for Malaria at he location of study
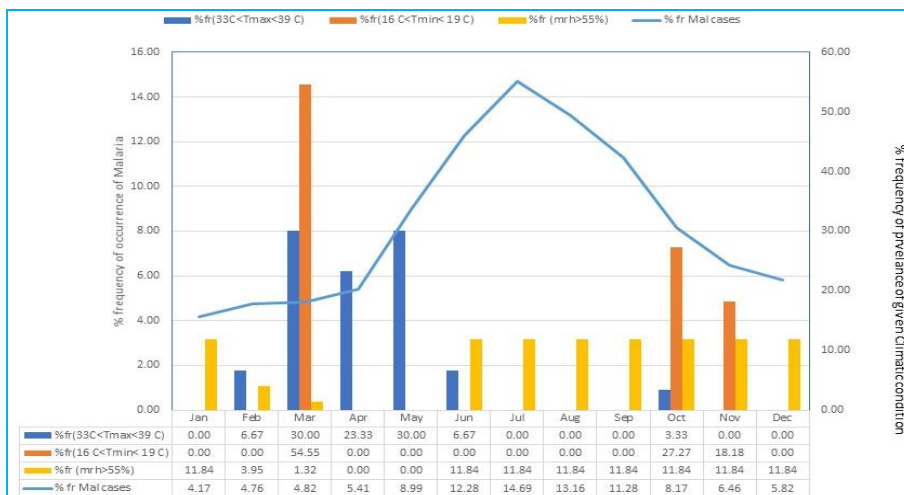

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
%fr(33C<Tmax<39 C)	0.00	6.67	30.00	23.33	30.00	6.67	0.00	0.00	0.00	3.33	0.00	0.00
%fr(16 C<Tmin< 19 C)	0.00	0.00	54.55	0.00	0.00	0.00	0.00	0.00	0.00	27.27	18.18	0.00
%fr (mrh>55%)	11.84	3.95	1.32	0.00	0.00	11.84	11.84	11.84	11.84	11.84	11.84	11.84
% fr Mal cases	4.17	4.76	4.82	5.41	8.99	12.28	14.69	13.16	11.28	8.17	6.46	5.82

Fig. 1(c). Frequency of prevalence of climate suitability condition during 2010-2018 over the location of study
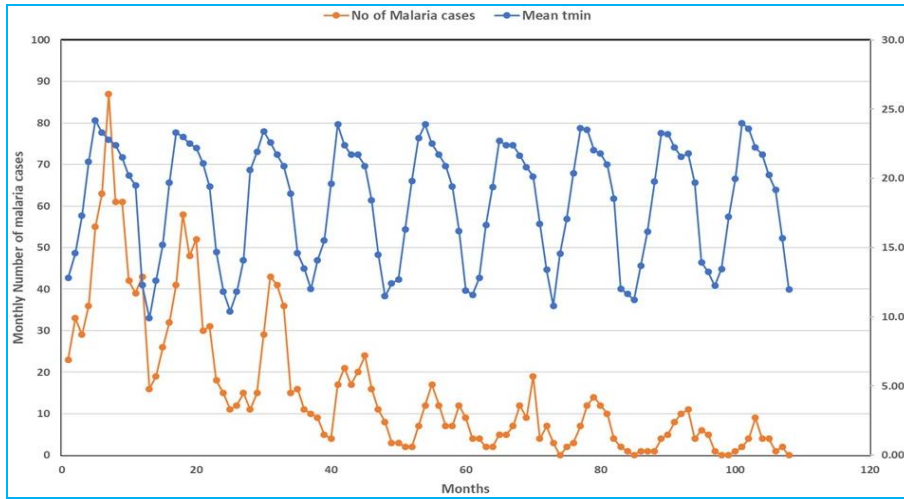
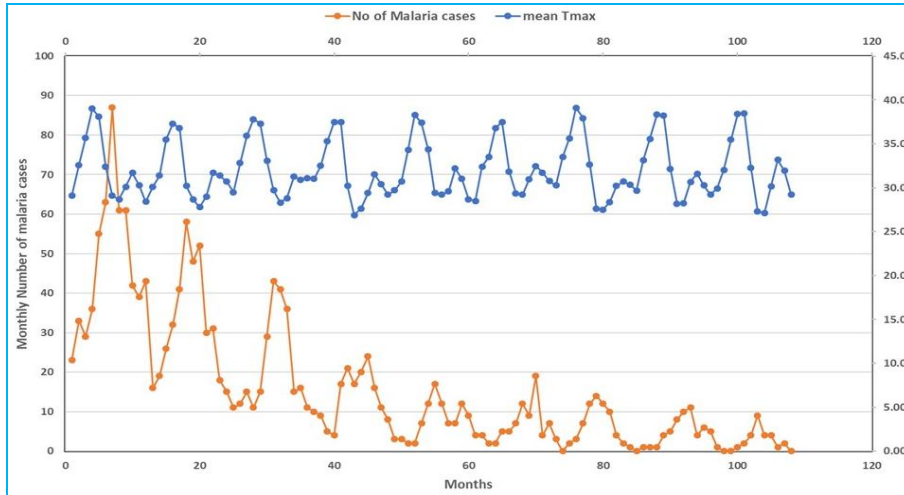**Fig. 1(d).** Monthly number of Malaria cases and mean *T*min

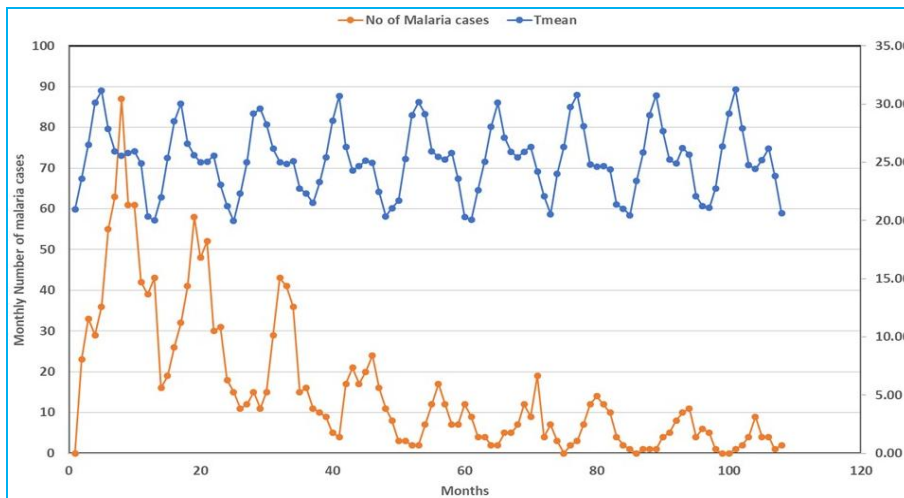**Fig. 1(e).** Monthly number of Malaria cases and mean *T*max

Fig. 1(f). Monthly mean of daily mean temperature and monthly number of malaria occurrence
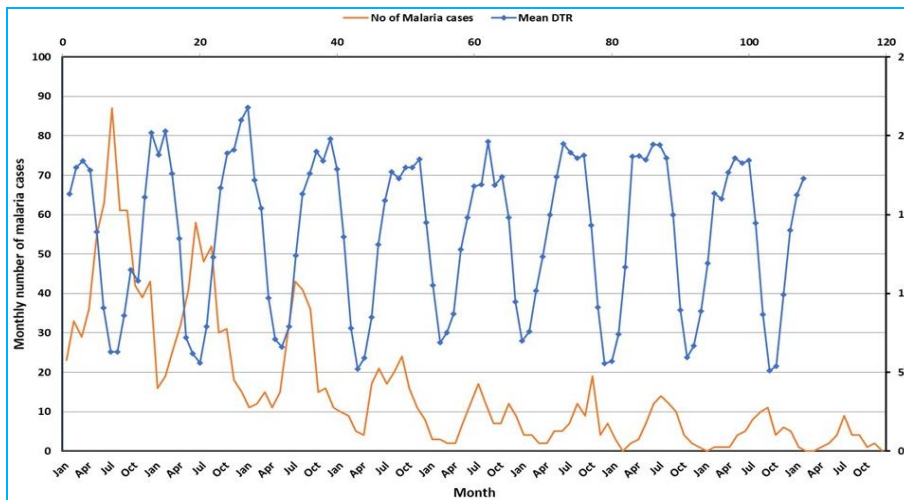
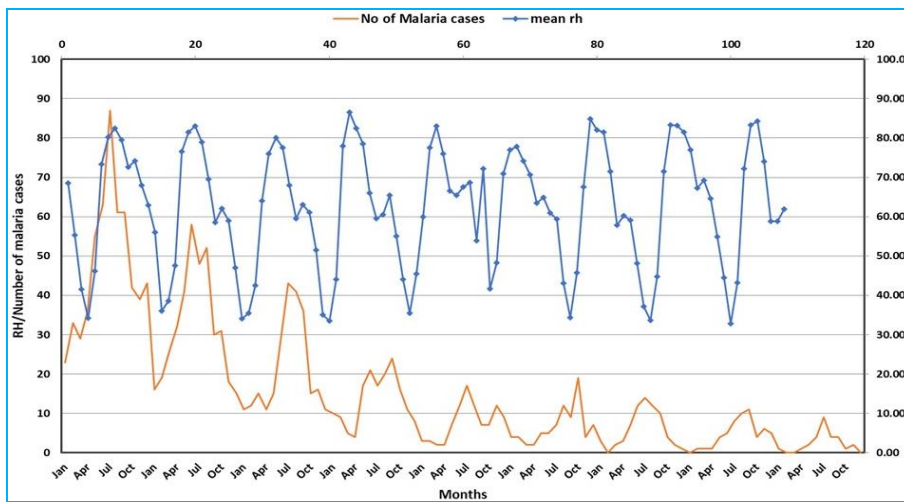**Fig. 1(g).** Monthly number of Malaria cases and mean monthly DTR

Fig. 1(h). Mean monthly daily mean RH and monthly number of malaria cases
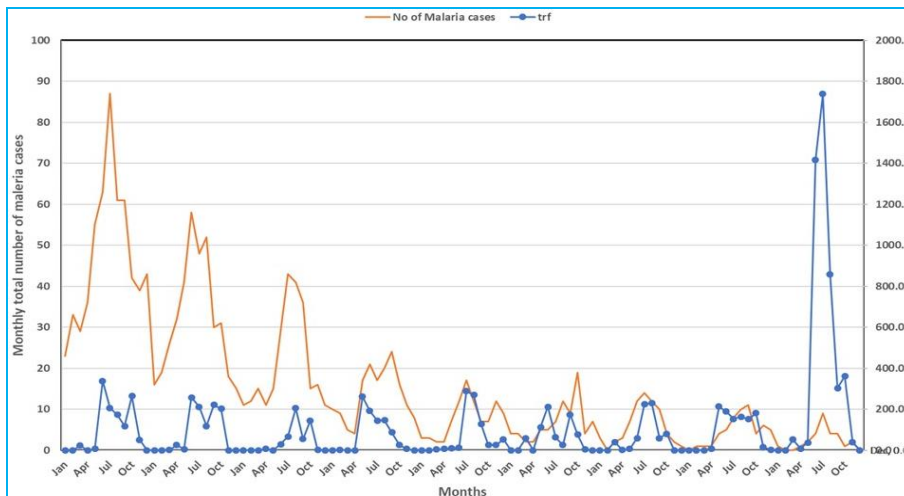

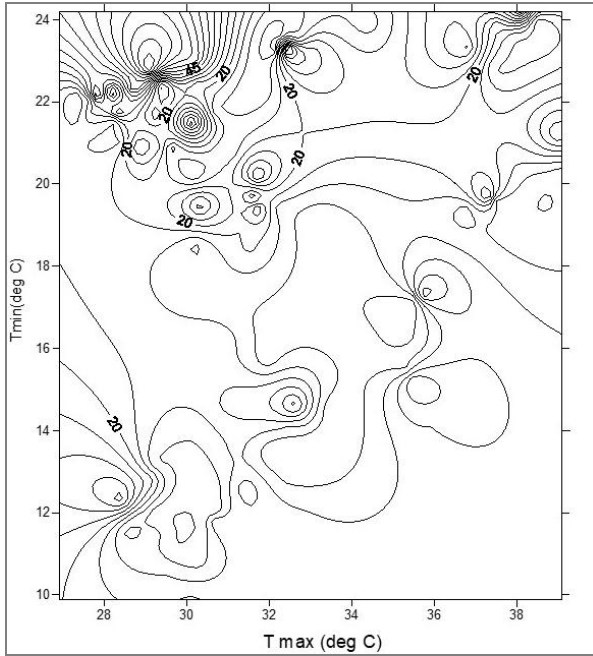**Fig. 1(i).** Monthly total RF and monthly number of malaria cases

Fig. 1(j). Joint dependence of monthly total number of malaria with monthly mean *T*max & *T*min
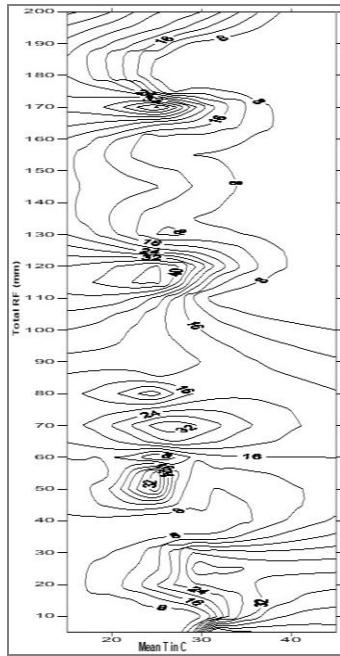
Fig. 1(k). Number of malaria cases *vis-à-vis* mean T and total rainfall
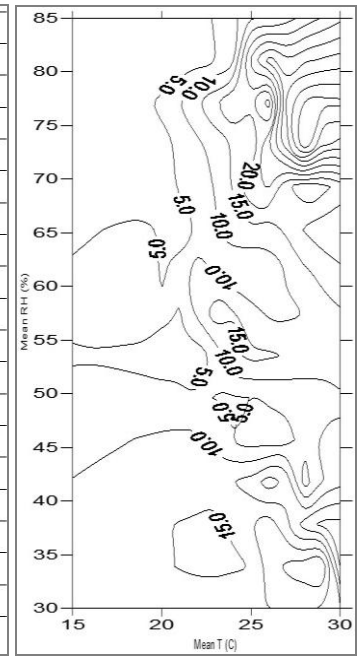
Fig. 1(l). Monthly number of malaria cases *vis-à-vis* *T*mean & Mean RH
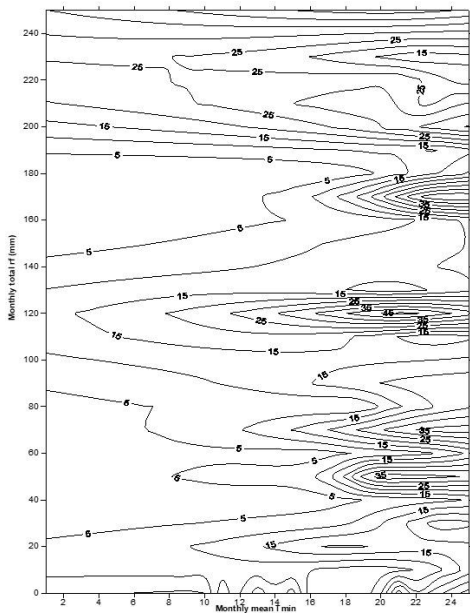

Fig. 1(m). Joint dependence of monthly total malaria occurrence with monthly *T*min & total rf
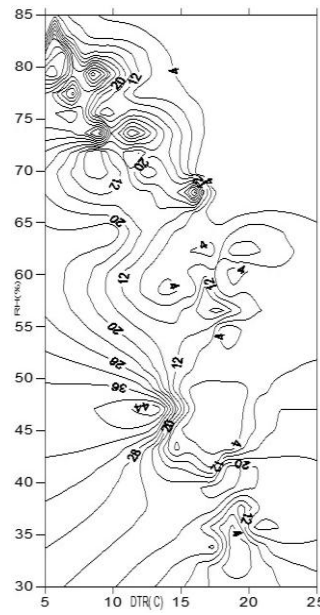
Fig. 1(n). Joint dependence of monthly total number of malaria with monthly mean DTR & RH

Fig. 1(o). Joint dependence of malaria occurrence on monthly mean *T*mean & DTR

Ehelepola & Ariyaratne (2015) have shown that Dengue incidence in the city of Kandy in Sri Lanka is negatively correlated with large diurnal fluctuations of both temperature and humidity. Ko-Chang *et al.* (2016) attempted to develop a mathematical model using lagged-time Poisson regression analyses to evaluate the effect of

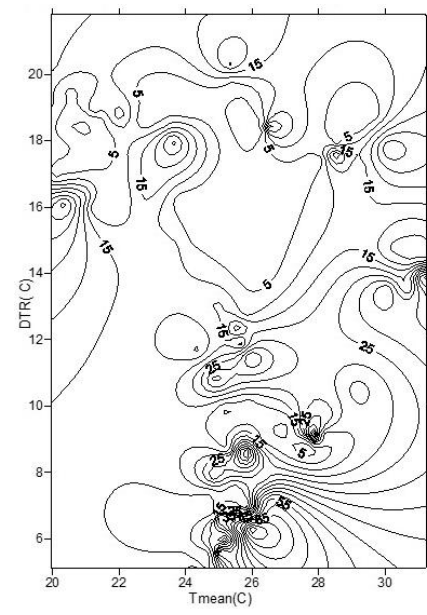meteorological parameters on dengue incidences during 2000-2014 in Kaohsiung, Singapore. They found that increased minimum temperatures rendered a 2- and 3-month lagging interactive effect on higher dengue risks and higher rainfall a 1- and 2-month lagging interplay effect on lower risks.

Shil *et al.* (2018) showed that overall, mosquito abundance increased during the SW Monsoon due to low diurnal temperature range (DTR) along with increased rainfall and humidity, but decreased during winter followed by a slight increase during the Pre-Monsoon season. Sahai *et al.* (2020), using weekly total malaria and acute diarrheal diseases cases for Pune (Nagpur) for the period 2012-2016 (2012-2016) and 2013-2016 (2012-2016) respectively and using weekly Climate data of above two locations, for the period 2009-2016, found that higher amounts of rainfall, moderate maximum temperature and high minimum temperature are more conducive for the incidence of malaria and diarrhea over above two locations.

In recent years locations under the jurisdiction of Pune Municipal Corporation (PMC) and Pimpri-Chinchwad Municipal Corporation (PCMC) have witnessed an enhanced number of Dengue cases, although Malaria cases have been reduced (Based on information on dengue and malaria cases provided by health departments of Pune Municipal Corporation (PMC hereafter) and Pimpri-Chinchwad Municipal Corporation (PCMC hereafter). Also India Meteorological Department, following GFCS requirement, has initiated Climate service for health sector. Following WMO/WHO, one of the aspects for holistic approach towards Climate service to health is research and development, aiming to find out threshold values of Climatic parameters for the outbreak of different VBD, at local level.

Objective of this study is to understand the role of different climatic parameters in the locally outbreak of VBD like Malaria and Dengue over the region under the jurisdiction of PMC & PCMC and also to estimate threshold values of Climatic parameters for the outbreak of Malaria and Dengue, at local level for this specific location.

2. Data

Monthly number of Malaria and Dengue cases during 2010-2018 have been obtained from Health department of PMC & PCMC, Maharashtra and daily maximum temperature, minimum temperature, relative humidity and rainfall for all months during these years of Pune have been obtained from office of Climate Research & Services, India Meteorological

Department, Pune. From daily maximum and minimum temperature (Tmax and Tmin) and relative humidity (RH0300 UTC and RH1200 UTC), daily mean temperature [Tmean = (Tmax + Tmin) / 2], mean relative humidity [RH = (RH0300 UTC + RH1200 UTC) / 2] and daily diurnal temperature range (DTR = maximum temperature-minimum temperature) have been computed. Monthly total rainfall has been computed by summing up the daily rainfall.

3. Analysis

In this section we shall discuss the climate disease relationship for Malaria and Dengue separately:

3.1. *Malaria*

Year wise distribution of monthly total number of Malaria cases for all months during 2010-2018 over Pune has been shown in Fig. 1(a). From this figure it can be seen that in general there is a decrease in the malaria cases for all months and in any year maximum incidences occur during June-September.

3.1.1. *Climate suitability for occurrence of Malaria over PMC & PCMC areas and its observed monthly and yearly variation*

Climatic suitability for the outbreak of Malaria is defined in terms of the prevalence of threshold values of certain climatic parameters, *viz.*, Tmax, Tmin etc. Study by Craig *et al.* (1999) suggests that five months above 80 mm rain is sufficient and rain above 80mm for one month is not sufficient for a transmission season but rain for three months above 80 mm is. In Bikaner (India), malaria outbreak occurred with 40 mm rainfall in two consecutive months at the threshold of transmission season. Lingala *et al.* (2020) using district-wise monthly malaria cases and monthly meteorological data for the period from January 2009-December 2012 showed that Malaria outbreaks can occur in post monsoon over arid and semi-arid region whereas in summer/ monsoon over humid and per-humid regions. The study also suggests that lag period between rainfall and outbreak differs from one month with short lag (humid and per-humid) to long lag (arid and semi-arid). However, no conclusive information about rainfall threshold for malaria over PMC & PCMC areas are available. WHO document (2010) suggests that threshold limits of maximum and minimum temperatures for Malaria are respectively 33 °C-39 °C and 16 °C-19 °C, however Craig *et al.* (1999) suggested 32 °C to be the upper limit for maximum temperature. Mordecai *et al.*, 2013, using a large data set in Africa have shown that optimal malaria transmission takes place at 25 °C and transmission decreases dramatically at temperatures above 28 °C. However, in the present study,

TABLE 1

Correlation coefficient between monthly total number of malaria and mean monthly maximum/minimum temperature, DTR, RH and monthly rainfall at different lags. (t.05,106 = 1.6610, t.05,105 = 1.6613, t.05,104 = 1.6615, t.05,103 = 1.6617)

Correlation coefficient between monthly total number of malaria and	Lag = 0	t - value	Lag = 1 month	t - value	Lag = 2 months	t - value	Lag = 3 months	t - value
Monthly mean Tmax	-0.1667	-1.7409	0.0318	0.3259	0.2274	2.3813	0.3374	3.6380
Monthly mean Tmin	0.3499	3.8461	0.3996	4.4668	0.3457	3.7573	0.1988	2.0587
Monthly mean daily mean temp	0.1607	1.6759	0.3095	3.3354	0.3817	4.2111	0.3375	3.6384
Monthly mean DTR	-0.4171	-4.7251	-0.3235	-3.5033	-0.1446	-1.4903	0.0564	0.5736
Monthly mean RH	0.2964	3.1956	0.1221	1.2610	-0.0983	-1.0069	-0.2745	-2.8974
Monthly total rainfall	0.0485	0.5001	0.0230	0.2360	-0.0615	-0.6283	-0.1125	-1.1491

for studying the Climatic suitability over these regions following thresholds have been used:

(*i*)   33 °C < Tmax < 39 °C,

(*ii*)   16 °C < Tmin < 19 °C,

(*iii*) RH > 55% (WHO, 2010).

Using last 30 years mean monthly Tmax, Tmin and RH of Pune, climatology has been prepared for percentage frequency of prevalence of above climatic conditions for individual parameters and the same has been shown in Fig. 1(b).

From Fig. 1(b), it can be seen that:

(I) Condition (*ii*) is satisfied in 69% cases in October, followed by 30% during March-April 18% in November and 10% in February.

(II). Condition (*iii*) is satisfied in 100% during June-September, followed by 96% in October, 93% in January and 89.6% in December.

3.1.2. *Number of malaria cases reported & prevalence of Climate suitability condition*

Fig. 1(c) shows the prevalence of Climate suitability for Malaria over Pune during 2010-2018 and number of Malaria cases reported (Based on Health department of PMC & PCMC, Pune, Maharashtra, India). From this figure it can be seen that:

(*i*)   Malaria cases over the location of study during 2010-2018 increased slightly from January to February and then it remains almost stationary till March then it rises attains maxima in July and then it falls.

(*ii*)   All parameters don't show simultaneous fulfillment of Climate suitability criteria as discussed in above subsection 3.1.1.

(*iii*) In June, fulfillment of climatic suitability criteria, by Max temp is 5-10% and by RH is 10-12%.

(*iv*) In July-September, December and in January only RH fulfills the criteria in 10-12% cases.

(*v*)   In October, fulfillment of climatic suitability criteria, by RH is 10-12% and by Tmin is 25-30%.

(*vi*) In April & May, only Tmax fulfills the Climate suitability criteria by 20-30%.

(*vii*) In March RH (1-2%), Tmax (30%) and Tmin (50-55%) satisfy the criteria.

Thus, from the foregoing discussion, it is clear that climatic suitability criteria for Malaria, as described in subsection 3.1.1., didn't match mostly over the area under the jurisdiction of PMC & PCMC, Pune during the period

under study. Hence in the following subsection, we shall investigate joint dependence of Malaria occurrence on different combination of Climatic parameters.

3.1.3. *Observed variability of Malaria occurrence on individual Climatic parameter over Pune*

Figs. 1 (d-f) show the monthly total number of occurrences of Malaria cases *vis-à-vis* mean monthly minimum temperature, maximum temperature and daily mean temperature. From this figure it is seen that during the period & region of study, after mean-monthly maximum or minimum or daily mean temperature attains a peak, a peak in the monthly malaria case takes place after approximately 1-3 months. Figs. 1 (e-g) show the monthly total number of occurrences of Malaria cases *vis-à-vis* mean monthly DTR, RH and monthly total rainfall. From the figure it is seen that monthly number of malaria cases is a maximum or minimum when monthly mean DTR has a minimum or maximum value. Survival and transmission of vectors (here mosquito) is very much temperature dependent. At a low DTR abundance of Mosquito is more and thus more bites and more transmission of the disease (Shil *et al.*, 2018). Physically it may be interpreted that with a moderate maximum temperature and higher minimum temperature are suitable of Malaria occurrence. Also it can be seen that when monthly rainfall and monthly mean RH increases, then monthly number of malaria cases also increases. These results are in conformity with the results of correlation analysis as discussed below.

Table 1(a) shows the correlation between monthly numbers of malaria cases and mean monthly maximum/minimum temperature, Daily mean temperature, DTR, RH and monthly rainfall at different lags (1-3). It is seen that mean monthly maximum temperature has significant (at 95% level) negative concurrent correlation, positive lagged correlation, with lag 2 & 3 months, with monthly number of occurrences of Malaria over PMC & PCMC areas. It can also be seen that the Monthly number of occurrences of Malaria over this area have significant (at 95% level) positive correlation (concurrent & lagged both) with Mean monthly minimum temperature and daily mean temperature. It has significant (at 95% level) negative correlation with monthly mean DTR with lag 0 & 1 month, which is in conformity with the findings of Shil *et al.* (2018) that Mosquito abundance and subsequent transmission is more at low DTR. Monthly number of occurrences has significant (at 95% level) concurrent positive correlation and negative lagged correlation with lag 3 months with monthly mean RH. Monthly total rainfall has a positive correlation with lag 0 & 1 and negative at lag 2 & 3, although the correlation is not statistically significant at 95% level.

3.1.4. *Observed variability of Malaria occurrence jointly on two climatic variables over Pune*

Fig. 1(f) shows joint dependence of monthly number of Malaria cases on mean monthly daily maximum and minimum temperatures. From this figure it is seen that the Malaria hot spots are found when Tmax is between 28 & 32 °C and Tmin is between 20 & 24 °C.

Fig. 1(g) shows joint dependence of monthly number of Malaria cases on observed mean monthly daily mean temperature and monthly total rainfall. From this figure it is seen that for any mean temperature ranging from 20 to 30 °C, malaria hotspots are found, when monthly total rainfall is between 50-60 mm, 110-120 mm and 160-180 mm. From this figure it can also be seen that as mean monthly maximum temperature exceeds, approximately, 35 °C, number of cases decreases, even if rain fall increases.

Fig. 1 (h) shows the monthly number of Malaria cases *vis-à-vis* mean monthly mean RH and monthly mean of daily mean temperature. This figure suggests a hotspot for malaria when mean monthly value of daily mean temperature is between 25 °C-30 °C and monthly mean RH is between 70-80%. Fig. 1(i) shows the joint influence of mean monthly minimum temperature and monthly total rainfall on monthly number of Malaria cases. This figure suggests the presence of three hotspots for malaria, all when mean monthly minimum temperature is between 20 °C-24 °C and monthly total rainfall is between 40 mm-60 mm, 100 mm-120 mm and 160 mm-180 mm. Dependence of the monthly number of Malaria cases, jointly on mean monthly DTR and RH can be seen in Fig. 1(j). From this figure it is seen that malaria hotspot is found when monthly mean relative humidity lies between 72% & 82% and monthly mean DTR lies between 5 °C-10 °C. Fig. 1(k) shows the dependence of the monthly number of Malaria occurrence jointly on the monthly mean daily average temperature (Tmean) and DTR. This figure suggests that at a Tmean of 24-26 °C, Malaria hotspots found at DTR 6-8 °C. It can also be seen that as the Tmean increases from 28 °C, DTR reduces the number of occurrence. This result is in conformity with the findings of Paaijmans *et al.* (2010).

3.2. *Dengue*

Fig. 2(a) shows the yearly distribution of Dengue cases in different months, reported during 2010-2018 (Based on information shared by Health department of PMC & PCMC), from which, it is seen that in general, there is an increase in the dengue cases for all months from 2012 onwards and in any year maximum incidences occur during September-November, followed by August
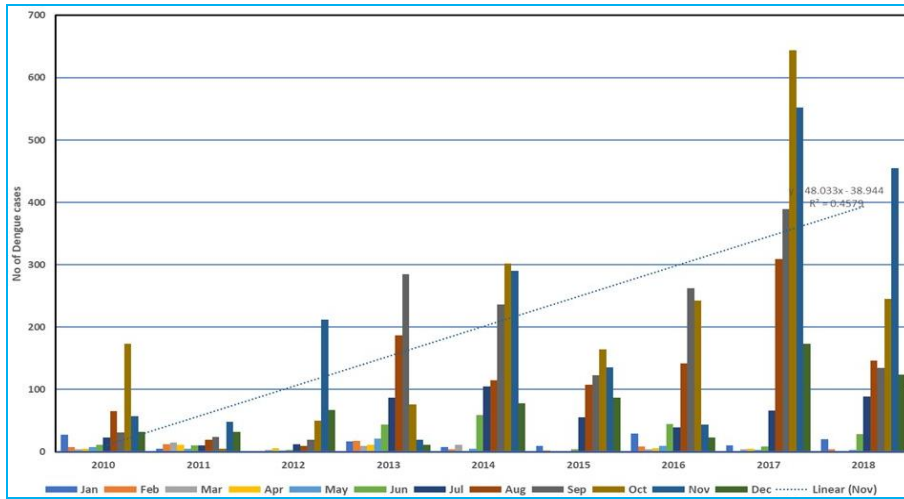
Fig. 2(a). Year wise distribution of monthly number of Dengue cases over Pune (based on PMC & PCMC data) during 2010-2018
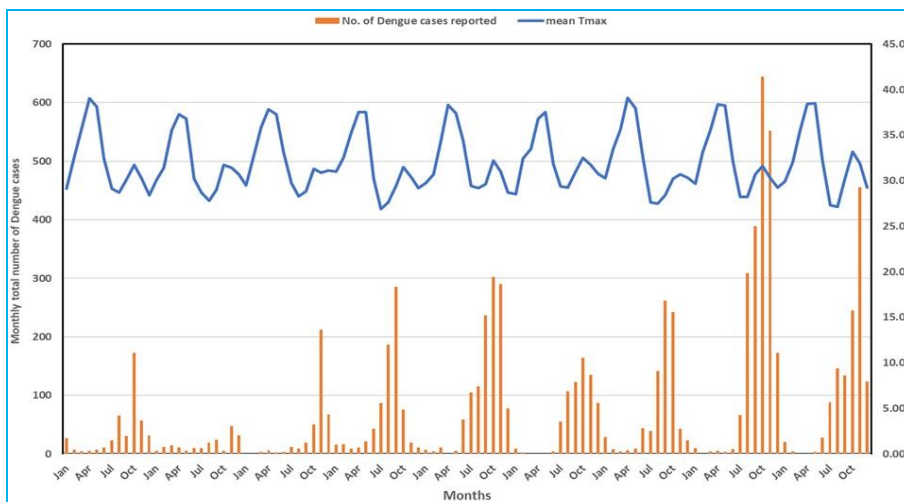

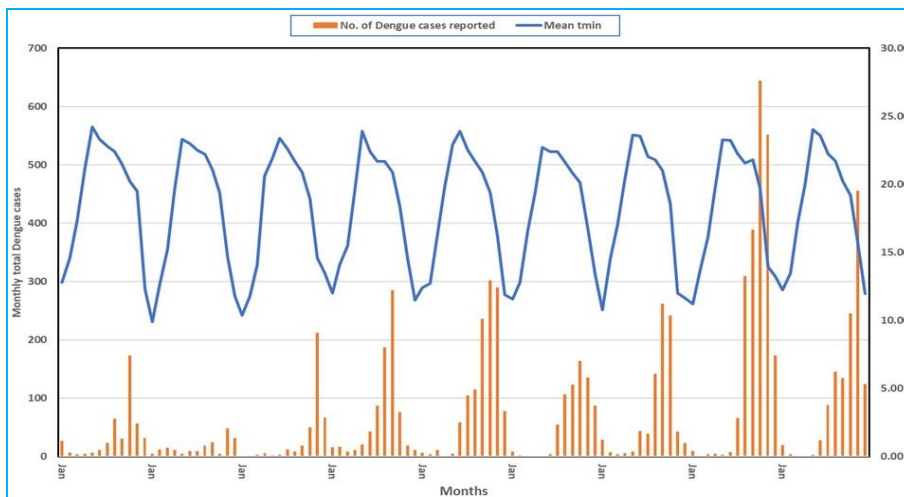**Fig. 2(b).** Monthly mean *T*max & total number of Dengue cases during 2010-2018

Fig. 2(c). Monthly mean *T*min & total number of Dengue cases
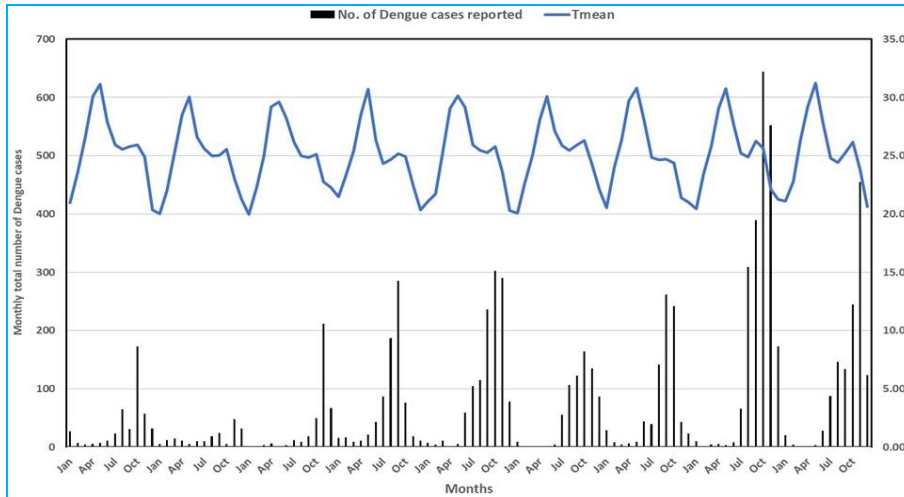
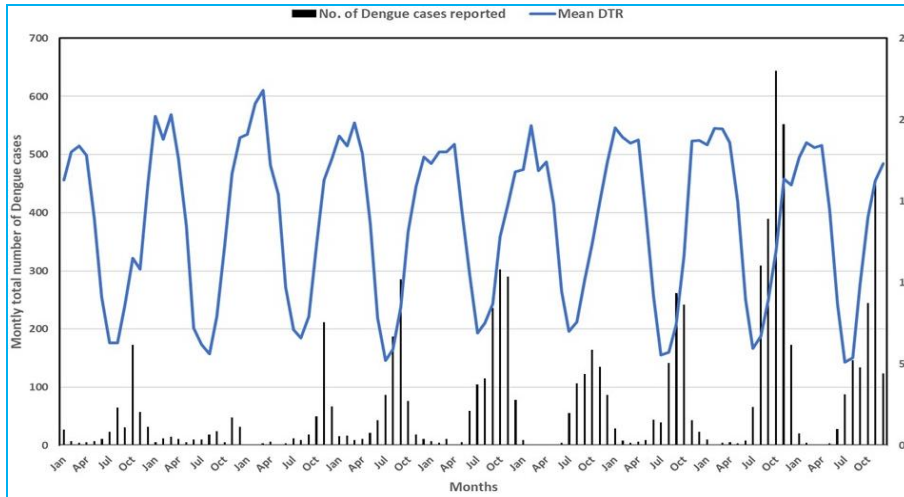**Fig. 2(d).** Monthly *T*mean & total number of Dengue cases

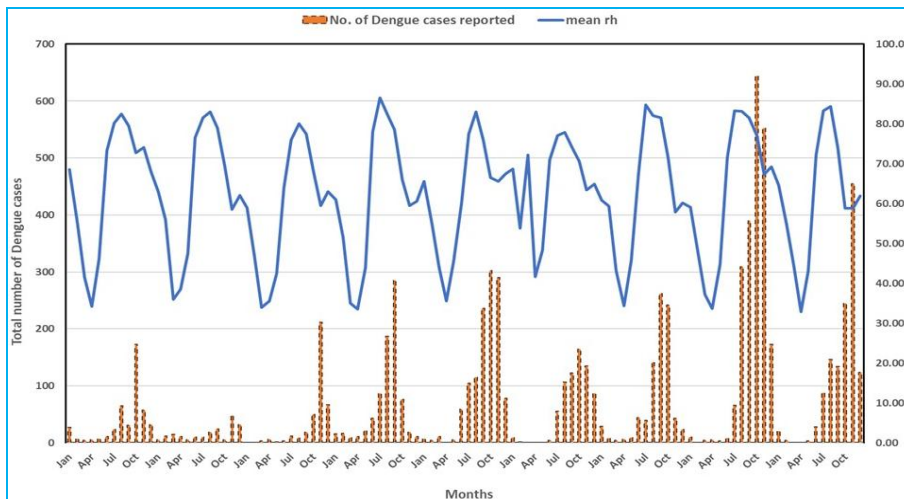**Fig. 2(e).** Monthly mean DTR & total number of Dengue cases

Fig. 2(f). Monthly mean of daily mean RH & total number of Dengue cases
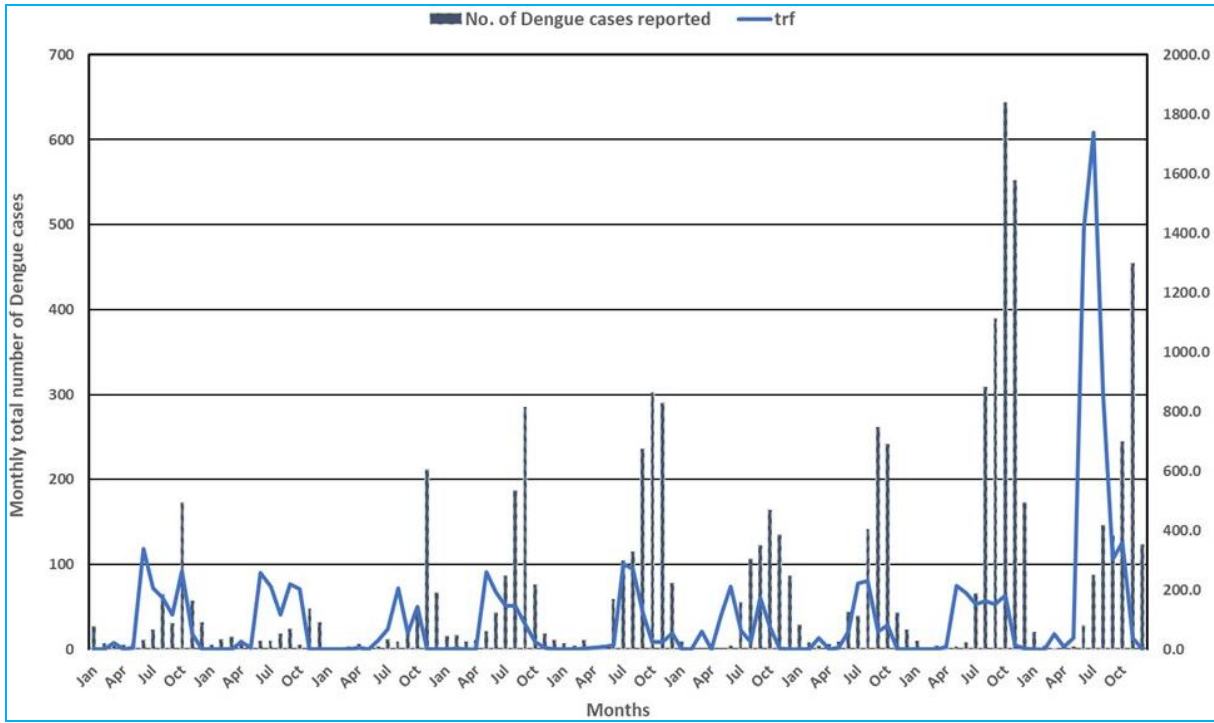
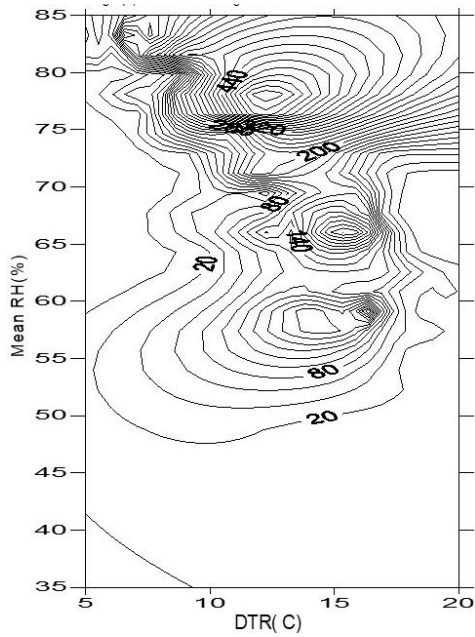**Fig. 2(g).** Monthly total rainfall and total number of Dengue cases

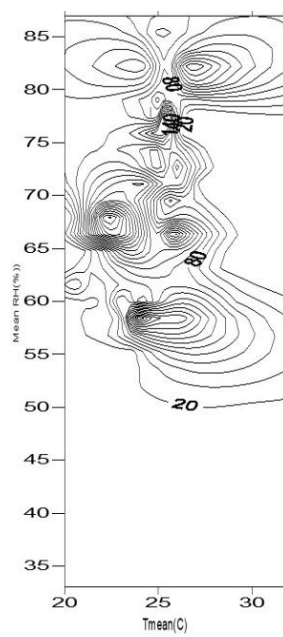**Fig. 2(h).** Number of Dengue cases *vis-à-vis* mean DTR & RH

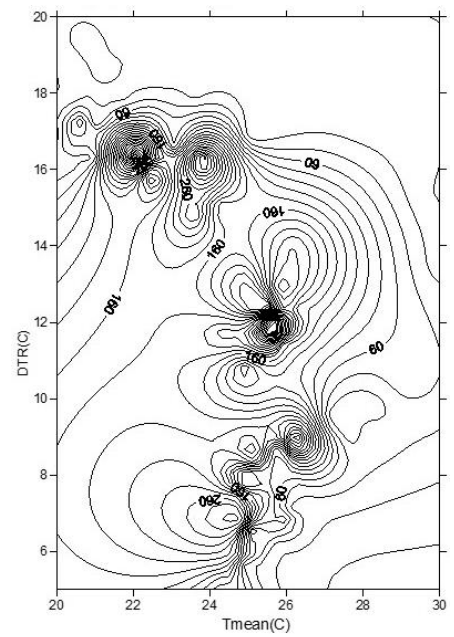**Fig. 2(i).** Number of Dengue cases *vis-à-vis T*mean Mean RH

Fig. 2(j). Number of Dengue cases *vis-à-vis T*mean & DTR

TABLE 2

Correlation coefficient between monthly total number of Dengue and mean monthly maximum/minimum temperature, DTR, RH and monthly rainfall at different lags. (t.05,106 = 1.6610, t.05,105 = 1.6613, t.05,104 = 1.6615, t.05,103 = 1.6617)

Correlation coefficient between monthly total number of malaria and	Lag = 0	*t* - value	Lag = 1 month	*t* - value	Lag = 2 months	*t* - value	Lag = 3 months	*t* - value
Monthly mean *T*max	-0.2989	-3.2251	-0.3122	-3.3669	-0.3029	-3.2409	-0.1219	-1.2460
Monthly mean *T*min	0.0561	0.5780	0.3150	3.4005	0.4563	5.2295	0.5170	6.1296
Monthly mean daily mean temp	-0.1282	-1.3308	0.0517	0.5306	0.1596	1.6489	0.3073	3.2772
Monthly mean DTR	-0.2507	-2.6659	-0.4826	-5.6457	-0.5984	-7.6158	-0.5283	-6.3145
Monthly mean RH	0.3786	4.2115	0.4785	5.5836	0.4874	5.6931	0.3024	3.2194
Monthly rainfall	0.0857	0.8853	0.2485	2.6283	0.3204	3.4497	0.3873	4.2637

and December. Unlike Malaria, for Dengue, except for minimum temperature, no conclusive information about transmission window for climatic parameter is available in literature. However, for minimum temperature, optimally it is around 11 °C-12 °C (11.9 °C following WHO, 2010).

The transmission of dengue viruses is climate sensitive for several reasons. First, temperature changes affect vector-borne disease transmission and epidemic potential by altering the vector's reproductive rate, biting rate, the extrinsic incubation period of the pathogen, by shifting a vector's geographical range or distribution and increasing or decreasing vector-pathogen-host interaction and thereby affecting host susceptibility [Gratz, 1999].

Second, precipitation affects adult female mosquito density. An increase in the amount of rainfall leads to an increase in available breeding sites which, in turn, leads to an increase in the number of mosquitoes. An increase in the number of adult female mosquitoes increases the odds of a mosquito obtaining a pathogen and transmitting it to a second sensitive host [Kuno, 1997].

Third, a distinct seasonal pattern in dengue haemorrhagic fever (DHF) outbreaks is evident in most places in tropical regions where monsoon weather patterns predominate. DHF hospitalisation rates increases during the rainy season and decrease several months after the cessation of the rains [Gratz, 1993]. This decline may be related to a decrease in mosquito biting activity, a decrease in longevity of female mosquitoes, or both.

Promprou *et al*. (2005) investigated the climatic factors associated with DHF incidence in southern Thailand, using rainfall, rainy days, relative humidity and maximum, minimum, mean temperatures and monthly DHF data. Pearson's correlation coefficient was used to explore the primary association between the DHF incidence and all climatic factors. Step-wise regression technique was then used to fit the statistical model. The result indicated that the mean temperature, rainfall and relative humidity were associated with the DHF incidence in the areas bordering on the Andaman Sea, while minimum temperature, rainy days and relative humidity were associated with the DHF incidence on the Gulf of Thailand side of the southern peninsula.

Chandy *et al*. (2013) attempted to assess the effect of climate on the incidence of dengue in Tamil Nadu. The study uses climate data, *viz.*, rainfall and mean maximum and minimum temperature to assess its association if any,

with dengue incidence in two districts of Tamil Nadu, South India. Results of this study indicates that while precipitation levels have an effect on dengue incidence in Tamil Nadu, non-climatic factors such as presence of breeding sites, vector control and surveillance are important issues that need to be addressed. Ehelepola (2015) examined the interrelationship between dengue incidence and diurnal ranges of temperature and humidity in a Sri Lankan city and its potential applications. They found a negative correlation of dengue incidence withdiurnal temperature range (DTR) with 3.3-week lag when DTR>10 °C and with diurnal humidity range (DHR) with 4-week lag periods when DHR>20%. Additionally, they also found a positive correlations of dengue incidence with DTR when DTR<10°C and with DHR when DHR<15% with 3- and 4-week lag periods, respectively.

3.2.1. *Observed variability of Dengue occurrence on individual Climatic parameter over Pune*

Figs. 2(b-d) and Figs. 2(e-g) show the monthly total number of occurrences of Dengue cases *vis-à-vis* mean monthly maximum temperature, minimum temperature and daily mean temperature, mean monthly DTR, RH and monthly total rainfall. From the former one it is seen that during the period of study over the location of study, in general when these temperatures attain their peak values, then Dengue occurrence is low. From the later one it is seen that when monthly mean DTR has a maximum value then monthly number of dengue cases is a minimum. Also, it is seen that after monthly rainfall attains a peak, a peak in the monthly dengue occurrence cases takes place after approximately 1-3 months.

Table 2 shows the correlation between monthly numbers of dengue cases and mean monthly maximum/minimum temperature, DTR, RH and monthly rainfall at different lags (1-3). It can be seen that the monthly number of Dengue cases, over the location of study, has significant concurrent negative correlation with monthly mean maximum temperature & monthly mean DTR, significant concurrent & lagged (lag 1, 2 & 3 months) positive correlation with monthly mean relative humidity and significant lagged (lag 1, 2 & 3 months) positive correlation with monthly total rainfall.

3.2.2. *Observed variability of Dengue occurrence jointly on two climatic variables over Pune*

Fig. 2(h) shows the monthly total number of occurrences of Dengue cases *vis-à-vis* mean monthly relative humidity and diurnal temperature range. From this figure, it follows that the number of dengue cases appears to be related jointly with Diurnal temperature range and

relative humidity. From the adjoining figure, four hotspots of dengue occurrence can be seen, *viz.*, at RH : 80-85% & DTR : 5-10 °C; RH : 75-80% & DTR : 10-15 °C; RH : 65-70% & DTR approximately 15 °C and RH : 55-60% & DTR approximately 15 °C. First two can be clubbed and it corresponds to the situation of high RH and less DTR. Generally, this situation in Pune& Pimpri-Chinchwad region resembles with South West Monsoon Season. Third one corresponds to pre-monsoon season and fourth one post-monsoon/winter season.

Fig. 2(i) shows the monthly total number of occurrences of Dengue cases *vis-à-vis* mean monthly mean relative humidity and mean temperature. From this figure, it follows that the number of dengue cases appears to be related jointly with monthly mean of daily mean temperature (*T*mean) and relative humidity (Mean RH). Hotspots of occurrences of Dengue found when monthly *T*mean is within 20-25 °C & monthly Mean RH is within 55-60% & 65-70% and when monthly *T*mean is within 25-30 °C & monthly Mean RH is within 75-80%.

Fig. 2(j) shows the joint influence of mean monthly daily mean temperature and DTR on monthly number of Dengue cases. From this figure it can be seen that when mean temp is below 24 °C, then maximum Dengue cases occur at higher DTR (16-18 °C), When mean temp is between 24 & 26 °C , then hot spots are found at DTR 8-12 °C. Above 26 °C, as mean temp increases, dengue occurrence decreases.

4. Conclusions

From the above study, broadly following conclusions can be made:

(*i*) Broadly, there is a decrease in the malaria cases for all months and there is an increase in the dengue cases for all months till 2017.

(*ii*) In any year maximum incidences of Malaria occur during June-September and incidences of Dengue occur during September-November, followed by August & December.

(*iii*) Hotspot for Malaria were observed to be associated with RH between 70-82% and Mean temp 25-30 °C. At a *T*mean of 24-26 °C, Malaria hotspots were found at DTR 6-8 °C.

(*iv*) As regard rainfall, Malaria hotspot found, when monthly total rainfall is between 50-180 mm.

(*v*) Hotspots of occurrences of Dengue were found when monthly *T*mean was within 20-25 °C & monthly Mean

RH is within 55-60% & 65-70% and when monthly *T*mean was within 25-30 °C & monthly Mean RH is within 75-80%.

(*vi*) When mean temp is below 24 °C, then maximum Dengue cases occur at DTR between 16-18 °C, when mean temp is between 24 & 26 °C, then hot spots are found at DTR 8-12 °C. Above 26 °C, as mean temp increases, dengue occurrence decreases.

(*vii*) Monthly number of occurrences of Malaria in Pune & Pimpri-Chinchwad municipal corporation area have significant positive correlation (concurrent & lagged both) with Mean monthly minimum temperature and daily mean temperature. It has significant negative correlation with monthly mean DTR with lag 0 & 1 month, has significant concurrent positive correlation and negative lagged correlation with lag 3 months with monthly mean RH.

(*viii*) Monthly number of Dengue cases, in the region under the jurisdiction of Pune & Pimpri-Chinchwad Municipal Corporation, has significant concurrent negative correlation with monthly mean maximum temperature, monthly mean DTR and monthly mean relative humidity and has significant positive correlation with monthly total rainfall with lag 1, 2 & 3 months.

(*ix*) One limitation of the study is that gradual reduction in cases of malaria from 2010-2018 might have affected the analysis.

Disclaimer

The contents and views expressed in this research paper/article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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