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Meteorological variables and malaria cases based on 12 years data analysis in Dehradun (Uttarakhand) India

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ABSTRACT

An association between meteorological variables and malaria cases in district Dehradun (Uttarakhand), India has been worked out by taking into consideration 12 years data w.e.f. 1999 to 2010. Results revealed occurrence of 14 species of Anopheles mosquitoes with a dominating abundance of An. fluviatilis, An. maculatus, An. stephensi, An. culicifacies, An. subpictus and An. nigerrimus. Pearson's correlation analysis between malaria cases and various meteorological variables (total rainfall, mean of maximum, minimum and mean temperature and relative humidity at 07:19 and 14:19h) at 0, 1, 2 and 3 months lagged periods was conducted. It was gathered that all the variables except relative humidity (early hours i.e., 07:19 h) showed positive correlation with monthly incidence of malaria. Further, highest significant correlation was found between rainfall and MPI ($r = 0.705$; $p<0.0001$) when the data were staggered to allow lag of one-month. Autocorrelation among the independent variables exhibited high positive correlation between monthly mean temperature and minimum temperature (0.962), while highest negative association was found between monthly maximum temperature and relative humidity at early hours i.e., -0.706.

Key words: Malaria incidence, Meteorological variables, Anopheles mosquitoes, correlation analysis, Dehradun, India.

INTRODUCTION

Malaria is one of the most important tropical diseases which remain one of the major public health concerns in most tropical countries of the world with around 225 million cases and nearly one million deaths every year [1]. Despite continuous efforts to curb malaria transmission, the incidence in some parts of the world is reported to be increasing each year. As the disease malaria is the fourth leading cause of human morbidity and mortality with enormous medical, economic and emotional impacts in the world [2, 3], henceforth, it is the need of the hours to find out the actual cause /factors involved in its increasing level.

Malaria is caused by protozoan parasites of the genus *Plasmodium*, the intermediate host of which is the female *Anopheles* mosquito. Like all other mosquitoes, the Anophelines breed in water, each species having its preferred breeding ground, feeding pattern and resting place. For the completion of life cycle of the pathogen as well as of vector mosquito, an ambient temperature is required [4]. As the survival of the mosquito is temperature [5] and rainfall [6,7,8, 9] dependent, thus any change in the range would certainly exert its effect on the mosquito bionomics. In a study on temporal correlation analysis between malaria and meteorological factors in Tibet, it was found that the relative humidity (RH) was the greatest influencing factor, which affected the mosquito survival directly [10].

Meteorological factors have been considered as important drivers of malaria transmission by affecting both malaria parasites and vectors directly or indirectly [11,12]. Besides this, other factors, such as any change in land use patterns and construction of water control could have considerable effects on malaria transmission [13]. Climate change is also expected to affect malaria indirectly by modifying the behavior and geographical distribution of vectors, an important aspect in malaria transmission [14]. Recently, an analysis of spatial and temporal patterns of malaria incidence correlated with climatic factors (temperature, rainfall and humidity) over a period of ten years (1999-2008) in Mozambique revealed that malaria risk increases with maximum temperature over 28^{o}C and humidity at 95% [15]. Earlier, in Hainan (China) while developing a link between spatiotemporal distribution of malaria and climatic factors, it was found that temperature might be a major determinant of malaria epidemics [16].
In India, the principal vectors of malaria are *Anopheles culicifacies*, *An. stephensi* and *An. fluviatilis* in most of the parts [17]. While the role of *An. minimus*, *An. sundaicus*, *An. dirus*, *An. maculatus* and *An. annularis* is restricted to certain areas only. From Dehradun (Uttarakhand) itself, both *An. fluviatilis* and *An. stephensi* have been recorded as vectors of malaria in the past [18,19]. Further, in this regard an article on climate change and malaria in India focuses the likely influence of climate change on vector production and malaria transmission [8]. Others who have contributed on climatological aspects and malaria incidence from Rajasthan [20,21], Madhya Pradesh [22], Uttarakhand [23] and north east India [24] in the Country. In the adjoining countries like Pakistan and Sri Lanka, there are studies made on prediction of malaria cases with rainfall along with humidity [25,26].

According to the reports of Health Department, Uttarakhand (India), in district Dehradun, during the last 12 years, the epidemiological pattern of malaria transmission has been unstable and seasonal from place to place because of differences in altitude and rainfall patterns (unpublished data). More serious is the effect of deforestation in the hill areas in present scenario and thereby its effect on the temperature governing sporogony. Based on survey application on malaria incidence during the last decade or so minor changes in the transmission parameters such as mosquito population density and longevity could have a sustainable impact on *Plasmodium* incubation rate and mosquito vector activities.

In view of this, it is important to identify the forces that drive the proliferation of malaria transmission as a result of above stated changes. Further, there is a lack of proper understanding of the complex interaction between meteorological variability and malaria infections or transmission risk in district Dehradun. Though, any variability due to climate change and malaria transmission risk has been studied on a very minor scale despite increased occurrence of malaria cases in the last 3-4 years, henceforth, it is being initiated to explore any pattern of correlation by taking into consideration 12 years data *w.e.f.* 1999 to 2010.

MATERIALS AND METHODS

Study Area:
The study was conducted at district Dehradun in Uttarakhand state, India, covering altitudinal range of 450-2000 msl, the geographical coordinates of which are approximately 30°01' N and 30°57' N latitude, and 77°37' E and 78°13' E longitude. The district has unique type of climate, best suited for agricultural as well as for human settlement.

Entomological data:
Mosquito collection was done on fortnightly basis using an aspirator and torch-light [27] from both indoor and outdoor resting habitats during morning hours (06:00-08:00 h) because at this time the mosquitoes were found taking rest and it was easy to catch them**.** UV light traps have also been used for mosquito collection. The collected mosquitoes were first narcotised, separated and sorted out genera wise and then identified upto species level using standard keys and catalogues [28, 29, 30].

Disease data collection
It was performed in collaboration with District Malaria Office, Dehradun (Uttarakhand). However, the data on malaria cases for the last 12 years (1999 to 2010) reported from health centers, clinics and hospitals have been

obtained from Uttarakhand Health Directorate, Govt. of Uttarakhand (India). Before compiling the data, private hospitals and Nursing Homes in the vicinity of district were also consulted.

Meteorological data collection

After receiving permission from the Environment & Ecology Division, Forest Research Institute (Govt. of India), Dehradun, the previous 12 year's (1999-2010) mean monthly data on climatological parameters of the study area was obtained. In case there was any confusion or data confirmation of certain locality / month, the Meteorological Department, Uttarakhand State, Survey of India, Dehradun (India) was consulted.

Data analysis:

To observe the correlation between meteorological variables and malaria cases, the monthly malaria cases were regarded as the dependent variables, while meteorological variables such as monthly mean maximum, minimum and mean temperature, total monthly rainfall and monthly relative humidity of two different hours (07:19 & 14:19h), were considered as independent variables. Pearson's correlation analysis was conducted to examine the type and strength of relationship between meteorological variables and malaria cases. Since there might be auto-correlation among independent variables over time, so the analysis was performed accordingly. All data from meteorological and clinical records were checked thoroughly to avoid any inconsistencies.

RESULTS

Anopheline mosquito occurrence in the study area:

In all, 14 species of Anophelines were collected from both indoor and outdoor capture during 1999 - 2010 (Fig. 1). Among the collected species, *Anopheles fluviatilis* was on the top while *An. maculatus* was on the 2nd rank. Others in succeeding order were *An. stephensi*, *An. culicifacies, An. subpictus* and *An. nigerrimus*. There was least population of *An. minimus, An. jeyporiensis, An. gigas* and *An. pulcherrimus*. Further, no specimen of *An. gigas, An. jeyporiensis* and *An. minimus* was found in the year 1999 and 2000. A look on the percentage composition of vector species (reported from the Dehradun in the past) revealed 15.0%, 16.0% and 16.7 % respectively for 1999, 2008 and 2010 in *An. fluviatilis* and for *An. stephensi* it was 18.7%, 20.0% and 14.0% respectively for 1999, 2001 and 2010. However, for *An. culicifacies*, the composition was 12.7%, 14.0% and 15.0% respectively for 1999, 2009 and 2010.
As far as the abundance of other dominating species of *Anopheles* is considered, *An. maculatus*, *An. subpictus* and *An. nigerrimus* contributed 2nd, 5th and 6th level respectively. Besides Anopheline mosquitoes, other dominant groups in the collection belonged to *Aedes, Culex, Armigeres* and *Uranoteania*.

Table 1: Correlation between climatic variables and monthly parasite incidence of malaria in different lag periods.

Climatic variables		Monthly parasite incidence	P-value
Rain	0 month	0.381	<0.0001
	1 month	0.705	<0.0001
	2 months	0.445	<0.0001
	3 months	0.188	<0.0235
T_{Mean}	0 month	0.307	<0.0002
	1 month	0.536	<0.0001
	2 months	0.513	<0.0001
	3 months	0.440	<0.0001
T_{Max}	0 month	0.186	<0.0251
	1 month	0.465	<0.0001
	2 months	0.547	<0.0001
	3 months	0.483	<0.0001
T_{Min}	0 month	0.366	<0.0001
	1 month	0.645	<0.0001
	2 months	0.524	<0.0001
	3 months	0.340	<0.0001
$RH_{(0719\ hrs)}$	0 month	0.102	<0.222
	1 month	-0.235	<0.0044
	2 months	-0.482	<0.0001
	3 months	-0.667	<0.0001
$RH_{(1419\ hrs)}$	0 month	0.395	<0.0001
	1 month	0.432	<0.0001
	2 months	0.215	<0.0049
	3 months	-0.156	<0.0610

Table 2: Auto-correlation among climatic variables in Dehradun, 1999-2010.

	Rain	T_{Mean}	T_{Max}	T_{Min}	$RH_{(0719hrs)}$	$RH_{(1419hrs)}$
Rain	1.00					
T_{Mean}	0.532	1.00				
T_{Max}	0.261	0.936	1.00			
T_{Min}	0.696	0.962	0.813	1.00		
$RH_{(0719hrs)}$	0.136	-0.551	-0.706	-0.383	1.00	
$RH_{(1419hrs)}$	0.770	0.298	-0.012	0.523	0.425	1.00

Rain = Total monthly rainfall
T_{Mean} = *Monthly mean temperature*
T_{Max} = *Monthly mean maximum temperature*
T_{Min} = *Monthly mean minimum temperature*
$RH_{(0719hrs)}$ = *Monthly mean relative humidity at 7 am.*
$RH_{(1419hrs)}$ = *Monthly mean relative humidity at 2 pm.*

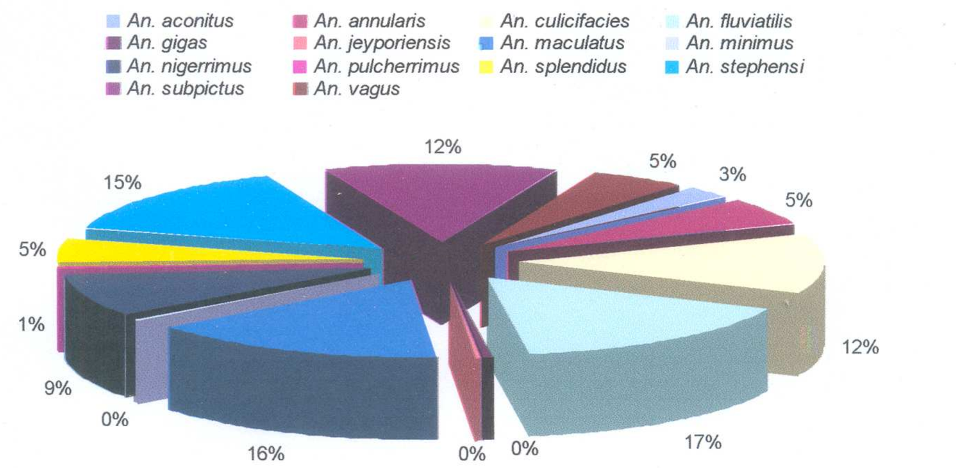

Fig. 1 : Showing composition of Anopheline mosquitoes in Dehradun during the study period.

Trend of meteorological factors in Dehradun, 1999-2010

The study area is generally characterized by a moderate climate with a mean annual maximum and minimum temperature of 28.3°C and 14°C respectively. The annual rainfall ranged from 1354.0 mm to 2717.6 mm. Maximum precipitation (rainfall) occurred during July to September, with minimum in December and January. As per records of Govt. of Uttarakhand, from climatic point of view, abundant rainfall makes this region conducive for agricultural production. Month-wise variations in the selected meteorological parameters *viz*., rainfall, mean temperature, maximum temperature, minimum temperature, early hours relative humidity (07:19 h) and late hour relative humidity (14:19 h) during the study period have been shown in Fig. 2. The rainfall was maximum in 2010 (2717.7 mm) followed by 2007 (2173.3 mm), 2000 (2159.1 mm) and 1999 (1993.1 mm) in succession.

Trend of annual incidence of malaria in Dehradun, 1999–2010

There was remarkable a slightly high incidence of malaria (MPI) in 1999 and thereafter a declining trend during the next successive eight years, *i.e.,* till 2007 in descending order. Again 2008 onwards, the cases increased to maximum in 2009 while a bit decrease in number was recorded in the year 2010. As far as number of malaria cases in each year is concerned, it was 80 in 1999 and decreased in 2000 and 2001 followed by an increase in 2002 (115). Thereafter, it was in descending order till 2007 and again it rises with a maximum in 2010 (528), thus exhibiting a periodic incidence. There has been a high pre-dominance of *P. vivax* over *P. falciparum* within the last 12 years. Further, till 2006 there were no cases of *P. falciparum* but the same has been recorded 2007 onwards. In the year 2010, as many as 55 cases of *P. falciparum* have been recorded (Fig. 3).

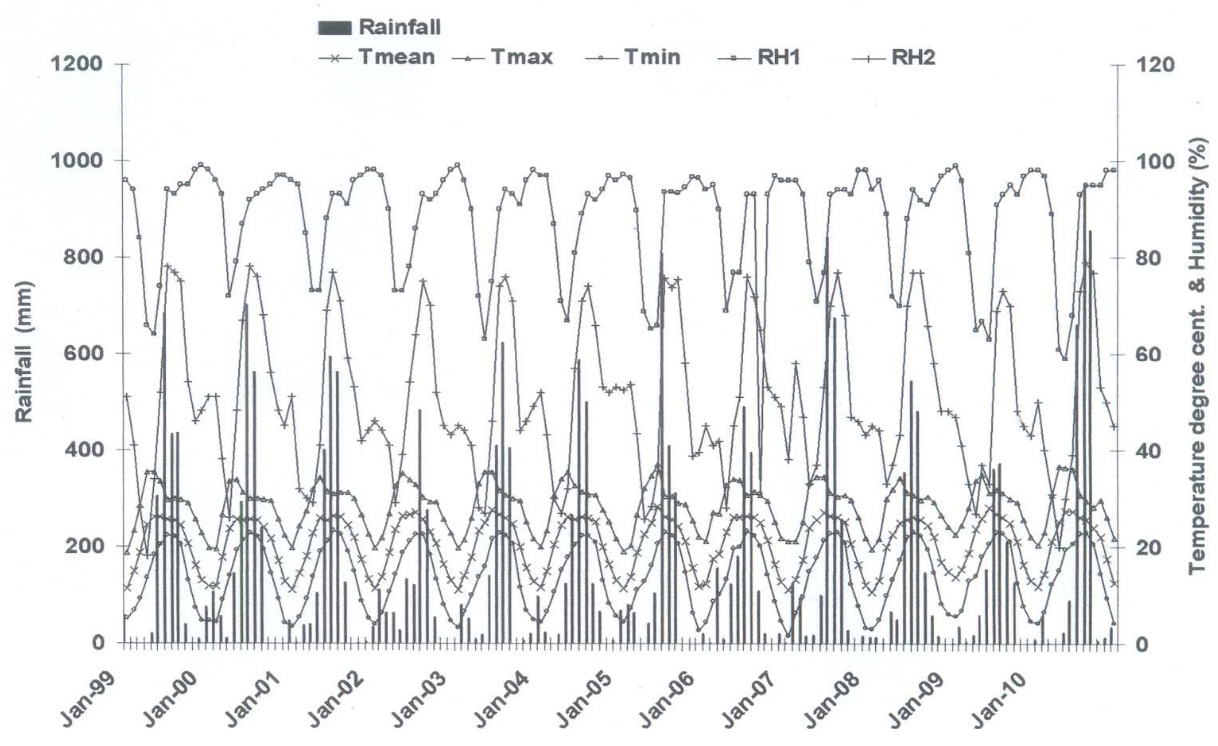

Fig. 2 : Showing Meteorological factors variation in Dehradun during 1999 to 2010.

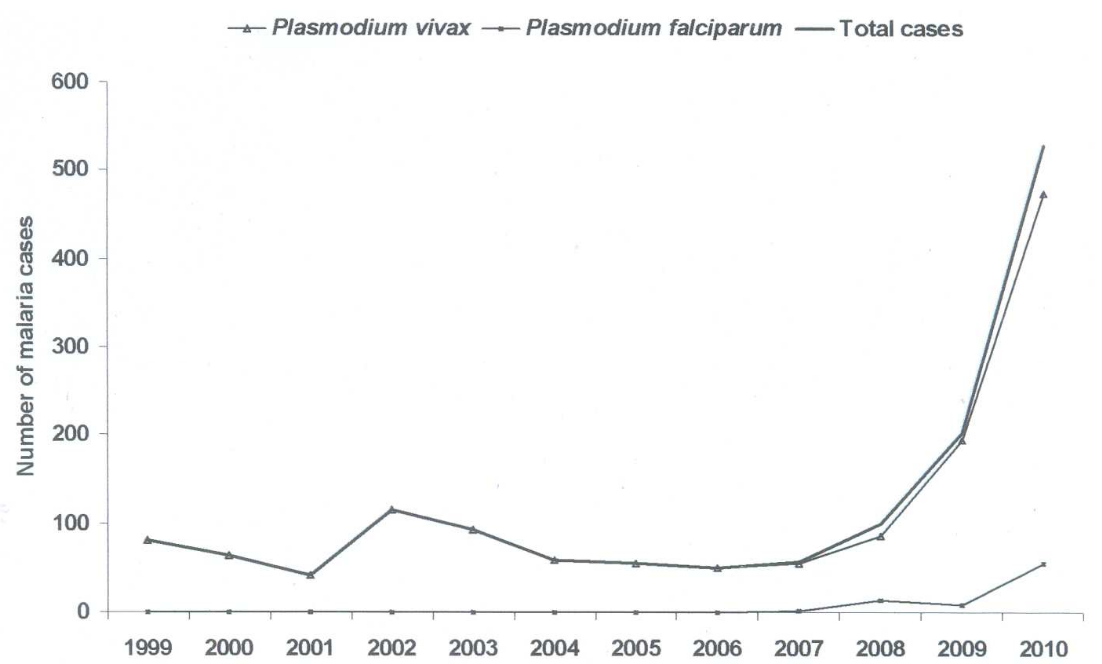

Fig. 3 : Annual trends of total malaria cases (*Plasmodium vivax* and *P. falciparum*) in Dehradun during 1999-2010.

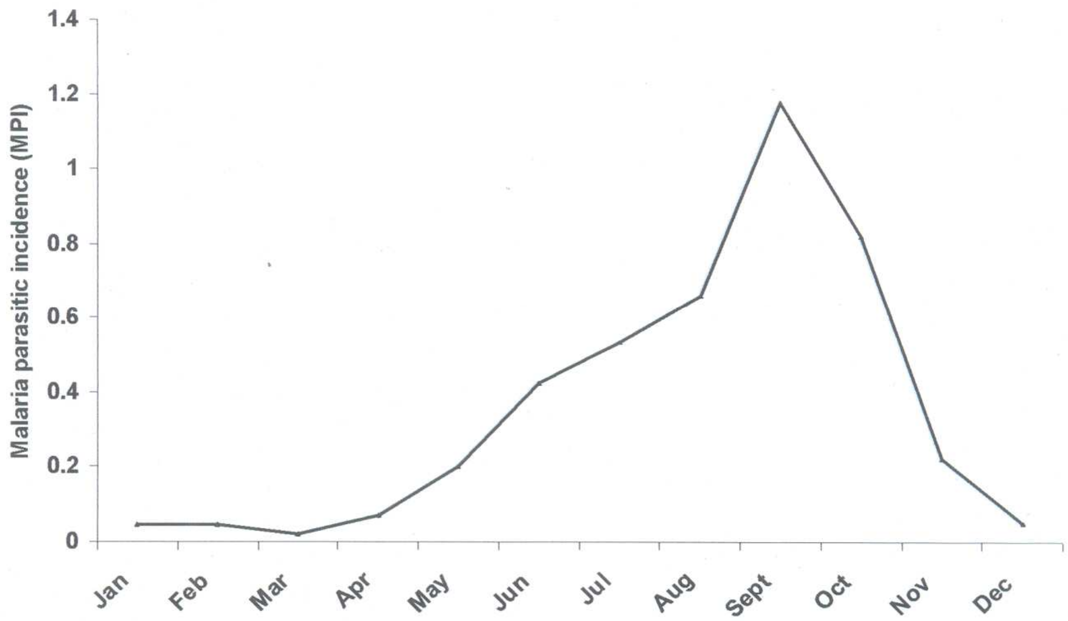

Fig. 4 : Monthly incidence of malaria cases (average) during the study period.

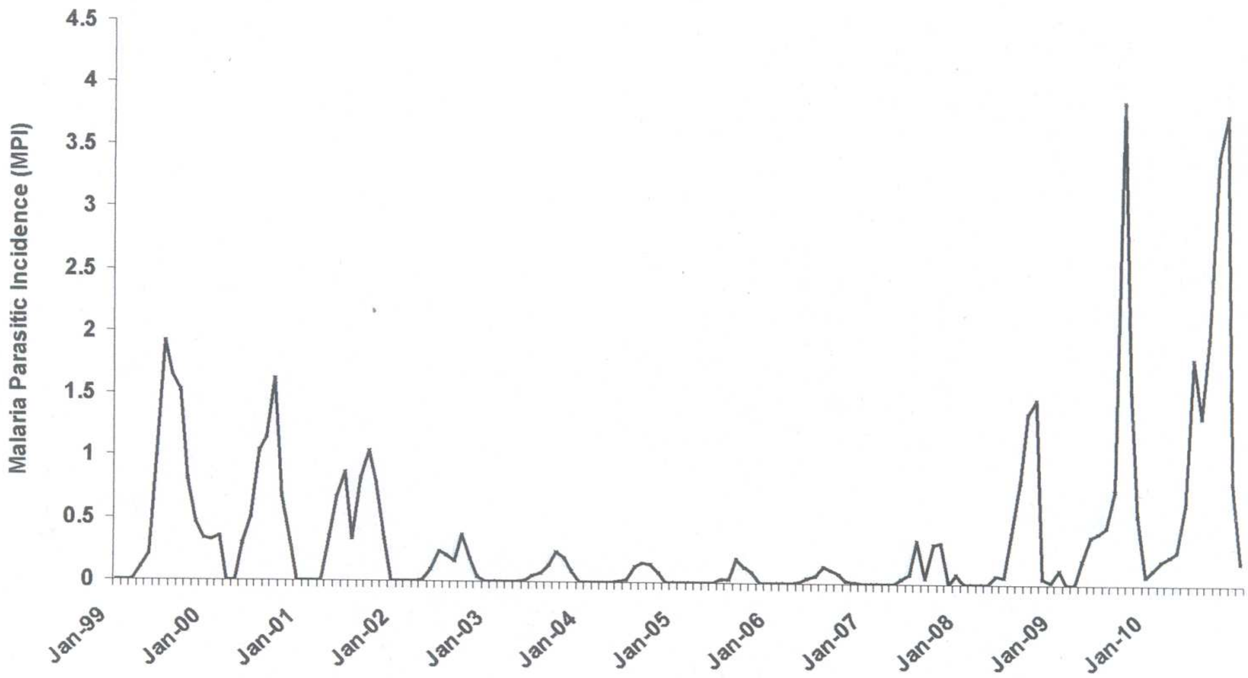

Fig. 5 : Monthly trend of total malaria cases in Dehradun during 1999-2010.

Trend of monthly and seasonal incidence of malaria in Dehradun, 1999–2010:
With regard to monthly variations in the incidence of malaria cases, the peak seasons were monsoon and post-monsoon (mid June to September) while the peak month was September (Fig. 4). Although more cases occurred between May to November but during the winter months (December to February), it was almost negligible. In the years of high incidence *i.e*., 2009 and 2010, the monsoon and post-monsoon period was more pronounced as compared to other seasons. The MPI was recorded in a considerable limit during 1999-2001 and 2008-2010 with less number of cases between 2002 to 2007 (Fig. 5).

Meteorological variables vs. malaria cases
When the data of monthly rainfall and MPI is considered, the rainfall was found highly seasonal (mid June to September) and almost no rains during winter months (December and January). Although malaria cases were seemed to be prevalent throughout the study period, but higher cases were reported in the year 2010 and that too during August-October. At certain points of the year it altered with a slight change. It is noted that average relative humidity at the late hours was in the range of 55 - 80 % which remains conductive to malaria transmission only between June to October. The average temperature remains between the ranges of 14^{o}C to 20^{o}C throughout the year with a change of 1^{o}C from January to December, which falls within the temperature transmission window of malaria. Though during mid June to September, a substantial amount of rainfall is recorded but the malarial cases still persisted in the months when the average rainfall was almost nil or negligible.

An association between monthly malaria cases and meteorological variables (total rainfall, maximum temperature, minimum temperature, mean temperature, relative humidity - early 07:19 h and late 14:19 h) was observed and further checked by Pearson's correlation at zero, one, two months and three months lagged periods. At zero month effect, none of the variables showed negative correlation but highest correlation was shown by relative humidity at late hours (0.395; $p<0.0001$) followed by total monthly rainfall (0.381; $p<0.0001$), monthly minimum temperature (0.366; $p<0.0001$), monthly mean temperature (0.307; $p<0.0002$), monthly maximum temperature (0.186; $p<0.0251$) and relative humidity at early hours (0.102; $p<0.222$) (Table 1).

All the variables except relative humidity of early hours (07:19 h) at 1, 2 and 3 months lagged period and relative humidity at late hours at 3 months lag period showed positive correlation with monthly incidence of malaria. Total rainfall, monthly minimum, mean and maximum temperature and relative humidity at late hours showed consistently stronger correlation with one-month time lag. In case of maximum temperature, highest correlation was found with 2-month lag period. Relative humidity at early hours showed negative correlation with the disease cases except zero month time lags. On the basis of correlation analysis, highest significant correlation was found between rainfall and MPI ($r = 0.705$; $p < 0.0001$) when the data were staggered to allow lag of one-month.

Autocorrelation among the independent variables exhibited high positive correlation between monthly mean temperature and minimum temperature (0.962), followed by monthly mean temperature and maximum temperature (0.936), monthly maximum temperature and minimum temperature (0.813), total rainfall and relative humidity at late hours (0.770) and total rainfall and monthly maximum temperature (0.532). Also, the highest negative association was recorded between monthly maximum temperature and relative humidity at early hours *i.e*., -0.706 (Table 2).

DISCUSSION

In the present findings there was a considerable incidence of malaria (MPI) in 1999 followed by a declining trend till 2007 and again 2008 onwards, the malaria cases increased to maximum in the year 2010, thus showing a periodic incidence. In this regard the findings resemble with the observations made on the periodic epidemics of malaria which was recorded every five to seven years [31, 17].

The three main climate factors that affect malaria are temperature, precipitation and relative humidity [32]. Among these, the temperature in particular has been found to affect life cycle of malarial parasite and the vector mosquito that carries the infection. This collaborates with Bouma and Van der Kaay [33] who pointed out that the climate predicts to a large degree the natural distribution of malaria. The authors are of opinion, that the mosquitoes are cold blooded creatures; hence their developmental stages of life cycle and development of parasite in their body could be affected by temperature, rainfall, relative humidity and wind velocity. In fact, the role of climatic factors has been studied extensively in malaria transmission since a long [11, 12]. As the present scenario is witnessing a major change in climate because of developmental activities in land-use pattern, it is expected that the role of some non-climatic factors if integrated, the actual spread of malaria could be enlightened.

Anopheline mosquitoes just require a right amount of precipitation for breeding purpose but too much rainfall, or rainfall accompanied by storm conditions can flush away breeding larvae [34]. Also, different Anopheline mosquitoes prefer a particular type of water bodies to breed [30]. Not only the amount and intensity of precipitation, but also the time in the year, whether in the wet or dry season, affects malaria survival [35]. The possible explanation could be that the rainfall plays an important role in malaria epidemiology because water not only provides the medium for the aquatic stages of the mosquito's life but also increases the relative humidity and thereby the longevity of the adult mosquitoes [36]. The authors are of the opinion that without sufficient rainfall or water collections mosquitoes cannot proliferate and infect humans. This clearly indicates that the malaria transmission is clearly associated with the rainy season [37].

A combination of the monthly maximum temperature in the range 14 to 29°C and relative humidity in the range 55% to 80% provides suitable conditions for malaria transmission. The negative association attained by maximum temperature in the range of 24 to 27°C to malaria incidence, could indicate a need of warmer temperature for malaria transmission [38]. High levels of humidity is generally observed when temperature and rainfall are also high, thus leading to suitable conditions of parasite development due to available breeding sites and survival of mosquitoes population [39].

In a study on impact of climate change at National and regional level, the transmission windows of malaria based on both temperature and relative humidity in the Himalayan region could have a major role [40]. If the average monthly relative humidity is below 60%, it is believed that the life of the mosquito is so shortened that there is no malaria transmission [32]. Mean temperature, night-time temperature, temperature in combination with rainfall and mean November and December temperature have been found related to malaria in Zimbabwe, the Debre Zeit sector of Ethiopia, Rwanda [41]. In Pakistan, rainfall along with humidity in December, predicted malaria rates fairly well [26] while the present findings are just quite different.

The present study shows higher positive correlation between monthly incidence of malaria and monthly minimum temperature, mean temperature and rainfall with one-month lag effect. The correlation coefficient for the association between monthly rainfall and monthly incidence of malaria was found greater than the association between temperature and malaria incidence. This indicates that rainfall seems to play a more important role in the transmission of the disease than temperature does. Several workers from different places found the same results [42, 43]. Further, the findings of present study are in a bit support with [10] in considering relative humidity having a greater influence than other factors in malaria mapping ; the relative humidity in late hours had more influence than the early hours.

Our findings in respect of one month lag effect are supported by earlier studies [44] who observed a two-week time lag between rainfall and vector abundance in a forest-fringed village of Assam. However, a strongest correlation for a time lag of 9 - 11 weeks between rainfall and malaria has been observed by earlier workers [45]. Due to the nature of biological processes and the degree to which they depend on certain physical factors as altitude, topography, temperature, surface water, vegetation and humidity [46], it seems probable that the time lag between rainfall and malaria would be somewhat region specific.

Although, the total number of cases of malaria in India has stabilized somewhat over the past ten years, while there has been an increase in the number of *P. falciparum* cases [8]. This supports our findings as no case of *P. falciparum* was recorded before 2007, however, from the year 2007 onwards, cases have been recorded with a considerable number of [58] during 2010. Occurrence of *P. falciparum* from 2007 onwards along with *P. vivax* states that transmission of malaria is related to change in climate as for the last 5 years or so, the ecosystem of Dehradun is in changing phase because of intensive urbanization, irrigation, agricultural practices, deforestation, etc. As there is no considerable work on the role of these non-climatic factors, the effect of climate itself on the intrinsic probability of malaria transmission remains controversial. Results of present study envisage that the climate variability that exert its impact on the incubation rate of *P. vivax* and *P. falciparum* and breeding activities of *Anopheles* is considered as the important environmental contributions to malaria transmission dynamics thus resembling to findings made at Uganda [47] and South west Ethiopia [14].

Conclusively, based on the statements as given above it can be mentioned that climate change has emerged as a threat which is likely to affect spatial and temporal distribution of malaria and other mosquito borne diseases. If the climate assessment is integrated with socio-economic factors including agricultural practices, water availability, urbanization and deforestation, it would be a holistic approach in finding out a specific cause in the malaria incidence and transmission.

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