J Vect Borne Dis 43, March 2006, pp. 21–28

Climatic variables and malaria incidence in Dehradun, Uttaranchal, India

N. Pemola Devi & R.K. Jauhari

Parasitology Laboratory, Department of Zoology, D.A.V. (P.G.) College, Dehradun, India

Abstract

Background & objectives: Mosquito-borne diseases particularly malaria and Japanese encephalitis (JE) are becoming most dreaded health problems in Dehradun district. Keeping in view that the climatic factors particularly temperature and rainfall may alter the distribution of vector species– increasing or decreasing the ranges, depending on weather conditions that are favourable or unfavourable for mosquito breeding, it is aimed to find out the effect of climatic factors on malaria incidence with particular emphasis to capture the essential events as a result of climatic variability.

Methods: Mosquito sampling and identification was done using WHO entomological methods and follow-up of recognised keys and catalogues. Data on malaria incidence and meteorological information were gathered in a collaborative study with the District Malaria Office, and the Forest Research Institute, Dehradun respectively. Pearson's correlation analysis was applied for establishing relationship between climate variables and malaria transmission.

Results: Higher positive correlation of association was found between monthly parasite incidence and climatic variables (temperature, rainfall and humidity). However, highest significant correlation was found between rainfall and malaria incidence ($r = 0.718$, $p < 0.0001$) when the data were staggered to allow a lag of one-month.

Interpretation & conclusion: Climatic variables that predict the presence or absence of malaria are likely to be the best suited for forecasting the distribution of this disease at the edges of its range.

Key words Climatic variables – correlation – Dehradun – malaria incidence – mosquito

Introduction

Among vector-borne diseases, the malaria is highly influenced by spatial and temporal changes in the environment, which are introduced mainly, but not exclusively by climate variability. Climate has been established as an important determinant in the distribution of vectors and pathogens[1]. In fact, the physical environment is an important modifier of local climate. Climate variability and the breeding activity of *Anopheles* are considered one of the important environmental contributors to malaria transmission[2]. There is a paucity of literature on climatic variables and malaria transmission from India[3,4] but a considerable amount of work has been carried out in other countries[5-13]. Githeko *et al* [14] assessed the evidence for the past and current impacts of interannual and inter decadal climate variability of vector-borne diseases on a continental basis with the aim of shedding light on the increased likelihood of climate change. As per their views the average global temperature with rise by 1–3.5°C, increases the likelihood of many vector-borne diseases in new areas. Investigations made on the climate change and the resurgence of malaria in the east African highlands revealed, if climate is not changed at the study sites, other changes must have been responsible for the observed increase in malaria[12]. As the malaria vectors are poikilothermic, temperature is a critical variable in malaria epidemiology, for instance in the range of 18–26°C a change of only 1°C in temperature can change a mosquito's life span by more than a week[15]. Previously it was reported that the temperature of 20–30°C and humidity > 60% are optimal for *Anopheles* to survive long enough to acquire and transmit the parasite[2]. Recently, Zhou *et al*[16] demonstrated the important role of climate variability in malaria dynamics in some high land sites. According to them the malaria transmission involves complex interaction between *Plasmodium* parasites, anopheline mosquitoes and humans. It has been observed, if the development time of the pathogen exceeds the life span of the insect, the transmission cannot occur[11].

In the Dehradun Valley, the main vectors of malaria are *Anopheles stephensi*[17] and *An. fluviatilis*[18] (Diptera : Culicidae). For the last couple of years vectors-borne diseases are becoming the most dreaded health problems in the state of Uttaranchal because of developmental activities in one or the other ways. Although many campaigns against these diseases have been conducted, malaria, Japanese encephalitis (JE) and dengue fever are still the major health problems in some of the districts of Uttaranchal particularly, Dehradun, Hardwar, Udham Singh Nagar and Bageshwar (Unpublished report—Uttaranchal Health Directorate, Dehradun). Although, there have been few studies on the relationship between climatic variables and malaria rates in India, many studies have addressed the ways that other factors like urbanisation, irrigation, deforestation and agricultural practices have affected malaria rates. Since no such study has been conducted in the Dehradun Valley, henceforth, it was decided to explore empirical relationship of primary climatic factors with the malaria incidence using Pearson's correlation analysis and to capture the essential events responsible for such variability.

Material & Methods

Study area: The actual site selected for the present study is the Doon Valley in district Dehradun geographically lies between 29°55' and 30°30' N latitude, and 77°35' & 78°20' E longitude. The following four spots—town area of the Valley, Sahaspur, Doiwala and Kalsi were chosen for recording climatic variables vs. malaria incidence.

Entomological data: Mosquito collection was done using aspirator and torch-light[19] from both indoor and outdoor resting habitats during morning hours (0600–0800 hrs) on fortnightly basis between January 1999 and December 2002. The collected mosquitoes were first narcotised, separated and sorted out genera wise and then identified[20-25]. Per man-hour density (PMHD) of vector mosquitoes collected from every possible indoor habitats like human dwellings, cattlesheds and mixed dwellings was calculated using the following formula:

$$PMHD = n \times 60/p \times t$$

(Where, n = Total No. of each mosquito species; p = No. of persons involved during collection; t = Time spent in min)

Meteorological data: The data on monthly maximum, minimum and mean temperature, mean rainfall and mean humidity of two different hours during the study period was obtained in a collaborative study with the Environment and Ecology Division, Forest Research Institute, Dehradun.

Parasitological data: The pattern of annual and monthly parasite incidence is based upon epidemiological data for the years 1999–2002, obtained from the District Malaria Office, Dehradun.

Data analysis: To examine the relationship between the monthly incidence of malaria/parasites and monthly mean temperature—maximum and minimum, monthly rainfall and monthly mean relative humidity of two different hours the calculation was done by applying Pearson's correlation analysis. A correlation of PMHD of vectors with malaria parasite incidence (MPI) and rainfall has also been developed to make the conclusion more informative.

Results

Mosquito prevalence in the Doon Valley: As many as 10 species of anopheline mosquitoes were collected during the study period. The collection includes both indoor and outdoor capture (Table 1). *An. subpictus* was predominant species followed by *An. stephensi*, *An. vagus*, *An. maculatus*, *An. fluviatilis*, *An. culicifacies*, *An. annularis*, *An. nigerrimus*, *An. splendidus* and *An. aconitus* in succession. The known primary vectors of malaria—*An. culicifacies*, *An. fluviatilis* and *An. stephensi* constituted 37.47% of the total anopheline population. Besides the anopheline mosquitoes other dominant groups in the collection belonged to *Culex mimeticus*, *Cx. vishnui*, *Cx. quinquefasciatus* and *Aedes albopictus* (Diptera: Culicidae).

Annual/Monthly incidence of malaria in Dehradun, 1999–2002: There was remarkable high incidence of malaria in 1999 which showed a declining trend during the next successive three years. With regard to monthly variations in the incidence of malaria cases the peak seasons were monsoon and post-monsoon (June to September) (Fig. 1). Although incidence occurred between May to November but during the winter months (December to February), it was almost negligible. In the years of high incidence—1999 and 2000, the monsoon and post-monsoon (June to September) peak was more pronounced as compared to other years.

Correlation between climatic variables and monthly incidence of malaria: Pearson's correlation analysis

Table 1. Anopheline mosquitoes collected from different habitats of study areas in District Dehradun

Anopheline species	Town area of Valley		Sahaspur		Doiwala		Kalsi		Total
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	
An. aconitus	105	0	78	1	29	0	35	3	251 (2.62)
An. annularis	275	0	113	3	87	2	121	8	609 (6.34)
An. culicifacies	297	3	213	6	175	2	283	10	989 (10.30)
An. fluviatilis	316	2	197	4	218	4	346	23	1110 (11.56)
An. maculatus	370	11	288	9	328	12	231	15	1264 (13.17)
An. nigerrimus	48	4	223	13	109	9	177	15	598 (6.23)
An. splendidus	87	4	67	1	78	4	76	2	319 (3.32)
An. stephensi	387	8	257	8	271	11	542	14	1498 (15.61)
An. subpictus	472	12	358	20	371	5	338	4	1580 (16.46)
An. vagus	305	5	372	11	352	3	327	1	1376 (14.34)
Total	2662	49	2166	76	2018	52	2476	95	9594 (100)

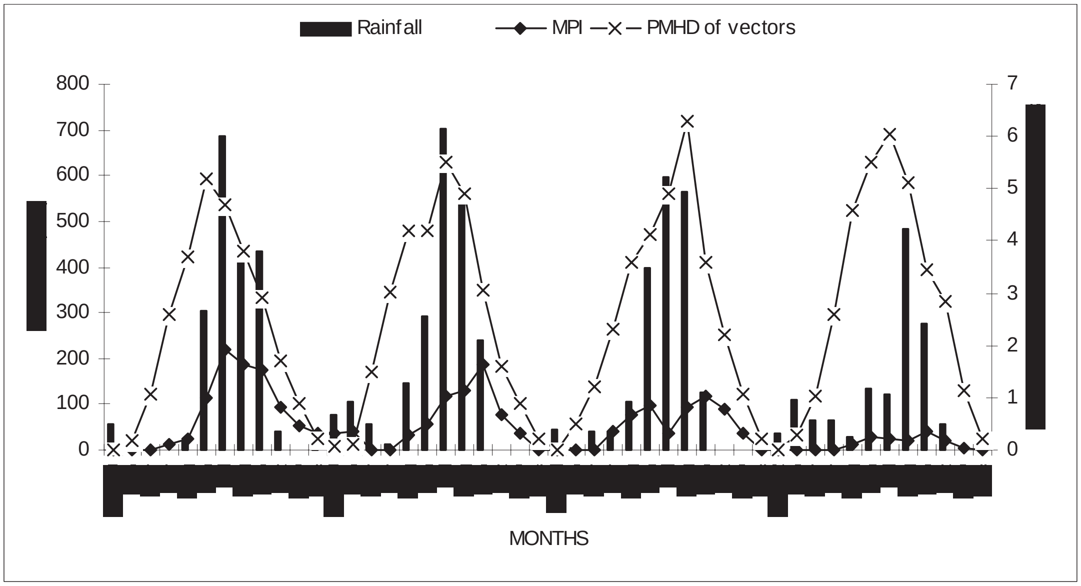

Fig. 1: Monthly rainfall, PMHD of vectors and MPI in Dehradun during 1999–2002

was conducted relating to monthly incidence of malaria vs. monthly climatic measures (temperature, rainfall and relative humidity) following different lagged periods (Table 2). All the variables showed positive correlation with the monthly incidence of malaria. Mean, minimum temperature and rainfall showed consistently stronger correlation with a one-month time lag. Less correlation was found with lags of 0, 2 or 3 months. In case of maximum temperature, highest correlation was found with two-month period lag. All correlation between relative humidity (different hours) and monthly incidence of malaria with different lag periods were very low. But highest correlation was found during 0 period lag, 0.114 in 0719 hrs and 0.692 in 1419 hrs. Relative humidity (RH) of 1419 hrs showed more positive relation with malaria incidence. On the basis of correlation analysis, highest significant correlation was found between rainfall and malaria incidence ($r = 0.718$; $p < 0.0001$) when the data were staggered to allow a lag of one-month.

When the data of monthly rainfall, vector density and monthly parasite incidence were plotted, the rainfall was found highly seasonal with maximum in July and almost no rain between November and December (Fig. 1). Although malaria cases were seemed to be prevalent throughout the years, higher incidence of malaria cases was mostly found during August and September. When rainfall was more, higher number of malaria cases were recorded. At some points there was a slight change, which may be due to other factors. As far as the vector density is concerned, there was a shoot up in the PMHD of vectors with corresponding increase in rainfall and MPI. In general, it can be mentioned here that PMHD of vectors showed a direct relationship to rainfall and MPI. Both the MPI and rainfall data showed statistically positive correlation with PMHD ($r = 0.482$; $p > 0.001$ and $r = 0.695$; $p < 0.0001$) of vectors.

Discussion

The transmission of malaria is determined by climatic, non climatic and biological factors. The climatic factors include all the independent variables like temperature, rainfall, humidity, etc. while the non climatic factors are human activities, socio-economic conditions like developmental changes, housing and living conditions, adopted control measures, local ecological environment (vegetation, introduc-

Table 2. Correlation between climatic variables and monthly parasite incidence of malaria in the study area

Climatic variables	Month(s)	Monthly parasite incidence	p-value
T_{max}	0	0.322	< 0.02
	1	0.491	< 0.0001
	2	0.567	< 0.0001
	3	0.523	< 0.0001
T_{min}	0	0.617	< 0.0001
	1	0.705	< 0.0001
	2	0.602	< 0.0001
	3	0.349	< 0.01
T_{mean}	0	0.509	< 0.0001
	1	0.636	< 0.0001
	2	0.613	< 0.0001
	3	0.444	< 0.001
Rain	0	0.667	< 0.0001
	1	0.718	< 0.0001
	2	0.555	< 0.001
	3	0.182	< 0.05
RH	0	0.114	< 0.05
(0719 hrs)	1	–0.235	< 0.05
	2	–0.502	< 0.05
	3	–0.667	< 0.05
RH	0	0.692	< 0.0001
(1419 hrs)	1	0.532	< 0.0001
	2	0.217	< 0.05
	3	–0.176	< 0.05

tion of irrigation schemes) and drug resistance in malaria parasites. The biological factors comprise abundance of *Anopheles* species, the propensity and frequency of the mosquitoes to bite human beings, its susceptibility to the parasite, the longevity of mosquitoes, the rate at which the parasite developes in mosquitoes, aquatic stages of immature, etc. that are depended on independent climatic variables[13]. It is already mentioned that climatic variables exhibit impact on the incubation rate of *Plasmodium* parasites and the breeding of *Anopheles* and thus considered as the important environmental contributors to malaria transmission[2].

The present study shows higher positive correlation between monthly incidence of malaria and monthly minimum temperature, mean temperature and rainfall with a one-month lag effect. The correlation coefficient for the association between monthly rainfall and monthly incidence of malaria was found greater than that for 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[13,26,27] found the same results. Moreover, it has been previously shown that a strong positive association exists between the incidence of falciparum malaria and rainfall[28,29]. Just contrast to this Poveda *et al* [30] found no significant association between entomological variables and primary climatic factors to which the authors do not agree.

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[2]. The impact of rainfall on the transmission of malaria is very complicated, varying with the circumstances of a particular geographic region and depending on the local habits of mosquitoes. Rains may prove beneficial to mosquito breeding if it is moderate, but may destroy breeding sites and flush out the mosquito larvae when it is excessive[2]. The authors agree with this statement and in particular with establishment of an interrelationship between climatic variability and breeding of anophelines.

The study reveals highest correlation between rainfall and malaria with a lag of one-month. Estimates for the duration of lag period include 15 days for the preimaginal development of vector *Anopheles,* 4–7 days for the gonadotrophic cycle for parous/nulliparous female mosquitoes and 12 days for the sporogonic cycle for the *Plasmodium falciparum* parasites in the vector mosquitoes[31]. In fact about 30 days are needed for the development of a new generation of infective female insect vectors.

Many processes get accomplished between the onset of rains and appearance of malaria cases. After a heavy rain, there is a possibility for water to recede so as to provide new breeding sites. Further, time is needed for larvae to hatch, mature pupae and form adults, for the adult female to find an infected host and become infected itself and for completion of sporogonic development of malaria parasite within the vector. Additional time may be required for the infected mosquito to bite an uninfected host.

Our findings in respect of one month lag effect are supported by earlier studies of Prakash *et al*[32] who observed a two-week time lag between rainfall and vector abundance in a forest-fringed villages of Assam. The authors also agree to the fact that rainfall also increases the rate at which humans were bitten[33]. In the dry zone of Sri Lanka, two-month time lag between rainfall and increased malaria was observed[34]. However, Vanderwal and Paulton[35] found strongest correlation for a time lag of 9–11 weeks between rainfall and malaria. Due to the nature of biological processes and the degree to which they depend on such physical factors as altitude, topography, temperature, surface water, vegetation and humidity[36], it seems probable that the time lag between rainfall and malaria would be somewhat region specific. Peng *et al*[13] reported highest positive correlation between monthly incidence of malaria and monthly mean minimum temperature with a one-month lag effect. A rise in temperature, especially minimum temperature, would, in some locations, enhance the survival chances of *Plasmodium* and *Anopheles* during winter and thus accelerates the transmission dynamics of malaria and spread it into populations that are currently malaria-free and immunologically naïve[5].

If annual parasitic index (API) or monthly parasitic index (MPI) are directly related to climate, it should be possible to predict malaria outbreak before its occurrence, either to strengthen control measures enough to prevent the outbreaks or at least to create adequate facilities for the appropriate treatments. As long-term weather forecasting becomes more accurate, it may even be possible to forecast the weather that might trigger an outbreak[29]. Rainfall provides the breeding sites for mosquitoes and increases relative humidity necessary for mosquito survival, leading to increase in the number of mosquitoes biting an individual per unit time, the human biting rate[33,37,38]. The authors are of the opinion that without sufficient rainfall or water collections mosquitoes cannot proliferate and infect humans.

Although malaria cases usually occur after periods of heavy rainfall, excessive rainfall does not always trigger an epidemic[39]. On the contrary a negative correlation was observed between rainfall and malaria incidence in a nine years study on Colombian Pacific coast[40]. Hicks and Majid[41] believed that it was high humidity, not the total rainfall that was the key factor leading to an epidemic. In Madhya Pradesh, weak correlation was observed between the number of rainy days and the incidence of malaria[4].

Conclusively, the climatic variables that predict the presence or absence of malaria are likely to be best suited for forecasting the distribution of this disease at the edges of its range. However, the transmission of malaria is very complicated and detailed ecological and epidemiological studies are still needed to assess the true local risk factors.

Acknowledgement

The authors are grateful to the District Malaria Officer, Health Directorate, Uttaranchal and the Officer Incharge, Environment and Ecology Division, Forest Research Institute, Dehradun for providing relevant data on malaria cases and climatic factors of some parts of Dehradun. The financial assistance rendered by DST and CSIR, New Delhi is gratefully acknowledged.

References

1. Gill CA. The role of meteorology in malaria. *Indian J Med Res* 1921; *8*: 633–93.
2. McMichael AJ, Martens WJM. The health impact of global climate changes: grasping with scenarios, predictive models and multiple uncertainties. *Ecosyst Hlth* 1995; *1:* 23–33.
3. Akhtar R, McMichael AJ. Rainfall and malaria outbreaks in western Rajasthan. *Lancet* 1996; *648* (ii): 1457–8.
4. Singh N, Sharma VP. Patterns of rainfall and malaria in Madhya Pradesh, central India. *Ann Trop Med Parasitol* 2002; *96*(4): 349–59.
5. Loevinsohn ME. Climatic warming and increased malaria incidence in Rwanda. *Lancet* 1994; *343:* 714–8.
6. Martens WJ. Climate change and malaria: exploring the risks. *Med War* 1995; *11:* 202–13.
7. Martin PH, Lefebvre MG. Malaria and climate: sensitivity of malaria potential transmission to climate. *Ambio* 1995; *24:* 200–7.
8. Bryan JH, Foley DH, Sutherst RW. Malaria transmission and climate change in Australia. *Med J Aust* 1996; *164:* 345–7.
9. Lindsay SW, Birley MH. Climate change and malaria transmission. *Ann Trop Med Parasitol* 1996; *90:* 573–88.
10. Kilian AH, Langi P, Talisuna A, Kabagambe G. Rainfall pattern, El Nino and malaria in Uganda. *Trans R Soc Trop Med Hyg* 1999; *93:* 22–3.
11. Reiter P. Climate change and mosquito-borne disease. *Environ Hlth Perspect* 2001; *109:* 141–61.
12. Hay SI, Cox J, Rogers DJ, Randolph SE, Stern DI, Shanks GD, Myers MF, Snow RW. Climate change and the resurgence of malaria in the East African highlands. *Nature* 2002; *415:* 905–9.
13. Peng Bt, Tong S, Donald K, Parton KA Jinfa Nt. Climatic variables and transmission of malaria: A 12-year data analysis in Shuchen County, China. *Pub Hlth Rep* 2003; *118:* 65–71.
14. Githeko AK, Lindsay SW, Confalonieri UE, Patz JA. Climate change and vector-borne diseases: a regional analysis. *Bull WHO* 2000; *78*(9): 1136–47.
15. Jepson WF, Moutia A, Courtois C. The malaria problem in Mauritius: The bionomics of Mauritian anophelines. *Bull Entomol Res* 1947; *38:* 177–208.
16. Zhou G, Minakawa N, Githeko AK, Yan G. Association between climate variability and malaria epidemics in the East African highlands. *Proc Nat Acad Sci*, USA 2004; *101*(8): 2375–80.
17. Singh RP, Singh S, Jauhari RK. Incrimination of *Anopheles stephensi* Liston, 1901 as a vector of malaria in south-eastern Doon Valley. *J Parasit Appl Anim Biol* 1994; *3*(2): 103–5.
18. Mahesh RK, Jauhari RK. Incrimination of *Anopheles fluviatilis* James, 1902 as a vector of malaria in forested areas of Doon Valley. *Indian J Forestry* 2001; *24:* 72–6.
19. *Manual on practical entomology in malaria vector bionomics and organization of antimalaria activities*. Pt I & II. Geneva: WHO 1975 (Offset Publication).
20. Christophers SR. *The Fauna of British India including Ceylon and Burma.* Diptera, v IV (Family: Culicidae, Tribe Anopheline). London : Taylor and Francis 1933, p. 371.
21. Barraud PJ. *The Fauna of British India, Ceylon and Burma*. Diptera v V (Family : Culicidae, Tribe Megarhinini and Culicini). London : Taylor and Francis 1934, p. 463.
22. Wattal BL, Kalra NL. Region wise pictorial keys to the female Indian *Anopheles*. *Bull Nat Soc Ind Mal Mosq Dis* 1961; *9*(2): 85–138.
23. Knight KL, Stone A. *A catalogue of the mosquitoes of the World* (Diptera: Culicidae). Maryland : The Thomas Say Foundation, Entomological Society of America 1977; p. 611.
24. Darsie RF Jr, Pradhan SP. The mosquitoes of Nepal: their identification and biology. *Mosq Syst* 1990; *22*(2): 69–130.
25. Nagpal BN, Sharma VP. *Indian Anophelines*. New Delhi: Oxford and IBH Publishing Co. Pvt. Ltd. 1995; p. 1–416.
26. Greenwood BM, Pickering HA. A malaria control trial using insecticide-treated bednets and targeted chemoprophylaxis in a rural area of the Gambia, West Africa. *Trans R Soc Trop Med Hyg* 1993; *87*(Suppl 2): 3–11.
27. Ramasamy R, Ramasamy MS, Wijesundera DA Wijesundera AP, Dewit I, Ranasinghe C. High seasonal malaria transmission rates in the intermediate rainfall zone of Sri Lanka. *Ann Trop Med Parasitol* 1992; *86:* 591–600.

28. Gupta R. Correlation of rainfall with upsurge of malaria in Rajasthan. *J Assoc Phys Ind* 1996; *44:* 385–9.

29. Bouma MJ, Dya C, Van der Kay HJ. *Falciparum* malaria and climate change in the Northwest Frontier Province of Pakistan. *Am J Trop Med Hyg* 1996; *55*(2): 131–7.

30. Poveda G, Rojas W, Quinones ML, Velez ID, Mantilla RI, Ruiz D, Zuluaga JS, Rua GL. Coupling between annual and ENSO timescales in the malaria-climate association in Colombia. *Env Hlth Perspectives* 2001; *109:* 489–93.

31. Molez JF, Desenfant P, Jacques JR. Bio-ecologie en Haiti d'*Anopheles albimanus* Wiedemann, 1820 (Diptera: Culicidae). *Bull Soc Pathol Exot* 1998; *91*(4): 334–9.

32. Prakash A, Bhattacharyya DR, Mohapatra PK, Mahanta J. Seasonal prevalence of *Anopheles dirus* and malaria transmission in a forest fringed village of Assam, India. *Indian J Malariol* 1997; *34:* 117–25.

33. Onori E, Grab B. Indicators for forecasting of malaria epidemics. *Bull WHO* 1980; *58:* 91–8.

34. Van der Hoek W, Konradsen F, Perera D, Amerasinghe PH, Amerasinghe FP. Correlation between rainfall and malaria in the dry zone of Sri Lanka. *Ann Trop Med Parasitol* 1997; *91*(8): 945–9.

35. Vanderwal T, Paulton R. Malaria in the Limbe river valley of northern Haiti: a hospital-based retrospective study, 1975-1997. *Rev Panam Salud Publica* 2000; *7*(3): 162–7.

36. Woube M. Geographical distribution and dramatic increases in incidences of malaria: consequences of the resettlement scheme in Gambela, South-west Ethiopia. *Indian J Malariol* 1997; *34:* 140–63.

37. Mahmood F, McDonald MB. Ecology of malaria transmission and vector capacity of *An. culicifacies* species A in rural Punjab, Pakistan. *Pakistan J Med Res* 1985; *24:* 95–106.

38. Lindsay SW, Martens WJM. Malaria in the African highlands: past, present and future. *Bull WHO* 1998; *76*(1): 33–45.

39. Zulueta JDE, Mujtaba SM, Shah IH. Malaria control and long-term periodicity of the disease in Pakistan. *Trans R Soc Trop Med Hyg* 1980; *74:* 624–32.

40. Gonzalez JM, Olano V, Vergara J, Arevalo-Herrera M, Carrasquilla G, Herrera S Lopez, JA. Unstable, low-level transmission of malaria on the Colombian Pacific coast. *Ann Trop Med Parasitol* 1997; *91:* 349–58.

41. Hicks EP, Majid SA. A study of the epidemiology of malaria in a Punjab district. *Rec Mal Surv Ind* 1937; *7:* 1–46.

Corresponding author: Dr. R.K. Jauhari, Reader, Parasitology Laboratory, Department of Zoology, D.A.V. (P.G.) College, Dehradun–248 001, Uttaranchal, India.
e-mail: jauharirk@hotmail.com