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Introduction, transmission and aggravation of malaria in desert ecosystem of Rajasthan, India

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Abstract

Background & objectives: Malaria is an important public health problem in northwestern desert part of Rajasthan. Since desert malaria is seasonal or unstable, there is a need to study its epidemiology in the totality to address factors like how malaria is introduced into desert every year and what are desert-specific transmission risk factors leading to epidemics?

Methods: Twenty-six villages in irrigated, semi-irrigated and non-irrigated settings of the desert have been selected. Periodic investigations were undertaken in all the seasons from 2001 through 2002 to determine causes of introduction of disease, the factors involved in its transmission and the epidemic risk factors. Standard methods/procedures for mosquito collection, preservation and identification and for parasitological studies were employed. Rainfall data were analysed and correlated.

Results: Importation of malaria infection through individuals was the major cause of introduction of disease in all the 12 villages showing some initial load of infection. Areas having higher population of cattle in relation to humans (human to cattle ratio of 1:25) had less transmission of disease (ratio of primary to secondary cases 1:3) as compared to relatively less cattle (human to cattle ratio 1:3) resulting into high transmission of disease with 1:47 ratio of primary to secondary cases. Introduced through migration, prospective transmission of malaria was observed as a resultant interaction of density of three components namely malaria cases, vector density and cattle to human ratio. Rainfall more than average when coupled with more cases of imported malaria leads to the eruption of malaria epidemics.

Interpretation & conclusion: Importation of malaria cases was the major cause of seasonal introduction of malaria in the desert. This initial or primary parasitic load available in a village leads to a particular transmission quantum depending upon the density of vectors, human and cattle population at a particular time. Areas with more imported cases when coupled with profuse vector population lead to epidemic malaria situations in the desert.

Key words Desert – epidemiology – importation of cases – malaria

Introduction

Malaria is a major public health problem in all the districts including desert part of Rajasthan. The disease appears in this region as a seasonal outbreak. Moreover, as the ecology of desert does not support the breeding and survival of vector mosquito species, therefore, the transmission and epidemic risk factors of malaria in this region are not same as in other parts and requires an in-depth study. Earlier, many authors have attempted to explain causes of malaria in desert implicating different risk factors from time-to-time [1,2]. Earlier workers on malaria[3–11] have emphasised the need to overview malaria as interacting system of man, mosquito and environment in the form of what has been termed as anthropoecosystem of malaria.

Thus, a comprehensive study was started in 26 villages representing irrigated, semi-irrigated and non-irrigated areas of Jaisalmer and Jodhpur districts of Rajasthan from August 2001 through July 2002 to study the means of introduction of disease into desert, factors associated with its prospective transmission and causal factors for epidemic outbreaks.

In the present study the epidemiology of malaria in desert has been studied with respect to three distinct research questions: what is the source of malaria?; in unstable or seasonal malaria foci of desert where year round transmission does not take place, what controls transmission of malaria in desert ecology?; and what aggravates this situation of malaria to present in epidemic form?

Material & Methods

Study areas: The present investigation was conducted in three different areas— (a) canal irrigated area for more than 20 years (setting I), (b) canal irrigated area for 10 years (setting II) and (c) an area without any irrigation system (setting III). Periodic investigations were undertaken from August 2001 to July 2002. Details of each study setting are given below:

Setting I: The area called Jaisalmer district is situated at 26.18 ^{o}N latitude and 73.04 ^{o}E longitude, represents a true desert ecosystem with irrigation through Indira Gandhi canal system for about 20 years. Ten study villages have been selected from this area. The area is characterised by extremes of temperature, lowest relative humidity in entire country and sparse far-flung population pockets in the vicinity of sand dunes. Rearing of cattle is a common means of earning and native human population migrate to adjacent states during months of March–April and return to their homes sometime during August. Ambient temperature ranges from as low as 1–2^{o}C in winters (January) to as high as 49^{o}C in summer (April to June). Soil is sandy composed of silica quartz predominantly and is loose and shifting type along with flow of winds.

Setting II: This area represents a desert area called *Phalodi* region situated at about 26.55^{o}N latitude and 70.57^{o}E longitudes. From irrigation point of view this area is supplied with branches of main canal present in setting I. This study was conducted in 11 villages from this area. This area represents desert ecology with less degree of desertification as compared to setting I and is having access to irrigation system for past ten years. Cattle rearing is the main source of livelihood and the population is of migratory type with almost similar timings of migration as in setting I. This area also exhibits extremes of ambient temperature and relative humidity like setting I.

Setting III: This study area called *Balesar* region is also desert ecosystem but unlike other settings and does not have any canal irrigation system. From this area five study villages were chosen. This area is also having sparse and migrating human population, cattle rearing as main source of livelihood and erratic rainfall, extremes of temperature and low relative humidity.

In all the 26 villages, three point investigations were conducted as first study, first follow-up and second follow-up covering each season, with a gap of 15 days. The observations for rainy season were recorded in August to October, for winter season in December to February and for summer season in April to July.

A fever case showing positive blood slide for malaria parasite was recorded as a case. The malaria cases present in a village during the first study (August-October 2001) in the rainy season were considered as primary cases and origin of these primary cases was enquired to determine whether initial infection in the village is imported or indigenous. After completing the studies regarding origin of introduction of infection, the subsequent observations in all the villages were made with respect to the type of vector species and its density, number of secondary cases and associated details of human and cattle density in the study villages. These investigations were made to understand interaction of components participating in the transmission of malaria in each village. The density of vector species with particular initial or primary load of infection was recorded in each village and secondary cases resulting by virtue of their interaction were observed during subsequent investigations. In addition, corresponding densities of humans and cattles in study villages were also recorded. Since all the details required to study the transmission factors of malaria in all the villages could not be collected we present here the data of 10 villages only in Setting I and II where all the required information was available. Of the four anopheline species encountered during field investigations, only densities of known vector species in the area— *Anopheles stephensi, An. culicifacies* and *An. annularis* have been taken into account, while density of *An. subpictus* has not been included.

For determining the causal risk factors for erupting epidemics in the desert, retrospective data of malaria incidence were analysed in relation to rainfall, magnitude of imported malaria, increasing or decreasing trend of slide positivity rate and mosquito density.

Mosquito collection and identification: Mosquitoes were collected with the help of suction tube and a torch during early morning (dawn) and evening (dusk) hours. The resting and bait collections were made from human dwellings as well as from cattle sheds. Density of mosquitoes was calculated in terms of adults caught per man hour (PMH). Field collected specimens were preserved dry and brought to the laboratory for species identification using standard keys[12].

Blood meal source analysis: In all the study villages wherever fed anopheline mosquitoes were collected, these were subjected to precipitin test following Gel-diffusion method[13] to identify blood meal taken by mosquitoes.

Parasitic examination: Blood slide examination reports of all the fever cases present in each study village were recorded from the hospital or subcentre of the study village.

Statistical analysis: Correlation coefficient was calculated for the association between imported malaria and total number of cases present during the beginning of the season in study villages. Chi-square analysis was done for the different associations in study villages between cattle density and malaria transmission.

Results

It was observed that in villages in setting I, in six out of 10 villages (60% of villages studied) all of malaria positive patients were inward migrants in last 2–3 days. In one village (10% of villages studied), one out of two patients showed history of inward migration and in two villages the current patients did not show any history of migration. In the villages of Setting II, out of three villages with some load of initial malaria, in one village 100%; in the second village 75% and in the third village 66% of initial load of disease was contributed by imported infection. In all other villages of this setting, no malaria incidence was observed during initial phase of season. In the villages of setting III, all the two villages which showed malaria in the beginning of season, 100% patients were inward migrants. The details are furnished in Table 1.

It was obvious from the observations that malaria appears to be introduced into desert through imported infection. However, to further confirm this aspect, age group of cases was enquired and none of the patients was found to be an infant. Presence of an infant as a malaria case normally indicates the local transmission, which was not observed in the present study (Table 1). Correlation coefficient applied between the association of total cases and migrated fever cases showed significant statistical association (r = 0.86). To exclude the possibility of malaria persistence in the region due to asymptomatic carriers of infection, 100 subjects at random were examined from normal population (without any clinical symptom of malaria) that showed no evidence of malaria parasite.

Table 2 shows observations on the association of human and cattle population and average vector density with transmission strength of malaria in the study villages. In village Tejpala vector density was highest (45 PMH) of all the study villages but malaria transmission ratio was 1:3 only. This low transmission strength was associated with high cattle density (1:25) in the village (Table 2). In village Lawah vector density was 6 PMH but due to less cattle in the village (1:3) the transmission of malaria was high (1:47). When human to cattle ratio was further less (1:1) in the village Roopsi even with 10 PMH density of vector, malaria transmission strength rose to 1:88. Almost in all the villages more cattle density was associated with low transmission strength of the disease and vice versa (Table 2).

Table 1. Study of introduction of malaria in study villages during August to December 2001

Village/ Setting	No. of cases in beginning of season	No. of cases migrated (%)
Setting I		
Deva	2	2 (100)
Moorani	2	2 (100)
Lawah	1	1 (100)
Khuri	1	1 (100)
Ashada	1	1 (100)
Tejsi	1	1 (100)
Tejpala	4	2 (50)
Brahamsar	2	0 (0)
Roopsi	1	0 (0)
Seuwa	0	0 (0)
Setting II		
Jor	2	2 (100)
Godarli	4	3 (75)
Bhojo ki Bap	3	2 (66.6)
Bhadeura	0	0 (0)
Chainpura	0	0 (0)
Kheerva	0	0 (0)
Malar	0	0 (0)
Paleena	0	0 (0)
Ren	0	0 (0)
Sonda	0	0 (0)
Shekhasar	0	0 (0)
Setting III		
Balesar	1	1 (100)
Bambore	1	1 (100)
Khari Beri	0	0 (0)
Dhandhaniya	0	0 (0)
Agolai	0	0 (0)

The observations with respect to association of malaria transmission strength with cattle density was further probed with the question whether more availability of cattle increases zoophilic index (ZI) of vector species or vice versa to exert a corresponding influence on malaria transmission strength in the study villages. The blood-fed mosquitoes could be collected from only six villages (from four in setting I and two in setting II) and hence data are depicted for six villages in Table 3. The observations show that more cattle lead to increased ZI which reduces transmission strength in spite of higher vector density (Table 3).

Table 4 shows malaria situation in two subsequent years—2001 and 2002 with former being the year of normal rainfall and latter a drought year. In setting I during the year 2001 outbreak of malaria had taken place. In this setting when average annual rainfall was 341 cm, average mosquito density in the villages was 70 PMH associated with 60% of malaria cases being imported from outside. As a result, annual SPR was 12.8% in this setting during the year (Table 4). In the same area during 2002 (drought year), when average annual rainfall was 63 cm only, mosquito density was reduced to 50 PMH, the corresponding value of migrated malaria was zero (SPR 0) throughout the year (Table 4). Similar trend of association of rainfall,

Table 2. Transmission of malaria in relation to densities of man, vector and cattle

Setting/ Village	Human population	Cattle population	Vector population* (Average PMH)	Ratio of Human: Cattle	Inward migrated cases	Cases due to local transmission	Transmission strength
Setting I							
Tejpala	1151	29000	45	1:25	4	15	1:3
Lawah	2640	7612	6	1:3	1	47	1:47
Roopsi	1315	1980	10	1:1	1	88	1:88
Khuri	1605	4660	25	1:3	1	34	1:34
Moorani	1460	2200	9	1:1	2	2	1:1
Brahamsar	935	1750	34	1:2	2	2	1:1
Deva	1975	14050	23	1:7	2	2	1:1
Setting II							
Jor	1100	1700	41	1:1	2	3	1:1
Godarli	550	7330	8	1:13	4	0	1:0
Bhojo ki Bap	300	2405	1	1:8	3	1	1:0

*Densities of *An. stephensi*, *An. culicifacies* and *An. annularis.*

Table 3. Association of malaria transmission, human and cattle population densities and blood meal preference of vector species

Setting/Village	Human to cattle ratio	Average vector density (PMH)	Blood meal preference			Transmission strength primary to secondary cases ratio
			AI	ZI	MBI (%)	
Setting I						
Tejpala	1:25	45	0	44.44	55.5	1:3
Khuri	1:3	25	0	0	100.0	1:34
Roopsi	1:1	10	0	24.8	55.1	1:88
Lawah	1:3	6	0	20.0	80.0	1:47
Setting II						
Godarli	1:1	8	100	0	0	1:0
Jor	1:1	41	4.4	44.44	51.1	1:1

AI—Anthropophilic index; ZI—Zoophilic index; MBI—Mixed blood index.

anopheline density and migrated malaria with annual malaria magnitude (SPR) was observed in settings II and III also (Table 4). These observations show that normal or excessive rainfall combined with increased imported cases of malaria formed a combination of epidemic risk factors in desert situations.

Discussion

The data clearly show that in the beginning of malaria season in the desert, infection was predominantly introduced by inward migrated population. The other possible means of disease appearance such as asymptomatic cases or relapse cases of preceding months, were also studied and excluded. Desert area represents a single crop region and due to frequent droughts, natives tend to migrate to adjacent states and as a result possibility of malaria being imported into regions is increased when these natives return to their homes at the onset of good rains next year. Sim-

Table 4. Association of rainfall, mosquito densities, migrated malaria cases and resultant malaria magnitude in study villages during the years 2001–02

Years/Study setting	Rainfall in setting (cm)	Average anopheline density (PMH)	% migrated malaria cases	Malaria magnitude (SPR)
2001				
Setting I	341	70	60.0	12.8
Setting II	430	79	70.0	9.8
Setting III	430	100	100.0	18.1
2002				
Setting I	63	50	0	0
Setting II	38.5	27	0	0
Setting III	38.5	30	0	0

SPR—Slide positivity rate; PMH—Per man hour; Data pertain to 10 villages in setting I, 11 villages in setting II and 5 villages in setting III.

ilar views on the migration as possible risk factors of desert malaria have been made by earlier workers also[4,5]. However, epidemiological significance of this aspect in unstable malaria zones such as Rajasthan has not yet been realised. In fact, identification of such cases and their management could serve as an effective preventive measure against disease. Such entry of infection can be checked through a check post at a central place in the group of some adjacent villages and each inward-migrant can be examined for the presence of malaria parasite through examination of a blood film during beginning of rainy season and can be treated to ensure interruption at possible dissemination of parasite by them. Adoption of this strategy may be feasible and cost-effective.

Study of association of malaria transmission with density of the vector, human host and cattle has been made for the first time assuming that a village represents a malaria system and in this system primary cases of malaria, interact with density of vector and bait population (cattle and human) to lead to a particular quantum of secondary infection. It was also observed that transmission of malaria in a given setting is associated with the density of cattle, human and vector species. This interesting association is understandable because risk of malaria transmission has to be associated with the biting preference of available mosquito species on vertebrate host (man or cattle). Abundance of non-human or cattle bait in a village will reduce transmission risk indirectly by protecting humans from the bites of zoophilic species[6]—*An. stephensi* and *An. culicifacies.* The association emerging here may not be enough to serve as confirmed predictor of transmission potential of an area but it opens a new way of thinking in which in addition to vector density, cattle population density may also be considered to evaluate transmission risk potential of an area. The point that emerges is that for effective control strategy of malaria in a desert setting an overall or anthropoecological view of the disease has to be kept in mind to treat the components of disease cycle as per their merit. The determinants of transmission could sometimes be those factors which have indirect association with the disease cycle rather than directly related factors such as causative organism, vector and parasitic density.

It has been a common observation that increased rainfall is frequently associated with epidemics of malaria in desert. The contention studied in the present paper was that can rain be the predictor of malaria epidemics in desert? Excess rains may provide more breeding sites for mosquitoes and better ambient humidity for adults to survive but it may be an infection amplifying factor only in the presence of parasite in the community in unstable malaria zone, the presence of parasite is not ensured throughout the year. Therefore, density of mosquito vectors in these areas is a dependent risk factor on the availability of parasite in the settings as far as its role as disease aggravation agent is concerned. Our studies made in two subsequent years one of which was a year of normal rainfall and other was a drought year, showed that conditions where more rainfalls meet more imported malaria cases will actually serve as the set of epidemic risk factors. Following inferences can be drawn on the basis of the studies reported in the present paper: In unstable malaria zones which are characterised by well-marked beginning and ending of morbidity, sequence of studying epidemiology of disease should be; study of introduction of disease, its prospective transmission and determination of factors aggravating malaria to epidemic levels. The studies of isolated factors of irrigation canals, mosquitoes some peculiar mosquito habitats or El-Nino effects, etc. as reported in past[1,2] may not serve the purpose of formulating an effective malaria control strategy for desert ecosystem. Our observations suggest that in desert, primary risk factor or introducing agent of malaria is the inward-migration of diseased population which can be treated as the preventive tool against malaria. Our studies further suggest that once introduced into desert villages through inward-migration, quantum of prospective malaria transmission is controlled as combined action of vector density and density of vertebrate blood meal baits, man and cattle. Present study further suggests that less rainfall in desert, in addition to exert influence on mosquito density, also influences inward-migration of human population. More rains, thus, combined with more migrated population forms epidemic risk factors of malaria in the Indian desert.

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