2

Malaria

Malaria cases in India ranged between 2 and 3 million after the resurgence in 1976 and in the last five years there has been a decrease and the reported cases were less than 2 million with 1.86 in 2003, 1.92 in 2004, 1.82 in 2005, 1.79 in 2006 and 1.52 in 2007. In recent years, there has been an increase in the proportion of *Plasmodium falciparum* contributing 55–60% to the total malaria cases every year, and this is followed by *P. vivax* (40–43%) and *P. malariae* which contributes to 1–2% of the cases. It is felt that the devastation of malaria in India is much more than what is being reported because of poor surveillance. Furthermore, malaria not being a notified disease, cases treated by private practitioners, and non-governmental agencies do not get included in the report of the national malaria control programme. Malaria transmission dynamics in India is complex with 9–10 *Anopheles* species (some of these are species complexes as well) with distinct biological characters acting as vectors in different parts of the country.

In India, there is a lot of diversity in terrain features, ecological conditions, prevalence of anopheline vector species and their biology, and immune status of people, which are causing differential malaria endemicity. Hence, there is a need to identify areas with similar malaria transmission potential and responses to malaria control tools and strategies. Different entomological, parasitological and environmental parameters can be and have been used to stratify the areas. Global malaria control strategy of the 1990s recommends identification of clearly recognizable eco-epidemiological types, namely malaria paradigms for local analysis and formation of effective control strategies. Malariogenic stratification of areas for suitable and effective control is one of the best strategies. With this background, two studies using RS and GIS application were initiated: (i) to delineate malaria paradigms at micro level and identify eco-epidemiological characters of paradigms in an epidemic prone area; and (ii) to identify malaria receptivity of different paradigms in an area with high malaria endemicity.

Anopheline fauna in India comprises 58 morphologically distinguishable species. Out of these, nine species are responsible for malaria transmission in India. Mosquito species establish their population in most suited eco-environment for their survival and longevity. There have been extensive and repeated surveys to map the distribution of anopheline species in general and vector species in particular, but large areas still remain unexplored. Furthermore, the increasing trend of change in environment that is rapidly changing vector distribution demands frequent surveys to monitor vector distribution. To identify species specific ecological parameters and to map the distribution of vectors in India, a third project has been initiated in which a GIS based technique has been evolved to for the anopheline species of India. Another project was initiated to use Remote sensing to identify the land use features specific to the villages where *Anopheles culicifacies*, the major malaria vector is prevalent.

2.1 RS and GIS in the Delineation of Malaria Paradigms at Micro-level to Identify Eco-epidemiological Characters of Paradigms in Mewat Region, Haryana State

The study was carried out by National Institute of Malaria Research (the then Malaria Research Centre), Delhi in collaboration with Haryana Space Application Centre (HARSAC), Hissar, Haryana from 2000–03.

In October 1996, high malaria incidence with deaths were reported from villages of Community Health Centres (blocks), Nuh and Ferozpur Jhirka of Mewat region of District Gurgaon, Haryana state (Source: Directorate of the National Anti Malaria Programme (now renamed as National Vector Borne Disease Control Programme, Delhi). The epidemic occurred due to unprecedented inundation of flood waters from the adjoining Rajasthan state. Investigation of the epidemic revealed that *Plasmodium falciparum* was the predominant species followed by *P. vivax*. In some blocks *P. falciparum* prevalence was as high as 87%, and *Anopheles culicifacies* was the major anopheline species found and was also incriminated. *An. annularis* was found in large numbers while *An. stephensi* was found only in a few blocks.

The study was carried out in this epidemic prone area with an objective to stratify the area to delineate malaria paradigms at macro-level to identify malaria receptivity and vulnerability of different eco-epidemiological areas. Maps on land use, slope, drainage, watershed, village and block boundaries, etc. were procured from HARSAC. Malaria data consisting of year-wise (1991–2001) annual parasite incidence (API), species-wise malaria cases and total population of the area were procured from the District Malaria Office, Gurgaon. Section-wise map and other attribute information were collected from the Mewat Development Agency.

Mewat region is situated between 26° and 30° N latitudes and 76° and 78° E longitude and is located about 120 km south of Delhi. It comprises six blocks, Nuh, Nagina, Taroru, Ferozpur Jhirka, and Punhana in Gurgaon district and a small portion of Hatin block in Faridabad district in Haryana state (Figure 1).

This region has 491 villages in 84 sections with a population of 0.9 million. The area has uneven topography with plain and undulating patches of land sandwiched between the two parallel ranges of Aravali hills. These ranges run 5–10 km apart and pass through the area north-south. Mewat region falls under subtropical and semi-arid climatic zones. The region normally gets on an average 480 mm rainfall within 25–30 days. Even this is erratic and shows great variation. Relatively low humidity and high velocity desiccating winds are of common occurrence in summer. The area experiences sporadic droughts. Agriculture is rain-fed, and there is no major industry in the region except for mining work and 62% of the population is below the poverty line.

Following ecological parameters were used in the study:

(i) District, block, section and village boundaries, road net work, habitation/settlement areas, and settlement locations to map entomological and parasitological data from ground surveys, and to identify boundaries of malaria paradigms;

(ii) Water bodies, drainage/stream/canal system, water shed boundaries, rain fall to estimate availability of surface water to correlate with vector breeding and consequently malaria receptivity;

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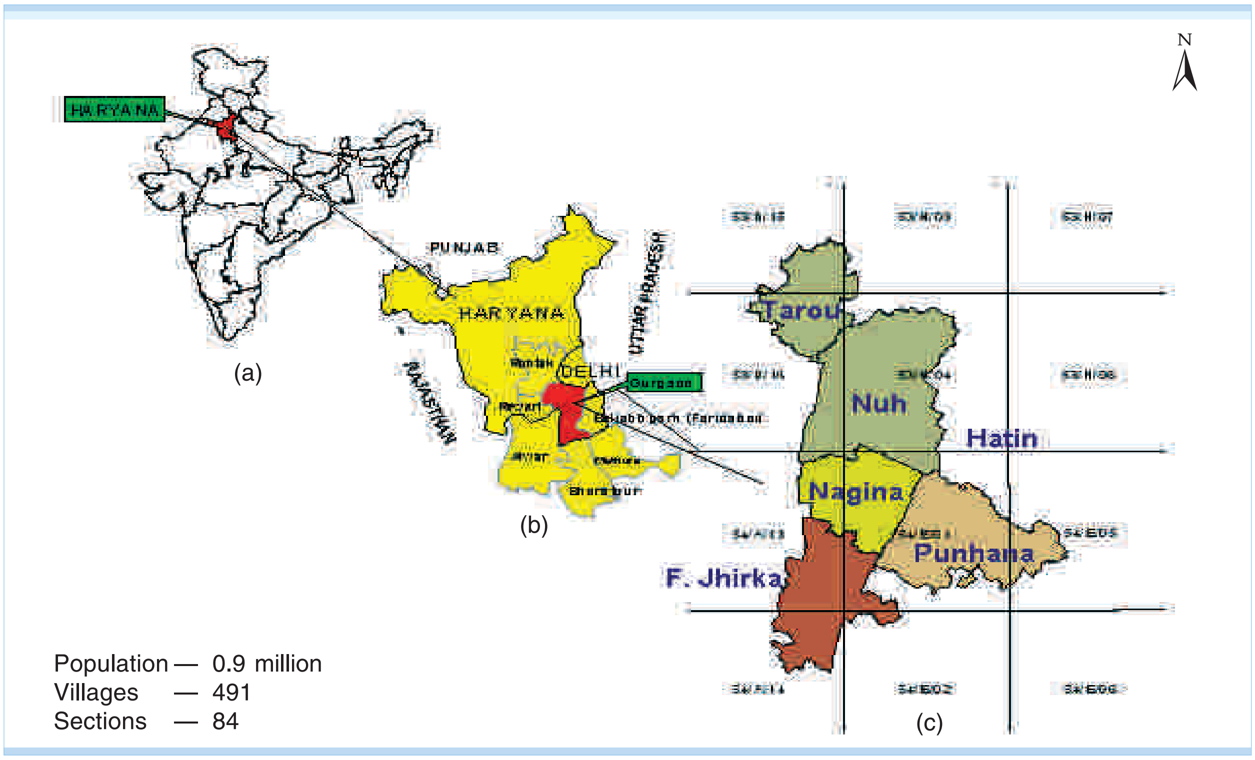


Figure 1: Location of the study area in (a) India, (b) Haryana state and (c) Mewat region

(iii) Elevation, slope, contour, spot light, and soil type to map areas receptive to water logging and water harvesting;

(iv) Location of mines and urban towns to identify vulnerable and receptive areas for malaria and to associate socio-economic practices with malaria; and

(v) Parasitological and entomological data and disease control operations in the area for trend analysis for determining different epidemic phases, and to identify sections of active malaria and their epidemiological charaterstics in relation to malaria paradigms.

Thematic maps of the selected parameters were prepared using RS images, ground survey data and survey of India topo-sheets in the scale of 1: 50, 000. GIS Arc/Info NT and Arc View 3.1 were used to overlay, integrate and analyze the maps. A GIS data base was generated by linking spatial attribute information with digitized map.

GIS analysis based on geographic reconnaissance, and ecological and socio-economic profile demarcated five malaria paradigms, namely Command, Catchment, Mining, Urban and Flood prone areas (Figure 2), which exhibited different eco-epidemiological features (Table 1). In Mewat region, there are two Command areas: AI–Dubalu minor area, and AII– Banarsi-Umra-Gangwani minor. Administrative sections falling in different paradigms were identified and extracted using GIS.

Malaria incidence of sections falling in each paradigm for the years 1991 to 2001 were pooled to estimate paradigm-wise malaria receptivity and trend. A detailed examination and analysis of malaria in a span of 11 years (1991-2001) in Mewat region led to classification of these years into different epidemic phases, namely 1991-93 as inter-epidemic with the API below 5, 1994–95 as pre-epidemic with API of 7, 1996 as epidemic phase (Figure 3). In 1996, API was around 33, statistically more than average $\pm$ 2 SD.

Table 1. Eco-epidemiological characteristics of malaria paradigms

Malaria Paradigm	Characteristics
1. Irrigated areas (a) A I: 68 sq km Command area	• Irrigated by Dubalu minor • Two crops, i.e. *Rabi* (winter) and *Kharif* (monsoon) • Very few seepages/leakages from canal system • Few villages with piped water supply • Live stock in good numbers • Inhabited by farmers with lower economic background • *An. culicifacies* breeding potential low
(b) A II: 320 sq km Command area	• Irrigated by network of canal minors • Water reservoirs, viz. Kotla lake formed due to natural drainage • Leakages/seepages from canal system • Vulnerable to floods • Some villages with piped water supply with *An. stephensi* breeding potential • Two crops—*Rabi* and *Kharif* • Live stock in good number • Inhabited by farmers of high to low economic background • *An. culicifacies* breading potential high
2. Catchment area	• Tapping of run off water by check dams/canalization • One crop only (*Kharif* in monsoon season) • Horticulture/Poultry—secondary income generating occupations • Vulnerable to inundation of flood water • Displacement of population in case of heavy inundation • Marginalized and poor farmers
3. Flood prone areas	• Encompasses the central and southern catchment and irrigated command A II areas • Provide additional potential for breeding of *An. culicifacies*, the vector species • Aggravate malaria situation in the absence of adequate drainage • Displacement of human and cattle population if flooding is enormous
4. Mining areas	• Restricted to hilly ranges of Aravali • Heavy excavations with water stagnation • High potential for *An. culicifacies* breeding i.e. high receptivity • Potential for importing infections through migratory labour high • Vulnerable to local/focal out breaks of malaria
5. Semi-urban/urban areas	• Water storage practices resulting from piped water supply • Potential for importing infections through migratory labour • High probability of low grade malaria transmission maintained by *An. stephensi*

During the epidemic period (1996), different paradigms responded differently. The urban/semi-urban paradigm had the maximum API of 45. In flood prone Command area A II and catchment area, the API was 40, in mining area it was 20 and in Command area AI it was 10. In 1997 there was a declining trend in the API in all the paradigms and by 1998 the API was as low as 2. Therefore, 1997 was classified as post-epidemic and 1998 onwards as inter-epidemic period. In the following years, API further declined and reached 0.5 in all the paradigms (Figure 4).

Spatio-temporal distribution map of malaria for the years 1991 to 2001 depicted spatial spread, i.e. in 1993 and 1998, the years with similar malaria situation in the inter-epidemic periods, flood prone paradigm, irrigation command area II and non-catchment area retained active pockets of malaria transmission, and amplification started in 1994–95 (pre-epidemic phase), which spread to all paradigms by 1996 (epidemic year).

Although rainfall did not correlate well with malaria when over all Mewat region is considered, rainfall correlated well with malaria in Taoru ($r = 0.75$, $p = < 0.05$), Nagina ($r = 0.86$), $p = < 0.05$) and Ferozpur Jhirka ($r = 0.84$, $p = < 0.05$) blocks, and in Nuh ($r = 0.59$, $p = > 0.05$), and Punhana ($r = 0.804$,

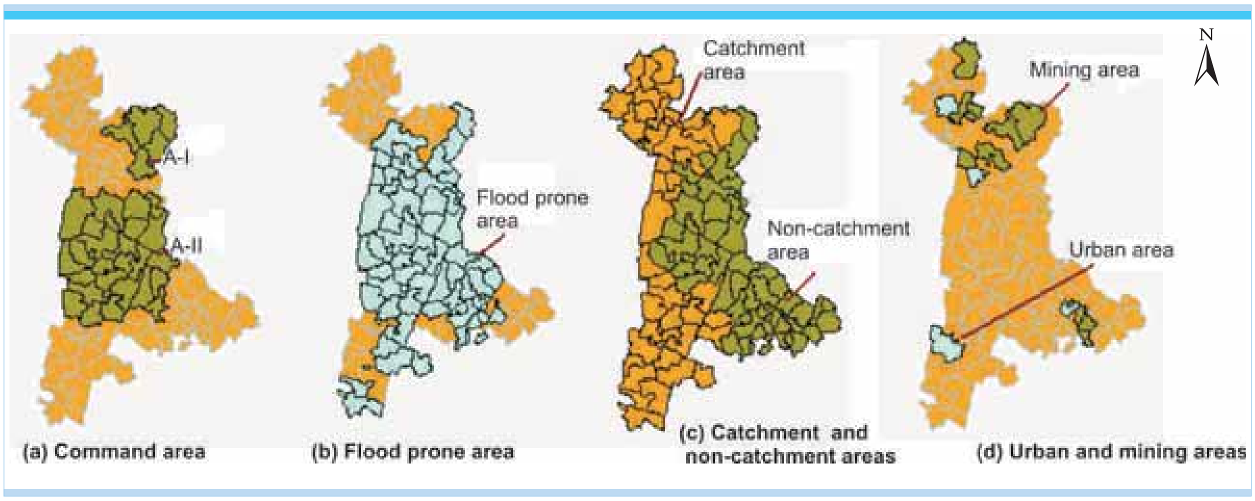


Figure 2: Five malaria paradigms identified in Mewat region – (a) Command areas I & II, (b) Flood prone area, (c) Catchment and non-catchment areas, and (d) Urban and Mining areas

$p = > 0.05$) it correlated poorly with malaria. All the sections in Nuh and Punhana blocks fall in the three paradigms, flood prone, irrigated command AII area and non-catchment, which have retained active malaria transmission even during inter-epidemic years (1993 and 1998) and thus did not correlate well with rainfall. It appears that any ecological change in the scenario of these three paradigms may lead to increase in malaria and spread to other paradigms leading to epidemic situation.

GIS analysis of Mewat region based on geographical reconnaissance, and ecological and socio-economic profile demarcated five malaria paradigms. And it also identified that flood prone, irrigated command AII area and non-catchment paradigms that retained malaria transmission during inter-

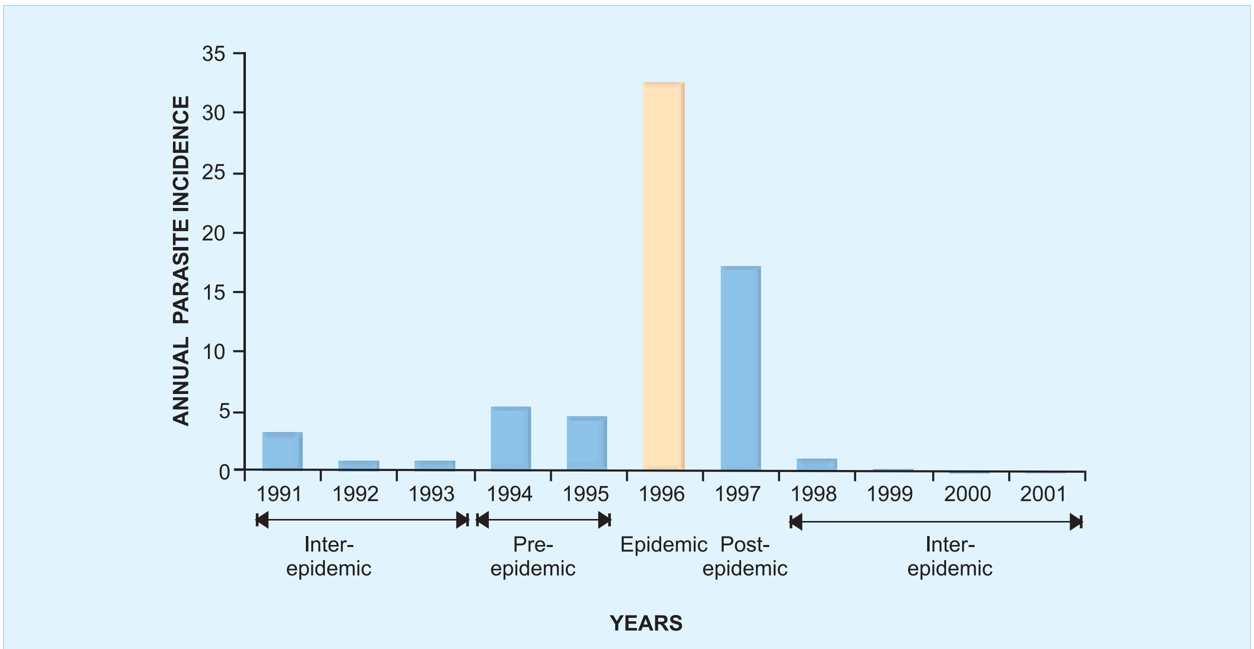


Figure 3: Classification of years from 1991–2001 into different malaria epidemic phases in the Mewat region

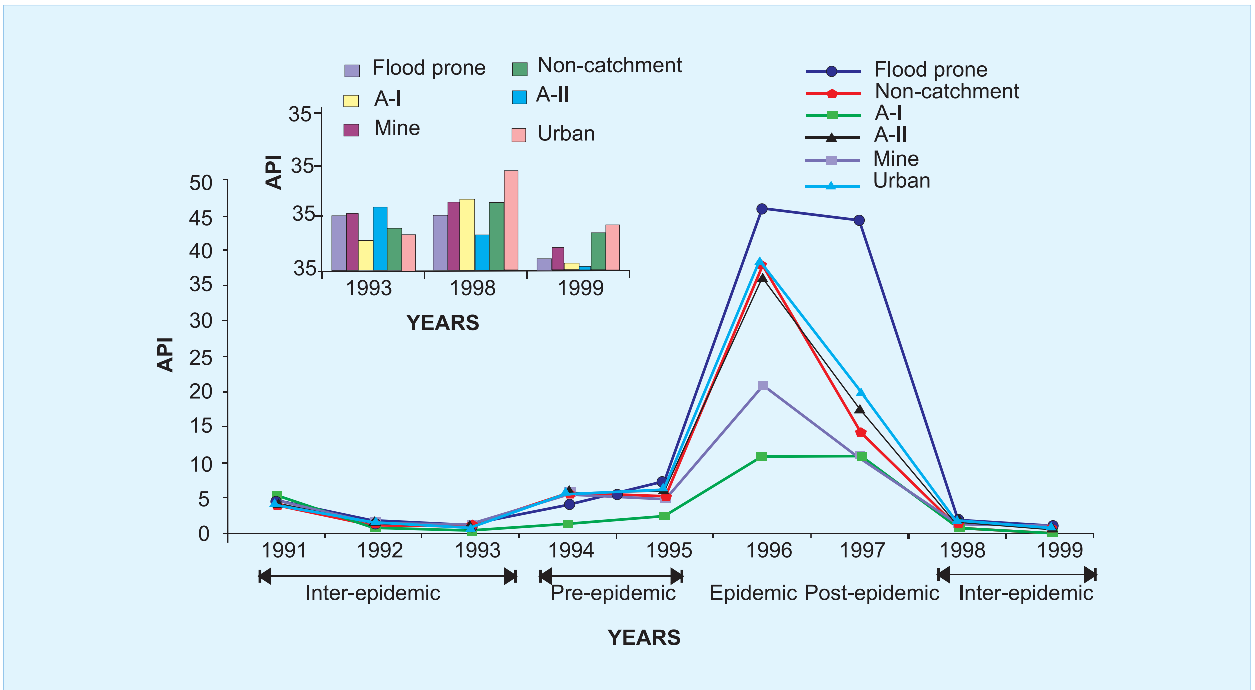


Figure 4: Paradigm-wise malaria incidence in Mewat region during the years 1991–2001

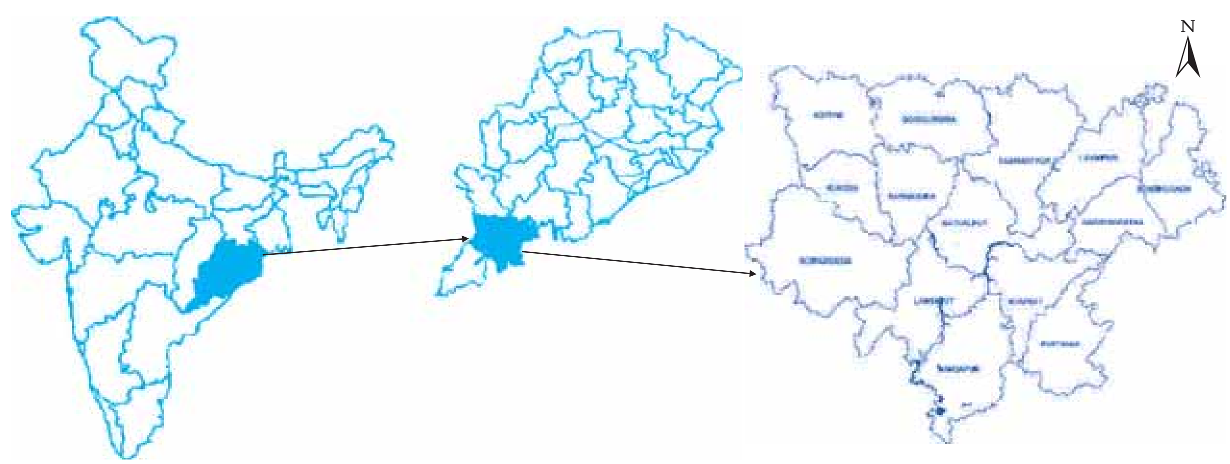
epidemic years (1993 and 1998) are the areas that require strengthening of surveillance to monitor malaria in order to take cognisance of changes in malaria incidence to avoid increase in incidence going unnoticed, and to plan suitable control operations as per the need. Such analysis will help in limiting the control strategies to the areas in need.

2.2 RS and GIS in Mapping Malaria Receptivity in Koraput District, Orissa

This study was carried out by the National Institute of Malaria Research (the then Malaria Research Centre), Delhi from 2000–03.

In Koraput district in the state of Orissa, this study was carried out with an objective to map malaria receptivity based on ecological profile and other attribute information. This district is situated at 18°15′ and 19°15′ N latitude and 82° 05′ and 83° 23′ E longitude and has been divided into 14 blocks/primary health centres (PHCs) (Figure 5). District Koraput with PHC boundaries was digitized. Malaria data of the years 1996–2000 were collected from the District Malaria Office of Koraput district and were linked to the district/PHC map (Figure 6). Correlation analysis revealed that overall in 5 years the highest ABER, API and drug distribution were from Laxmipur PHC (Figure 6). GIS predicted distribution map of vectors showed the entire district to be favourable for *An. culicifacies* (subject to that that the areas are rural) and *An. fluviatilis* (in hilly-forest areas), confirming already available field collected data. In addition, the GIS predicted map for the distribution of *An. minimus* has shown that some portion of Boipariguda and Lamtaput PHCs are favourable for *An. minimus*. These areas have recorded the highest SPR during the study period. Five thematic maps namely of geomorphology, land-use, soil, drainage network and water bodies of district Koraput (Figures 7a–e) were procured from Orissa Remote Sensing Application Centre, Bhuwaneshwar. Thematic maps of ecological parameters were over laid on malaria API map to identify the parameters responsible for the malaria incidence in each PHC (Figures 8a–e).

It has been observed that Laxmipur PHC, which has the highest malaria (30-40 API) had the highest forest cover, large network of streams, a number of valleys and mining activities. In other high malaria transmission PHCs (20–30 API) namely Boipariguda, Kundra, Kotpada, Boriguma, Dasamantpur, Pottangi and Narayanpatna also there was high forest cover, large network of streams and valleys. In low malaria PHCs, Lamtaput and Nandapur (0-10 API) there was less forest cover and



(a) India (b) Orissa (c) Koraput district

Figure 5: Location of the study area in (a) India (b) Orissa state (c) Koraput district

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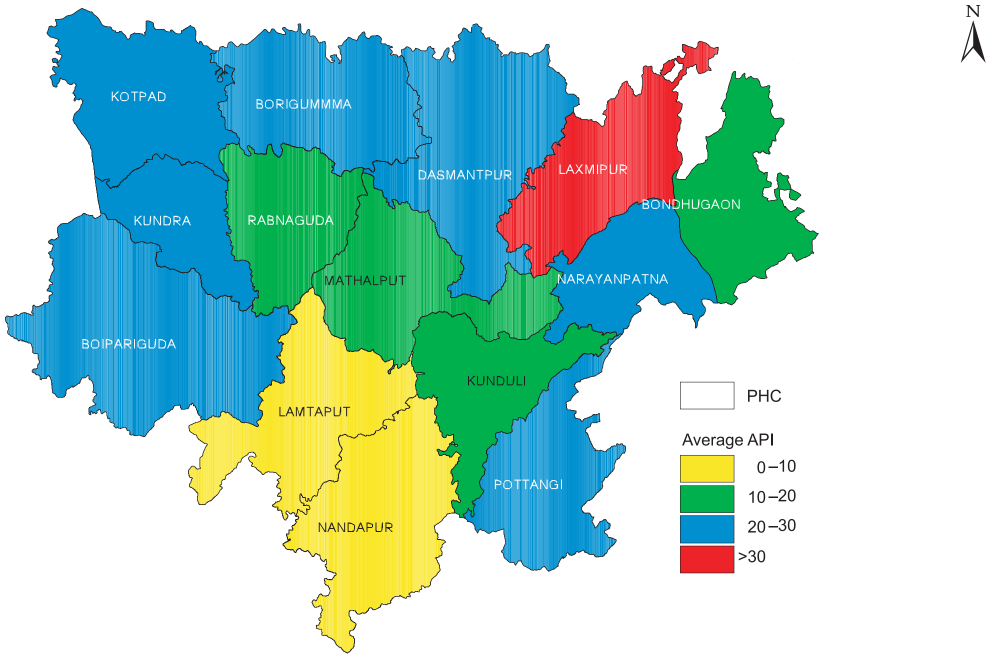

Figure 6: Map showing average malaria (API) of five years (1996–2000) in the Blocks of Koraput district

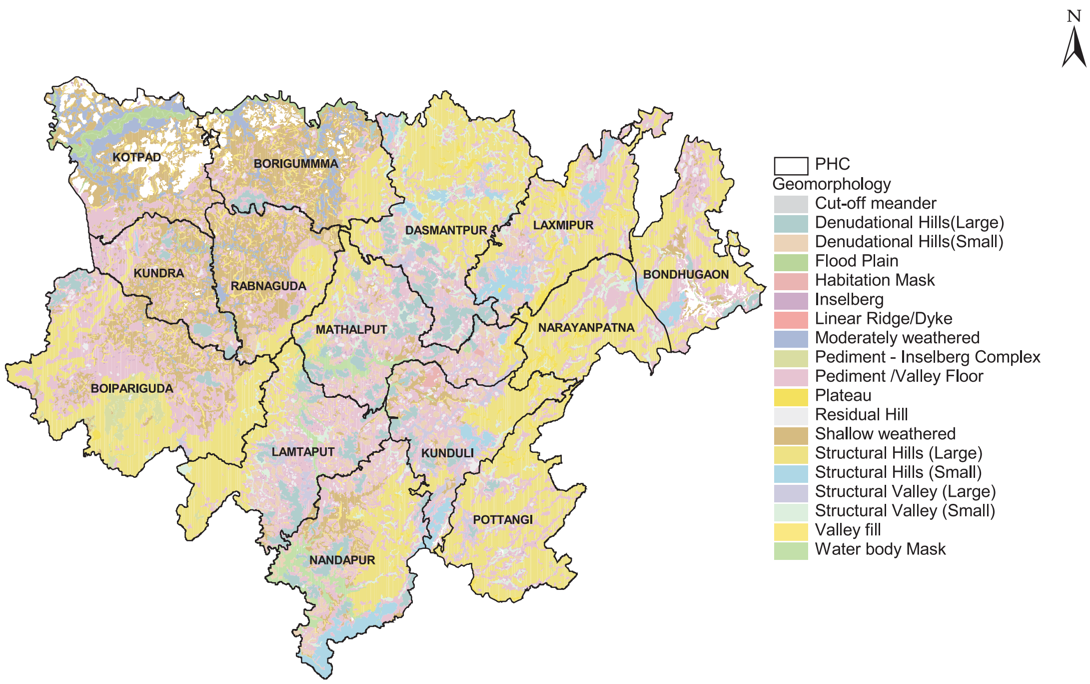

Figure 7a: Thematic map of geo-morphological features of Koraput district

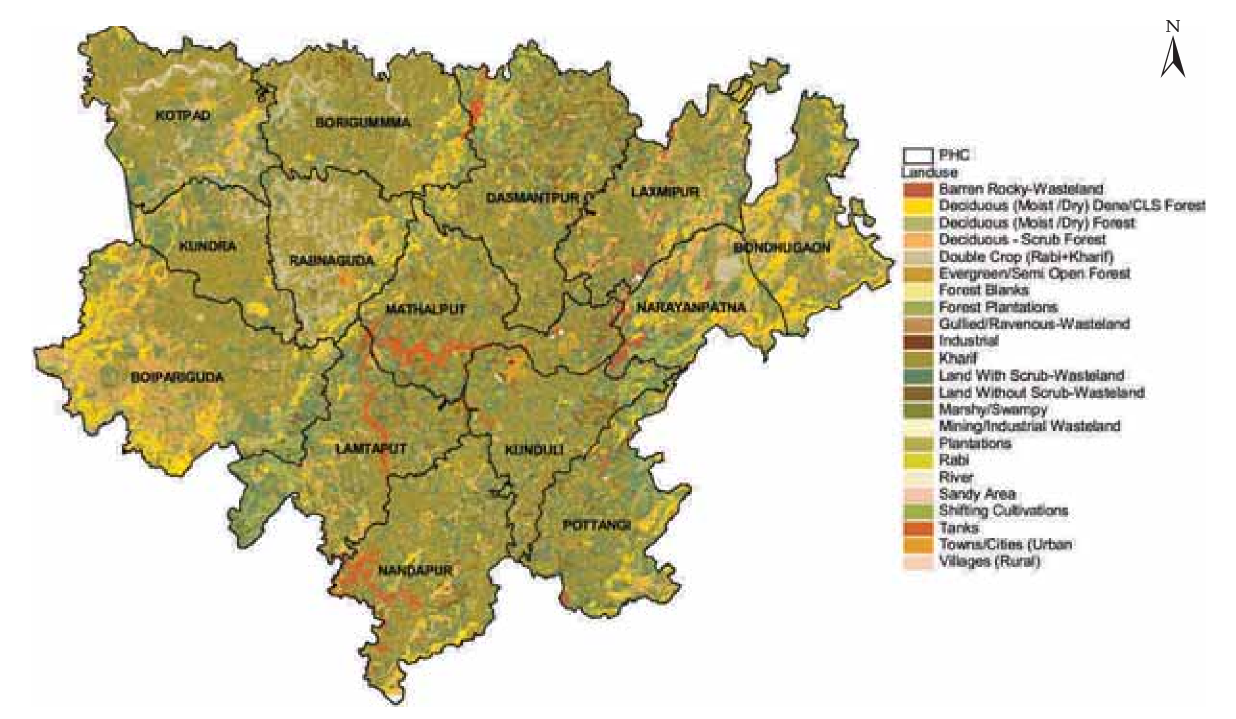

Figure 7b: Thematic map of landuse features of Koraput district

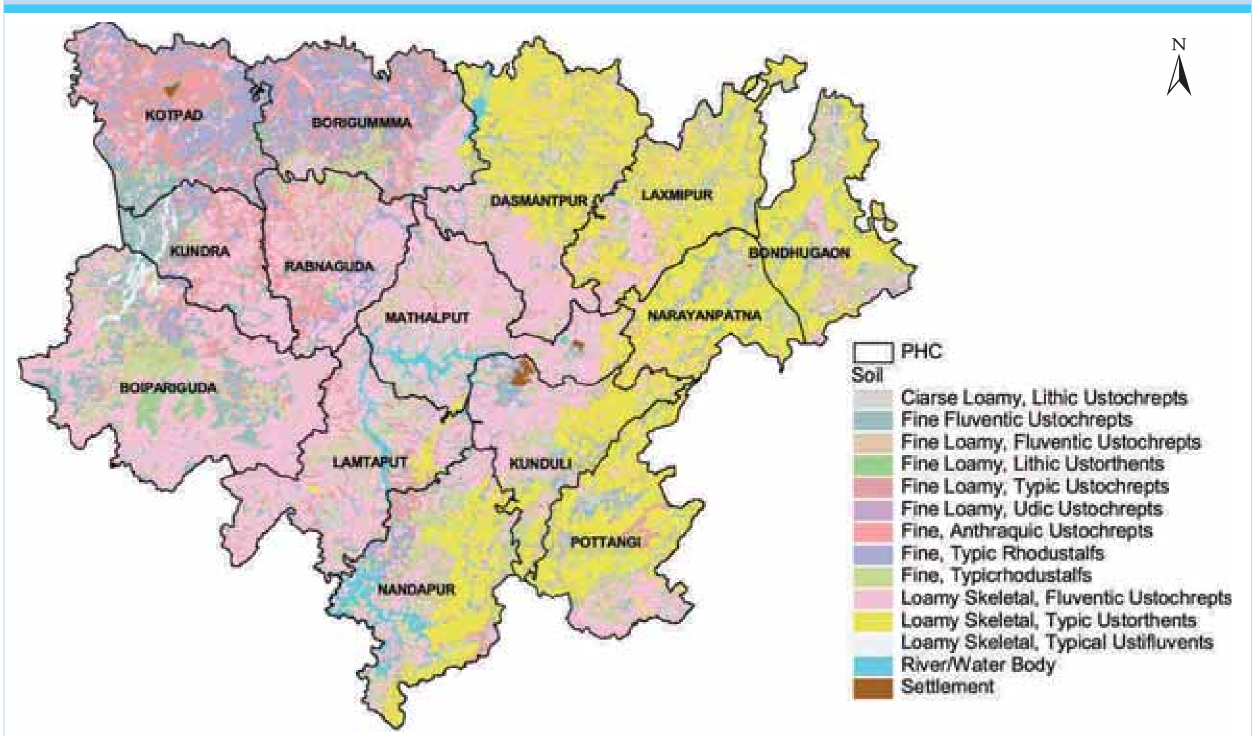

Figure 7c: Thematic map of soil types of Koraput district

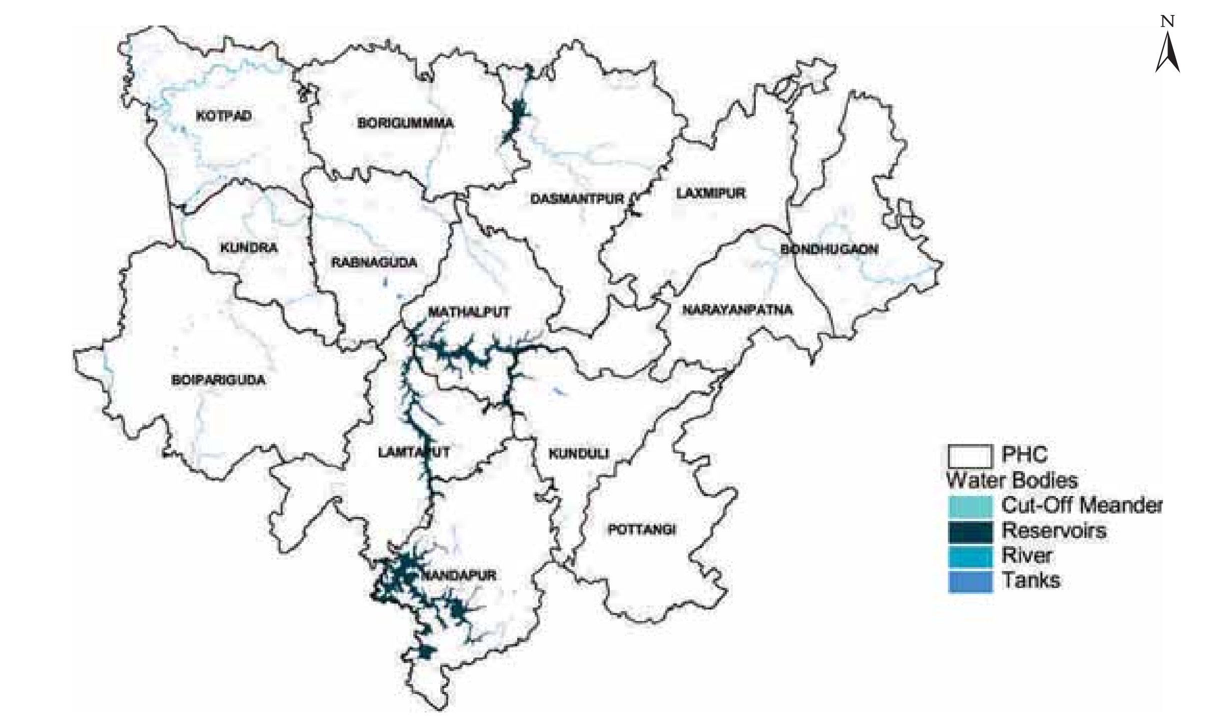

Figure 7d: Thematic map of water-bodies in Koraput district

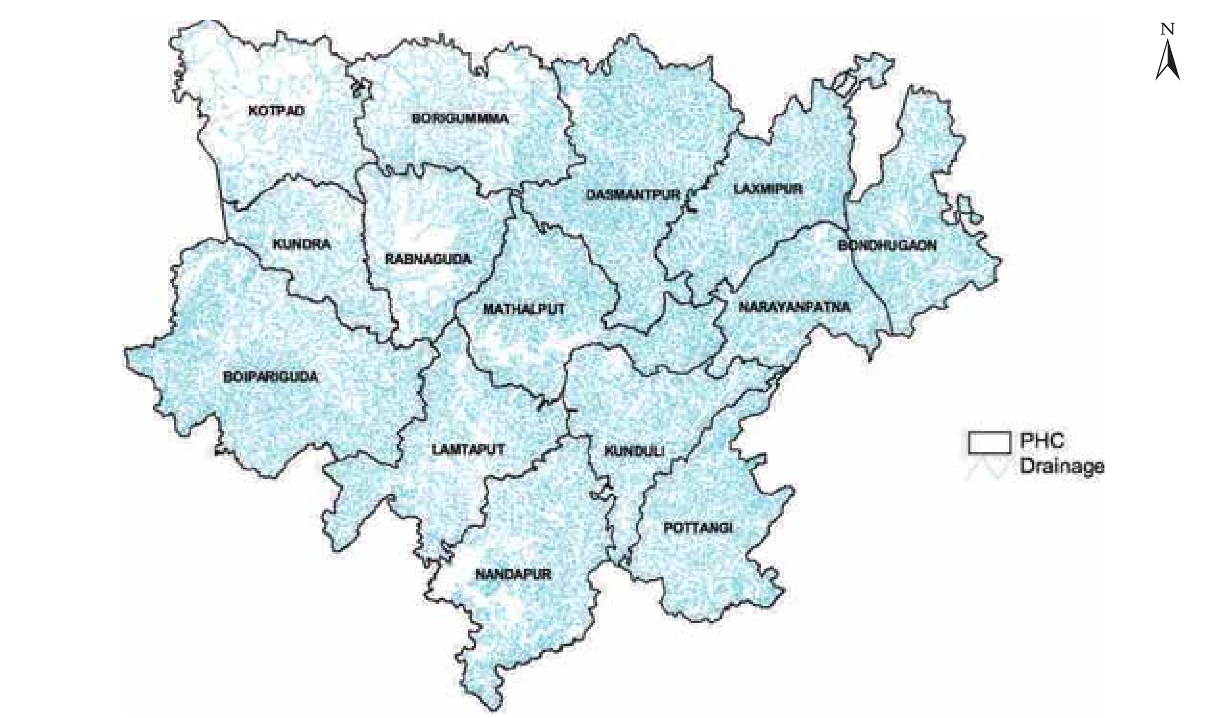

Figure 7e: Thematic map of drainage network in Koraput district

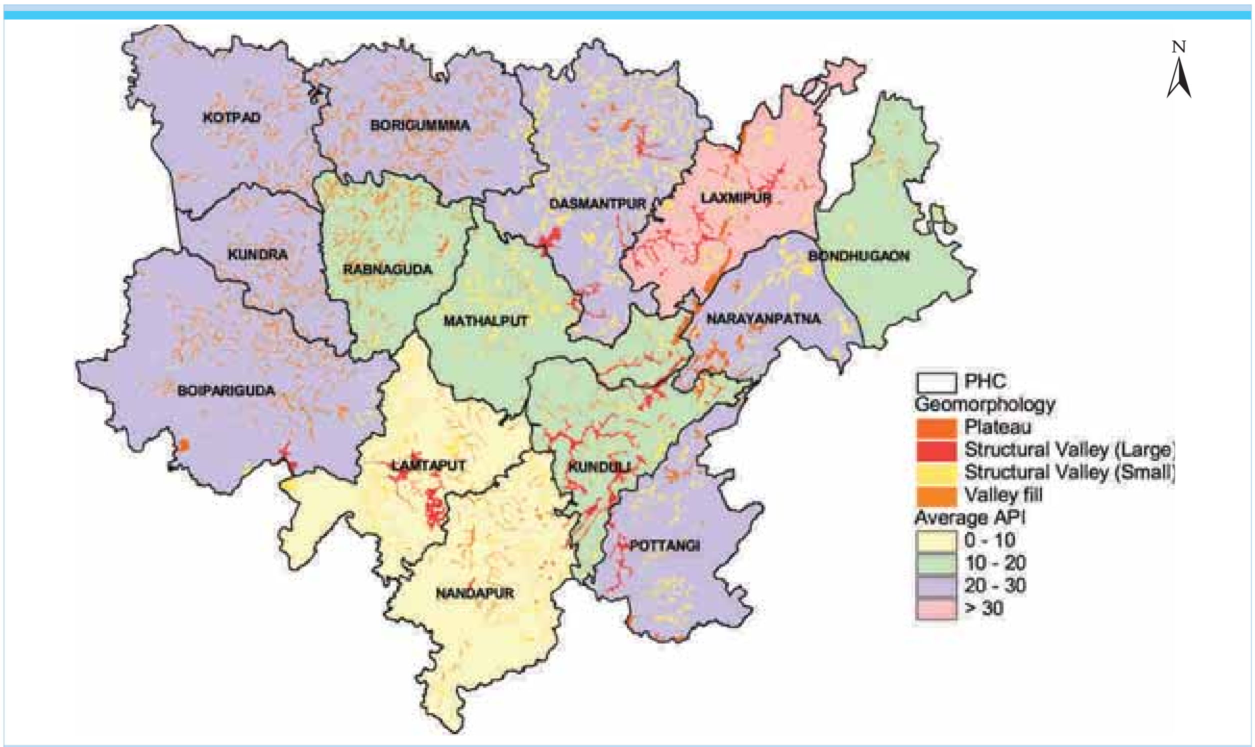

Figure 8a: Overlaying of geomorphology map on malaria incidence map of Koraput district

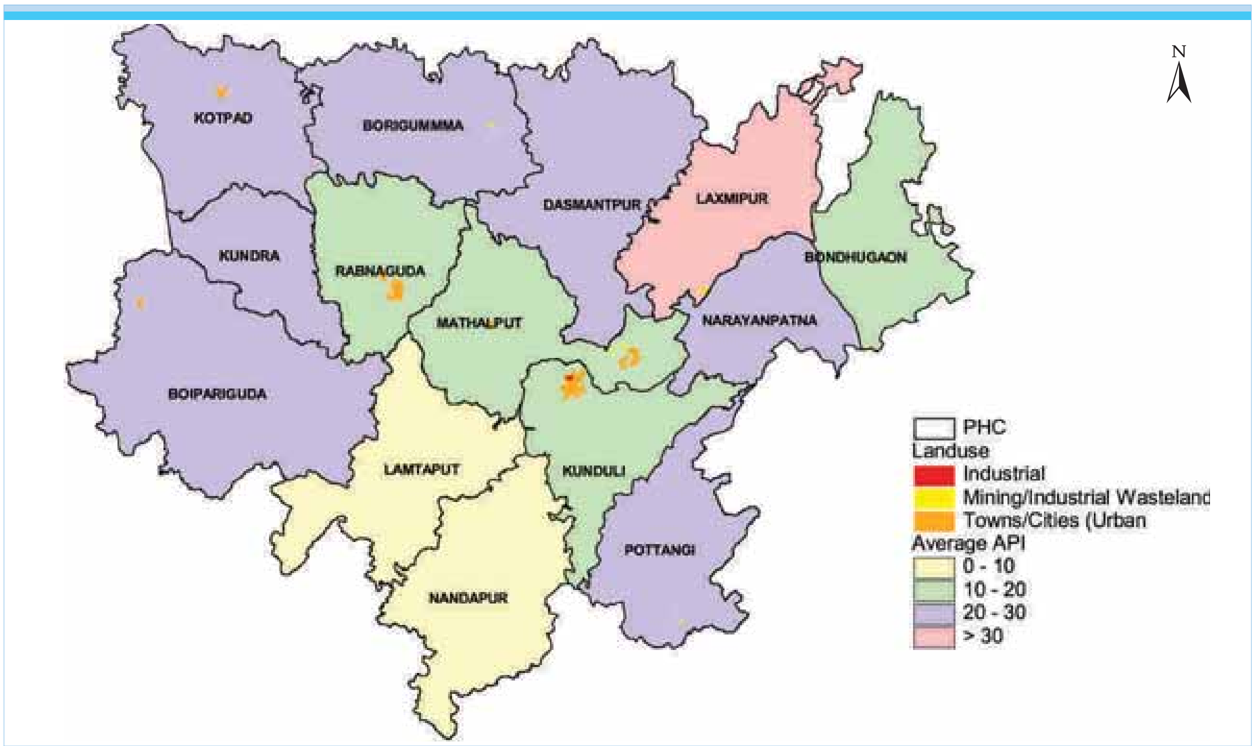

Figure 8b: Overlaying of land use map on malaria incidence map of Koraput district

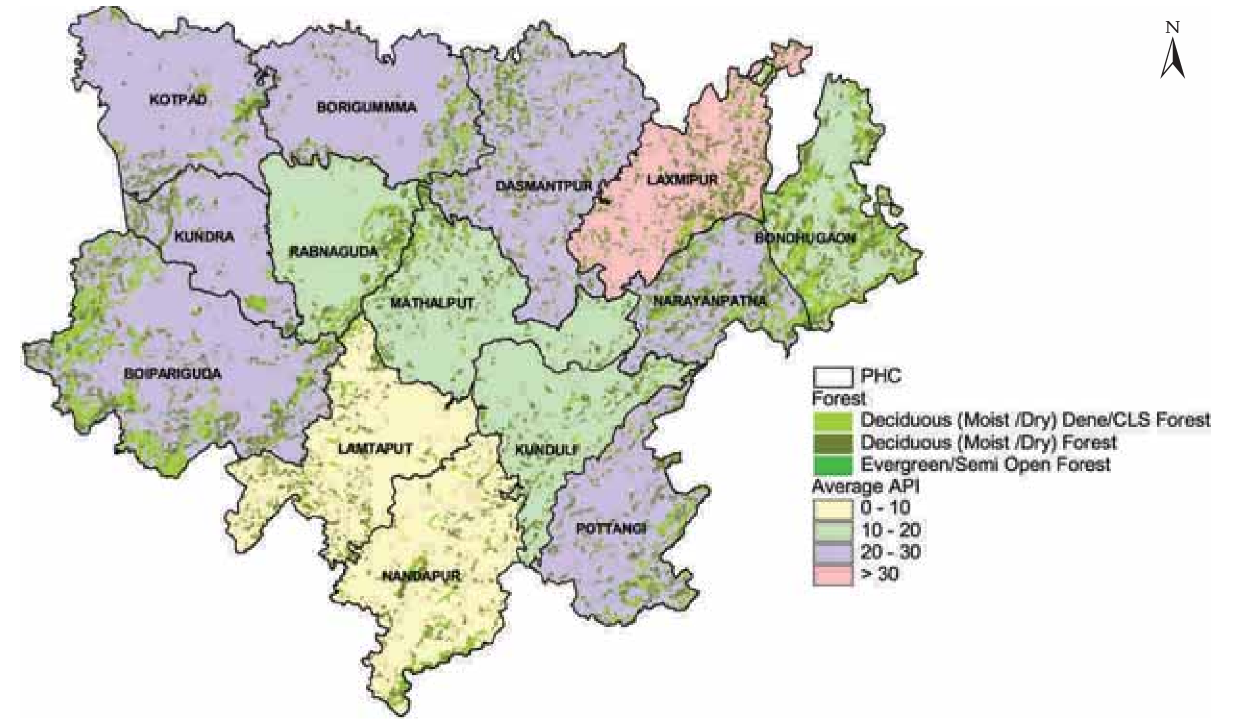

Figure 8c: Overlaying of forest map on malaria incidence map of Koraput district

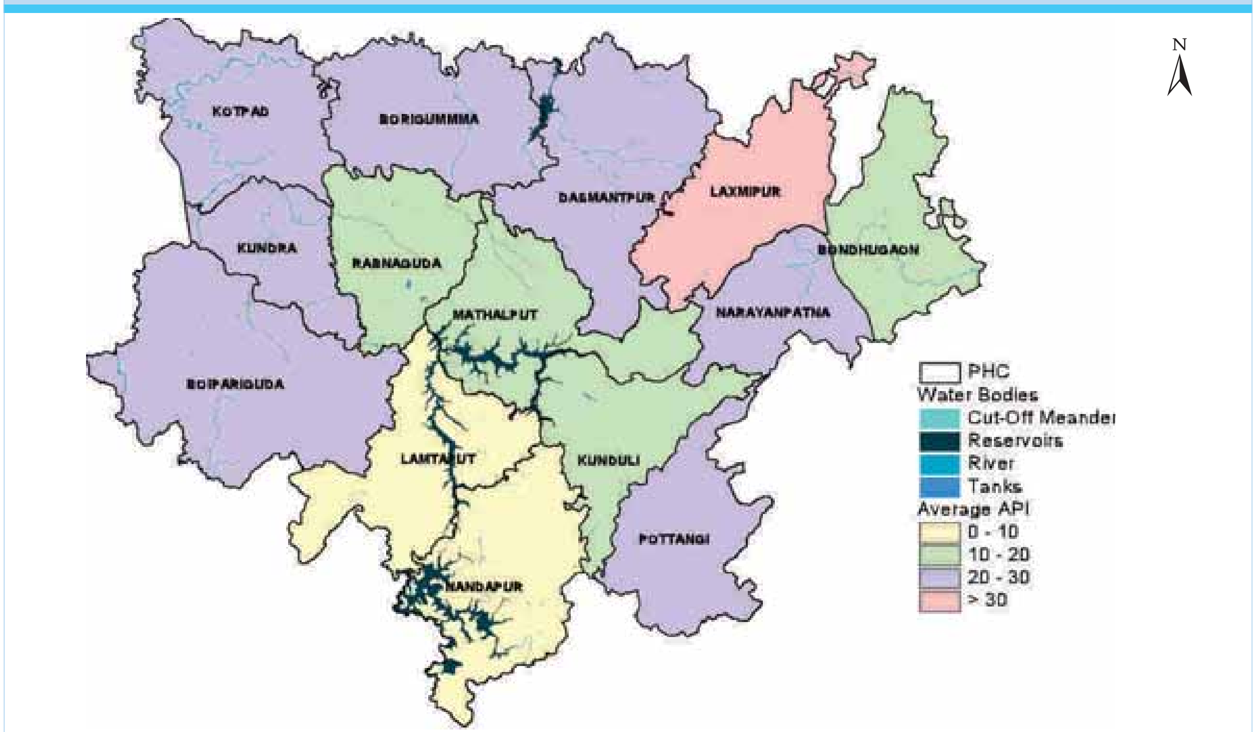

Figure 8d: Overlaying of water bodies map on malaria incidence map of Koraput district

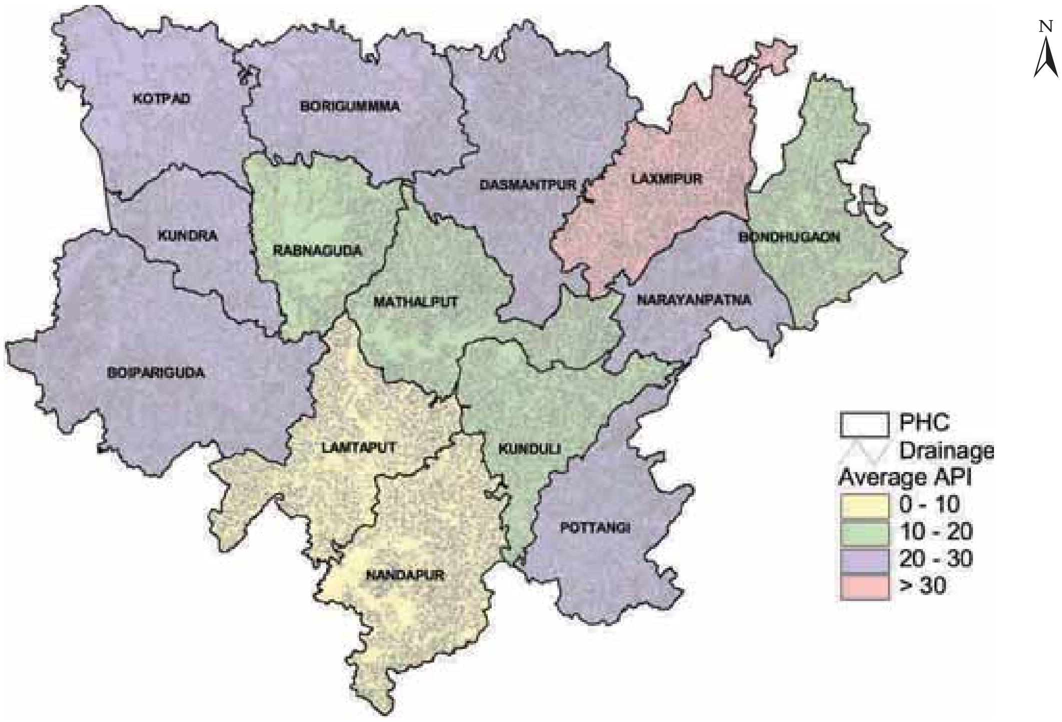

Figure 8e: Overlaying of drainage network map on malaria incidence map of Koraput district

good drainage network. Malaria in a few pockets in these two PHCs is mainly due to presence of water reservoirs. In Semliguda, Jeypore and Koraput PHCs where malaria transmission was not very high (10–20 API) as in other PHCs, the ecological and geo-morphological factors that were correlated with high malaria were also of medium occurrence.

GIS analysis of thematic maps has brought out a good correlation between malaria with the presence of forest cover, net-work of streams, water reservoirs and valleys. In areas with >30 API, extensive network of sreams and high forest cover were observed. It may be noted that *An. fluviatilis*, an efficient malaria vector is found in hilly-forested areas and breeds in slow moving channels. In these areas *An. fluviatilis* the major vector and *An. culicifacies* is a secondary vector.

2.3 RS and GIS in Mapping the Distribution of Malaria Vectors

The study was carried out by National Institute of Malaria Research (the then Malaria Research Centre), Delhi from 2000–03.

In India, out of the nine anopheline species that are considered to be transmitting malaria, six species are major vectors—*Anopheles culicifacies, An. fluviatilis, An. stephensi, An. dirus, An. minimus and An. sundaicus* in different ecological settings. Out of several ecological parameters that are required for the establishment of a species in an area, five are responsible for the variable distribution of mosquitoe species, namely forest-cover, soil type, altitude, temperature and rainfall and have been chosen for mapping the distribution of malaria vector species.

Altitude: Mosquito species prefer to establish at various heights where optimum ecological requirements which favour their survival are met. Anopheline species are reported from all parts of India from 1000 m below the mean sea level in mines to 4500 m above the mean sea level. Survey of India map showing 12 categories of altitude was used. Altitude up to 4500 m was considered in the study, as at altitude above which mosquito survival is greatly reduced due to low temperature.

Temperature: Mosquito species have different temperature threshold levels. In addition to survival and longevity, duration of sporogony in mosquitoes is also temperature dependent. Temperature lower than 20°C prolongs the duration of sporogony in mosquito beyond 30 days, i. e. more than the average life span and hence active malaria transmission does not take place. At extreme temperatures longevity of mosquitoes is drastically reduced. A temperature map consisting of five categories—$<$20°C, 20–22.5°C, 22.5–25°C, 25–27.5°C and $>$27.5°C was digitized.

Rainfall: Mosquito species breed in a variety of water-bodies, e.g. irrigation channels, pools, ditches, rain water collections, streams, shallow margins, domestic containers, tree holes, creeks, etc. For most of the species number of breeding sites is proportional to amount of rainfall and its pattern. Extreme conditions restrict mosquito proliferation as high rains cause flushing of breeding sites, killing eggs and immature stages and low rains reduce number of breeding sites. Ten categories of rainfall ranging from $<$100 to $>$3200 mm were considered.

Soil: Soil is an important factor, as its internal drainage capacity determines internal hydro-mechanics. A soil texture map consisting of 14 categories was digitized. Soil texture guides many characteristics e.g. water retention capacity, water availability, drainage conditions, etc. Impermeable soil allows water stagnation and creates ground for mosquito breeding. On the other hand porous soil is devoid of stagnant water-bodies making it unsuitable for anopheline breeding.

Forest: For species like *An. dirus* and *An. minimus*, the home land is deep forest and forest fringe areas respectively. Similarly, there are other species which are forest loving. Out of all climatic variables, rainfall plays a vital role in forest classification. A forest cover map with 11 classifications was used.

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Preparation of Thematic Maps

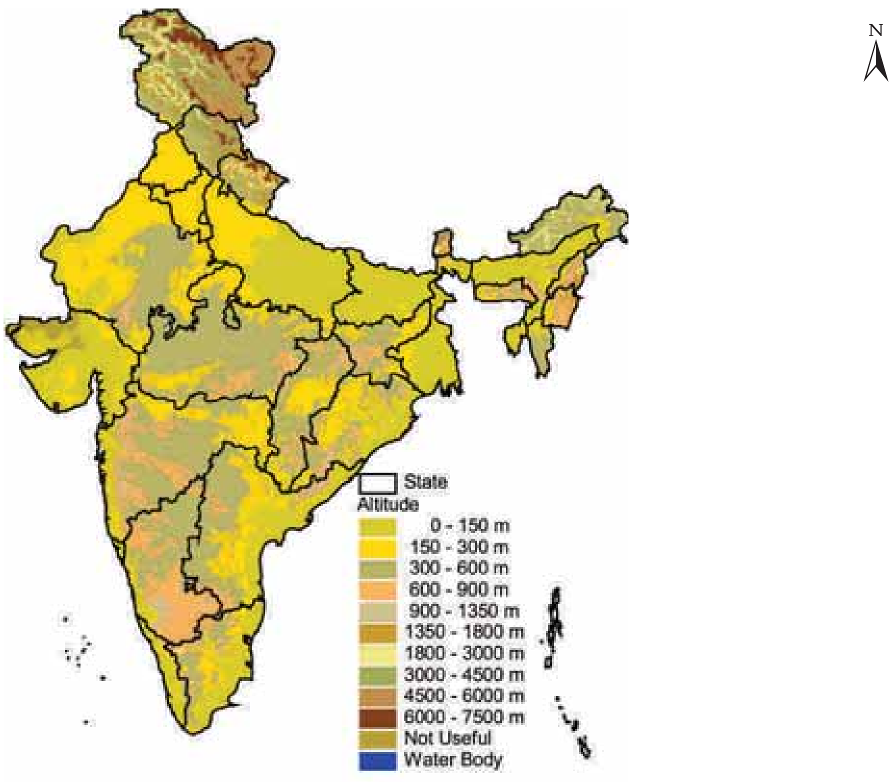
Altitude, temperature, rainfall and soil maps were digitized using plate nos. 2, 3, 4 and 6 of the *Water Resource Development Atlas of India* published by National Thematic Mapping Organization (NATMO) (1996). Thematic map of forest cover was digitized using plate 7 from the *Land Resource Atlas of India* (1996), published by NATMO, Govt. of India. All these thematic layers were on 1: 6,000,000 scale. Digitization, overlay and analysis were done using Environmental Science Research Institute (ESRI), USA. GIS software Arc/Info 8.1 and Arc/View 3.2 in vector format. Thematic maps of five ecological parameters chosen for this study are given in Figures 9a–e.

Algorithm for the identification of favourable range of ecological parameters and integration of thematic maps

Reported distribution of species was taken as baseline information. From each reported area distribution location was mapped on thematic maps to decipher the ecological conditions at that point. A matrix was formed to identify the favourable range for each parameter, where forest cover (j = 1), altitude (j = 2), rainfall (j = 3), temperature (j = 4) and soil (j = 5) are the parameters selected for the species.

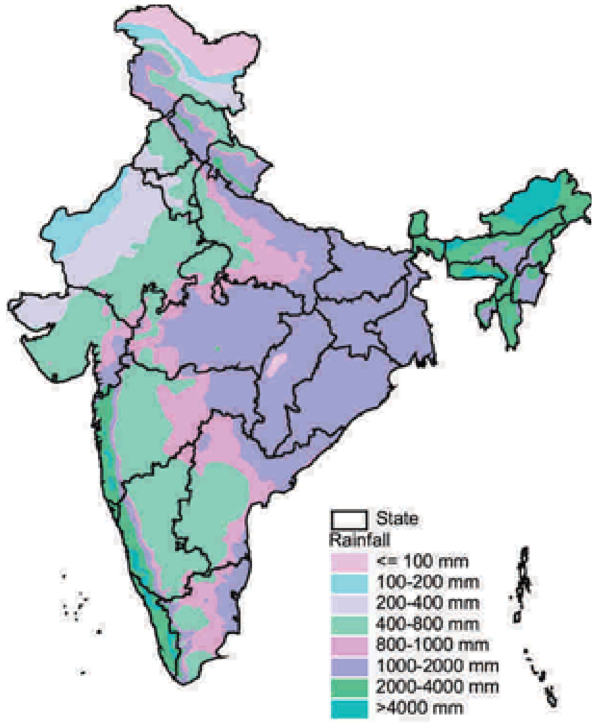
The range of each parameter was evaluated as follows:

Range = {least lower bound (X_{lj}, Y_{lj}, Z_{lj}), highest upper bound (X_{hj}, Y_{hj} Z_{hj})}... (1.1)

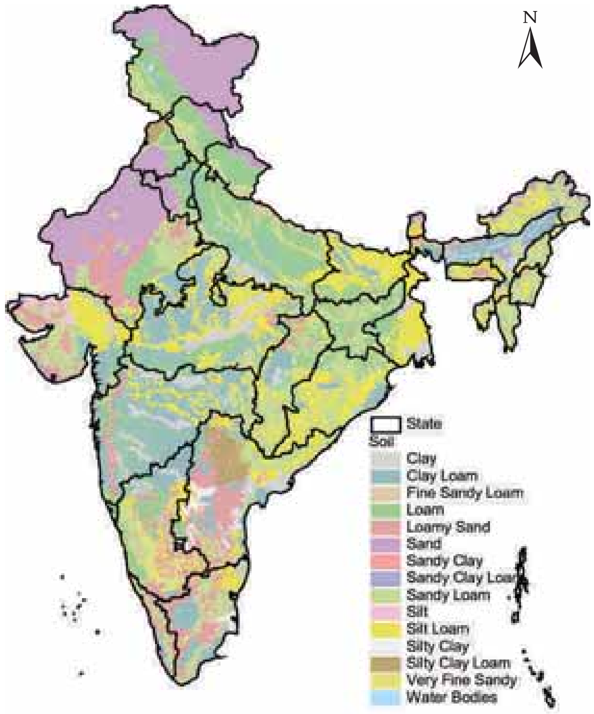


(a) Thematic map of Altitude

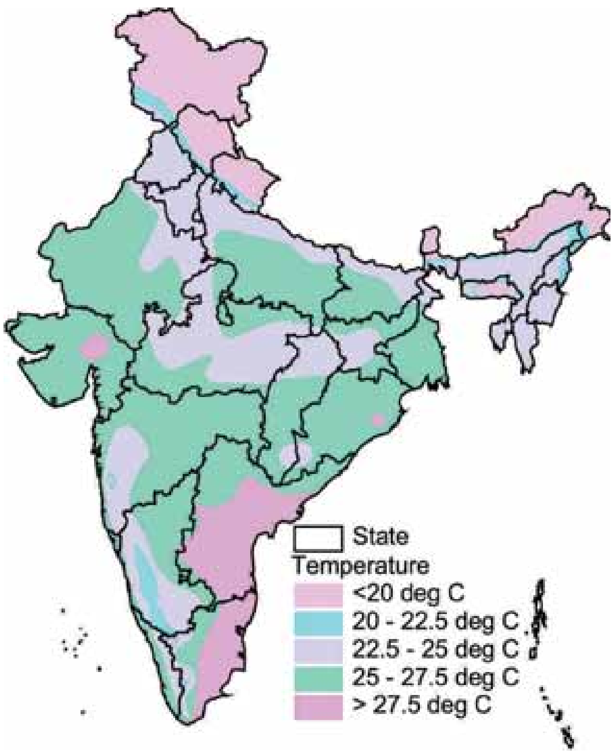
Figure 9 (a–e): Thematic maps of ecological parameters—Altitude, Rainfall, Soil, Temperature and Forest of India digitized on 1:6,000,000 scale



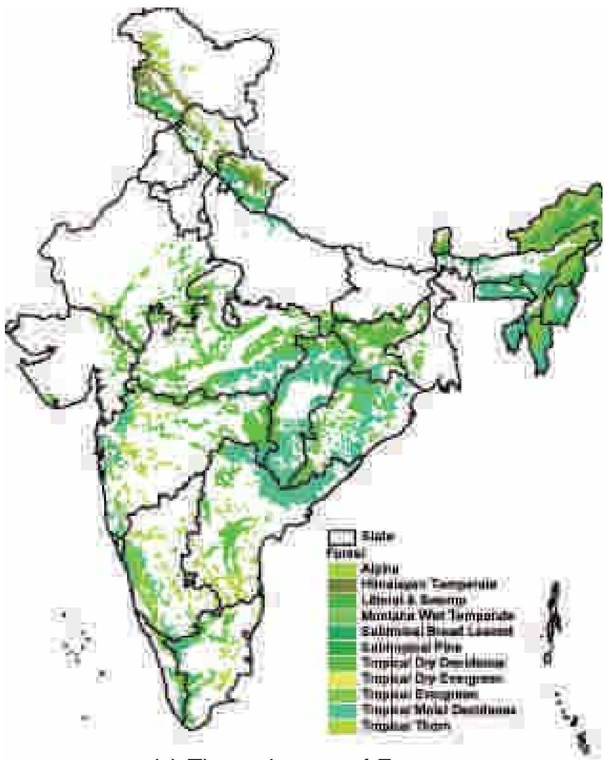
(b) Thematic map of Rainfall



(c) Thematic map of Soil



(d) Thematic map of Temperature



(e) Thematic map of Forest

For integration of themes, a three dimensional space was considered, where the location of each value of each parameter on the ground is defined by X_{lj} and Y_{lj} and attributable information is taken as the third value, i.e. Z_{lj} in 3D Cartesian coordinate system, and favourable areas were extracted out and themes were combined using the Boolean operator intersection ($\cap$) and union ($\cup$) using the following expression:

$$\cap \{(X_{lj}, Y_{lj}, Z_{lj}) < \cup (X_{kj}, Y_{kj}, Z_{kj}) < (X_{hj}, Y_{hj}, Z_{hj})\} \; j = 1, 2, 3, 4, 5 \ldots \quad (1.2)$$

wherein (X_{lj}, Y_{lj}, Z_{lj}) and (X_{hj}, Y_{hj}, Z_{hj}), X_{lj}, Y_{lj} and X_{hj}, Y_{hj} are the locations of Z_{lj} and Z_{hj}, the least lower and highest upper bounds for each habitat variables, and $\cup$ (X_{kj}, Y_{kj}, Z_{kj}) denote all geographic locations having favourable values of the habitat variable forest, altitude, rainfall, temperature and soil respectively.

2.3.1 *Anopheles culicifacies* – a species of rural areas

Anopheles culicifacies is widely distributed throughout India except in Andaman and Nicobar Islands. It is abundant in the plains and its prevalence is low in hilly areas particularly in the western region. This species transmits malaria in the entire rural and peri-urban areas in the country except in the north-eastern region. It transmits about 60–70% of new malaria cases every year in the country.

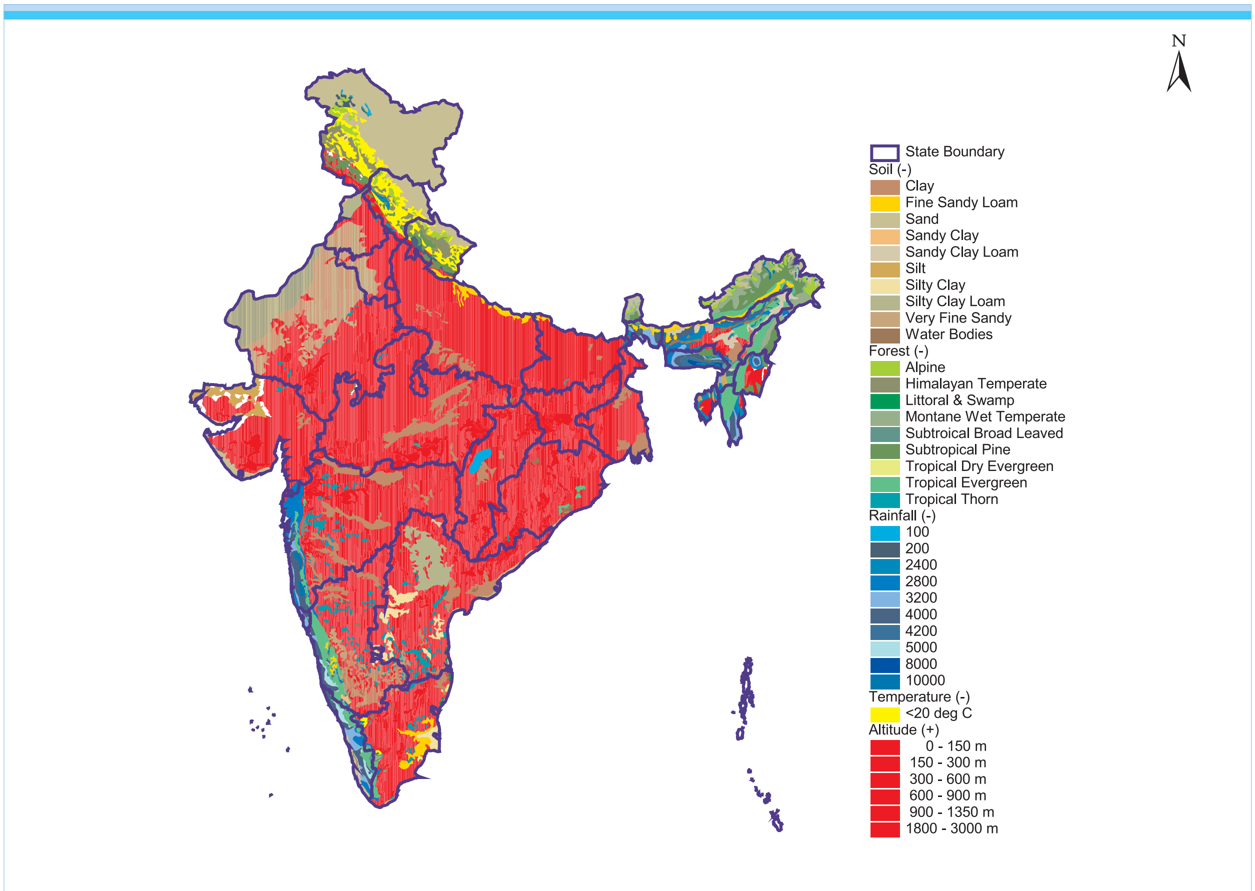


Figure 10: GIS predicted distribution of *An. culicifacies* in India (applicable to rural/peri-urban areas)

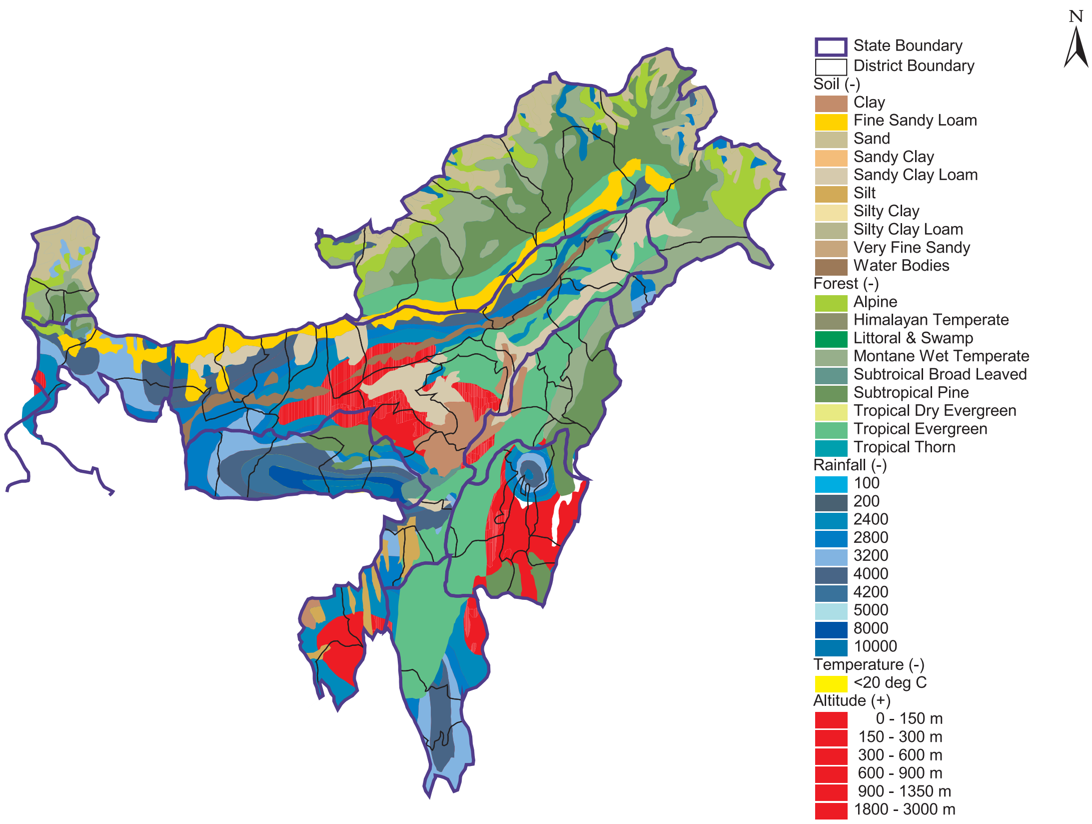


Figure 11: Distribution of *An. culicifacies* in north-eastern India. Areas favourable (as per the GIS analysis) for the distribution of *An. culicifacies* in the districts are marked in red colour

It is the main species responsible for fulminating epidemics in north-western plains of Punjab, Rajasthan and Uttar Pradesh (U.P.). It breeds in fresh water accumulations and major breeding sites are rain water collections. It also breeds in a variety of habitats such as irrigation channels, river bed pools, seepage water from canals and dams, borrow pits and hoof marks. Occasionally, its breeding is also seen in brackish water collections. Though the species is of the plains, it is also reported from higher altitudes, Nainital (1600 m), Kashmir (3000 m), etc. To identify the favourable ares, from the altitude layer 0–3000 m was selected as the base layer, and most favourable range was taken as 0–1350 m, with temperature $>20°C$ as favourable. Rainfall is an important factor for *An. culicifacies*. As this species is associated with monsoon and the maximum breeding occurs after the rains, high rainfall areas of ≥2400 mm and very low rainfall areas of ≤ 200 mm were not considered. Soil categories as shown in legend were considered non-favourable. Maps with favourable ranges of the selected parameters were integrated and the resulting map of *An. culicifacies* distribution is shown in Figure 10 and blowup of north-eastern region is shown in Figure 11. *An. culicifacies* is reported from all main land areas, and GIS predicted distribution similarly shows its distribution in rural and peri-urban areas all over the country. In north-eastern region earlier reported areas were seen more in the GIS predicted favourable areas (red coloured area) in Figure 10.

2.3.2 *Anopheles minimus* – a species of forest-fringe areas

Anopheles minimus is the most important vector of malaria along the foothills of Himalayas from Uttarakhand to north-east in India. The species breeds in streams, ditches, channels, tea garden drains, etc. and prefers to breed in clear unpolluted slow-moving water with grassy and particularly shaded edges. This species is essentially a species of hill and foothill areas in tropical monsoon regions. Because of its occurrence in forested areas in foothills, ecological parameters such as forest cover, soil type, altitude, rainfall and temperature were considered. The resultant map after integration of thematic maps using GIS shows the areas favourable for *An. minimus* (Figure 12). The reported distribution of the species formed the baseline information. Out of 50 reported locations, 30 representing various geographical locations were identified on thematic maps to decipher the corresponding parametric values. The remaining 20 reported locations were used for validation. GIS predicted favourable areas were not only found in the northeast but were also found in other states, namely Bihar, Uttar Pradesh, Madhya Pradesh, Orissa, Chattisgarh etc. where this species was recorded earlier (Figure 13). In addition, some new areas favourable for this species were found in Kerala, Maharashtra, Himachal Pradesh and Sikkim.

Field validation: To validate GIS predictions for *An. minimus* occurrence, surveys were conducted in nine locations in four states (Table 2). Sites were selected both from reported and non-

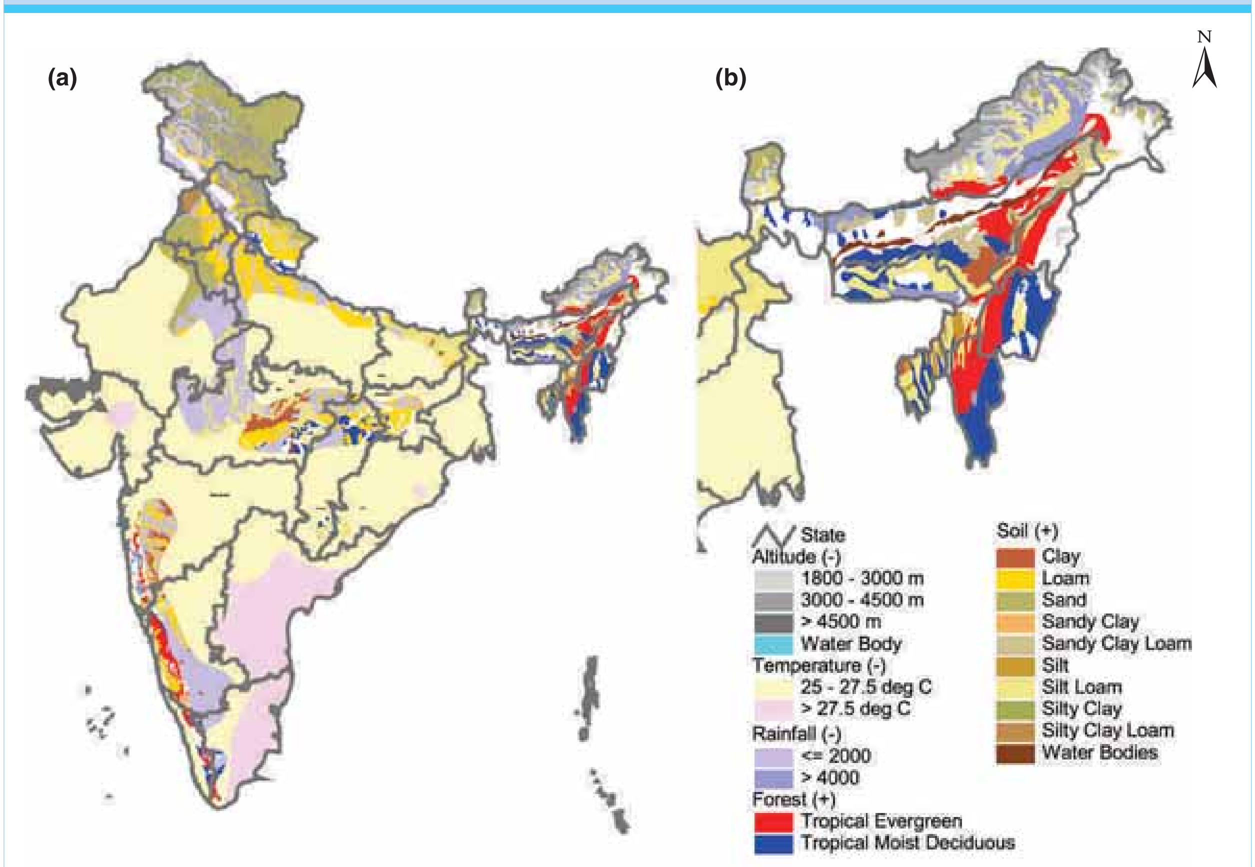


Figure 12: GIS predicted favourable areas for *An. minimus* in India, shown in red and blue colours depicting two types of forest covers, tropical evergreen and tropical moist deciduous respectively – (a) Distribution in India, and (b) Distribution in north-eastern states

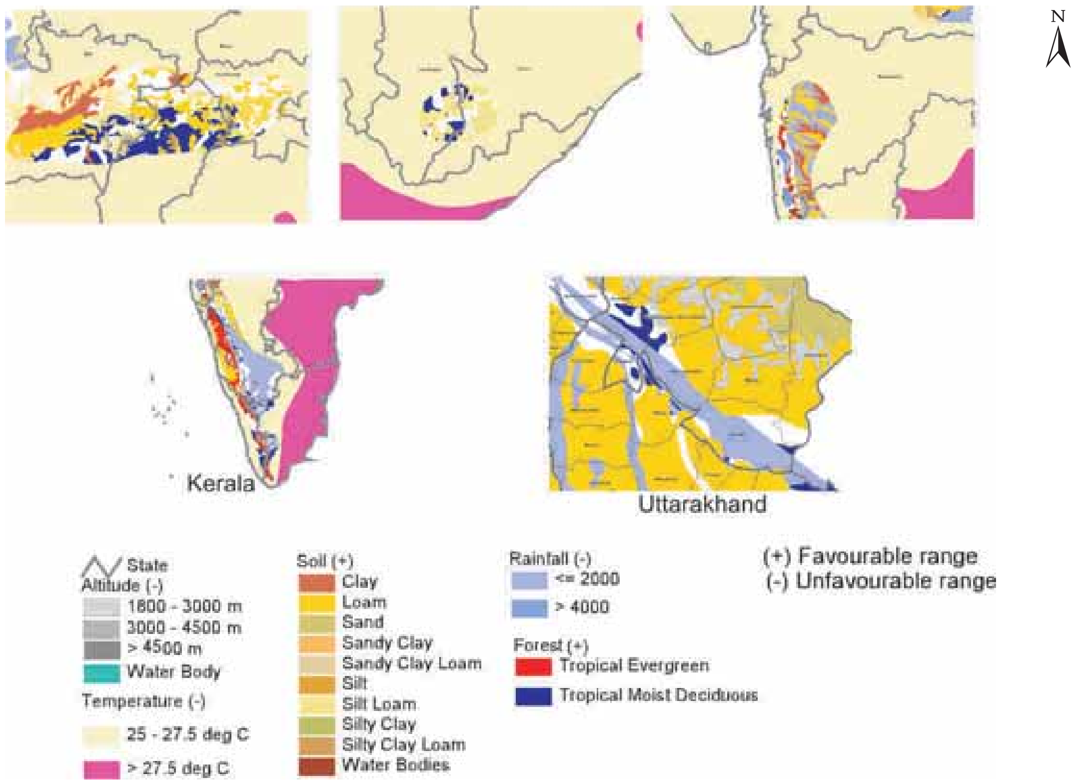


Figure 13: GIS predicted areas of *An. minimus* in states other than in the north-eastern region of India

Table 2. Validation of *An. minimus* in GIS predicted areas by ground surveys

Collection site/ district/state	Period of survey	MHD** of *An. minimus*	Larval density#	Remarks
Banbasa, Uttarakhand	May 2001	0.25	0	Reappearance of species
	Jul 2001	0.53	0	
	Aug 2001	0.73	20.03	
Jalpaiguri*, West Bengal	Oct 2001	1.7	0.08	–
Dhubri, Assam	Oct 2001	0.91	0.06	First report
Kamrup*, Assam	Oct 2001	21.8	1.4	–
Barpeta*, Assam	Oct 2001	Not done	0.18	–
Burnihat*, Meghalaya	Oct 2001	1.16	Not done	–
Shillong*, Meghalaya	Oct 2001	0.33	Not done	–
Darrang*, Assam	Jun/Jul 2001	4	Not done	–
Goalpara*, Assam	Sep 2001	21	Not done	–
Karbi Anglong	Oct 2002	Zero	–	Species was not found

*Areas already known for its presence; **Man hour density: Number of mosquitoes collected per man per hour; #Larval density: Number of larvae per dip

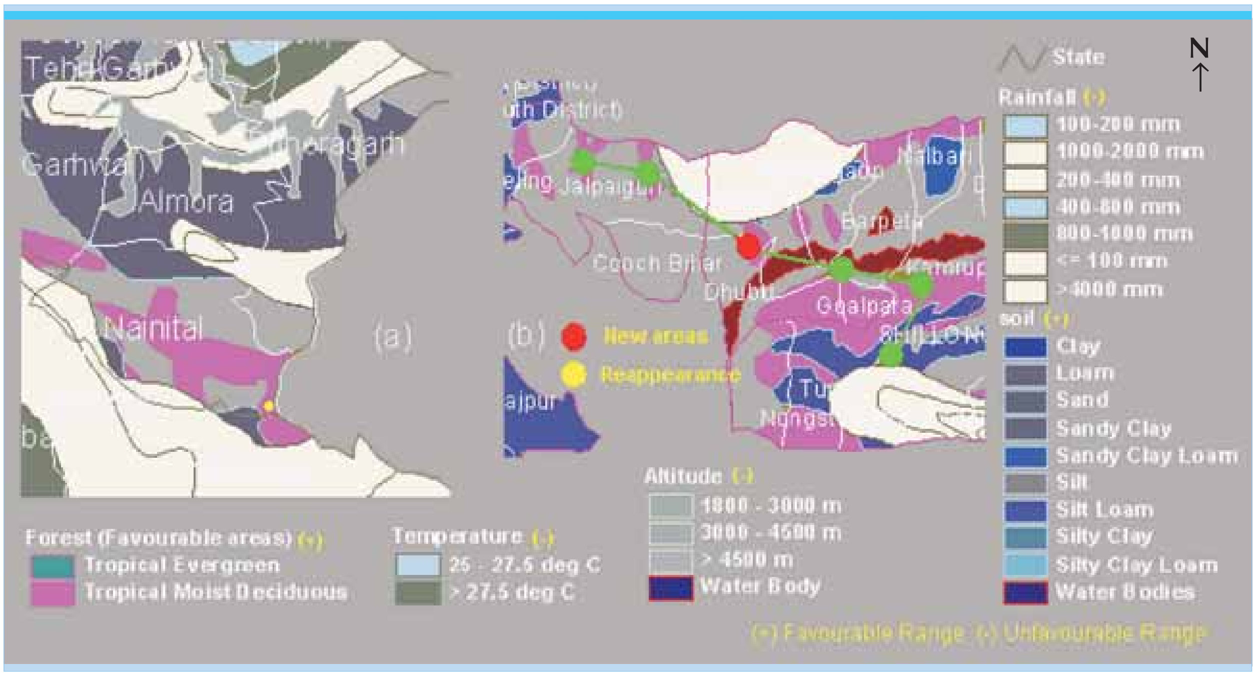


Figure 14: Validation spots in areas of *An. minimus* distribution predicted by GIS (a) Uttarakhand, (b) North-eastern states: (red)—areas where the species was reported for the first time, (yellow)—areas where species has reappeared after a long gap of years; and (green)—survey spots in non-favourable areas

reported areas in the north and in the north-east and from both favourable and unfavourable areas. In the northeast, a stretch of 900 km was covered (Figures 14a and b). *An. minimus* was found in all locations predicted as favourable by GIS analysis (Table 2). In two districts, Champavat in Banbasa area in Uttarakhand (reported to have disappeared after the 1950s) and in Dhubri in Assam (not found in recent surveys) *An. minimus* was found. In addition to validating GIS predictions, the surveys have established the reappearance of *An. minimus* at Banbasa and its presence for the first time in Dhubri. GIS predicted precisely the location in these districts, and the entomological ground surveys found the species at the exact locations. Blind surveys were also conducted by an independent team both in favourable and unfavourable areas. In favourable areas the species was found, and in unfavourable areas on the border of Karbi Anglong, the species was not found.

Using GIS, the percentage favourable area for the distribution of *An. minimus* in different states was estimated. It showed that most of the area in the north-eastern states is favourable for *An. minimus*. In Mizoram, favourable area is about 90.61%, in Manipur about 70%, and in Nagaland, Tripura and Assam about 35, 33 and 25% respectively. In other states, it is less than 10% except in Kerala. There are several favourable areas in Kerala and Maharashtra, but there have been no surveys in these areas, and therefore, there is no confirmation for the presence of *An. minimus* here. In the GIS

Table 3. GIS predicted favourable corridors for *An. minimus*

Favourability	Altitude (m)	Rainfall (mm)	Temperature (°C)	Forest cover
High	0 – 600	2000 – 2800	22.5 – 25	Evergreen
Medium	601 – 900	2801 – 3200	20 – 22.4	Moist deciduous
Low	901 – 1800	3201 – 4000	< 20	Moist deciduous

analysis, following were identified as most favourable parameters for the distribution of *An. minimus*: forest—evergreen, altitude—0–600 m; temperature—20–25°C and rainfall—2000–2800 mm. Furthermore, the favourable corridors based on the above parameters for the distribution of *An. minimus* were also stratified as high, medium and low categories (Table 3). The species is likely to be most stable in areas where ecological conditions are highly favourable.

2.3.3 *Anopheles dirus* – a species of deep-forested area

An. dirus is one of the most efficient vectors of malaria in the north-eastern region of India. It is estimated that about 50 million people mainly living in deep forested and forest foothill areas are exposed to this species along with *An. minimus*. *An. dirus* is prevalent in forested areas and is rarely found in human dwellings or cattlesheds during day-time and can be collected at night from inside the houses, it is mainly an outdoor rester. It enters houses and cattlesheds for feeding but leaves soon after feeding. This species maintains a high man-mosquito contact, hence, large numbers can be collected from human baits. It breeds in pools, disused wells, borrow pits, hoof prints and drains covered with foliage in deep forested areas.

Keeping in view that the four environmental parameters that influence the distribution of this species, digital thematic maps of forest cover, rainfall, temperature and altitude using Survey of India topo sheets in the scale of 1: 6,000,000 were prepared. Two types of forests, namely tropical wet evergreen and moist deciduous forests; an altitude up to 4500 m, temperature ranging from 20 to 27°C and rainfall >2000 mm, which is also the characteristic feature of evergreen tropical wet and moist deciduous forests, were identified as favourable parameters from the GIS analysis for the

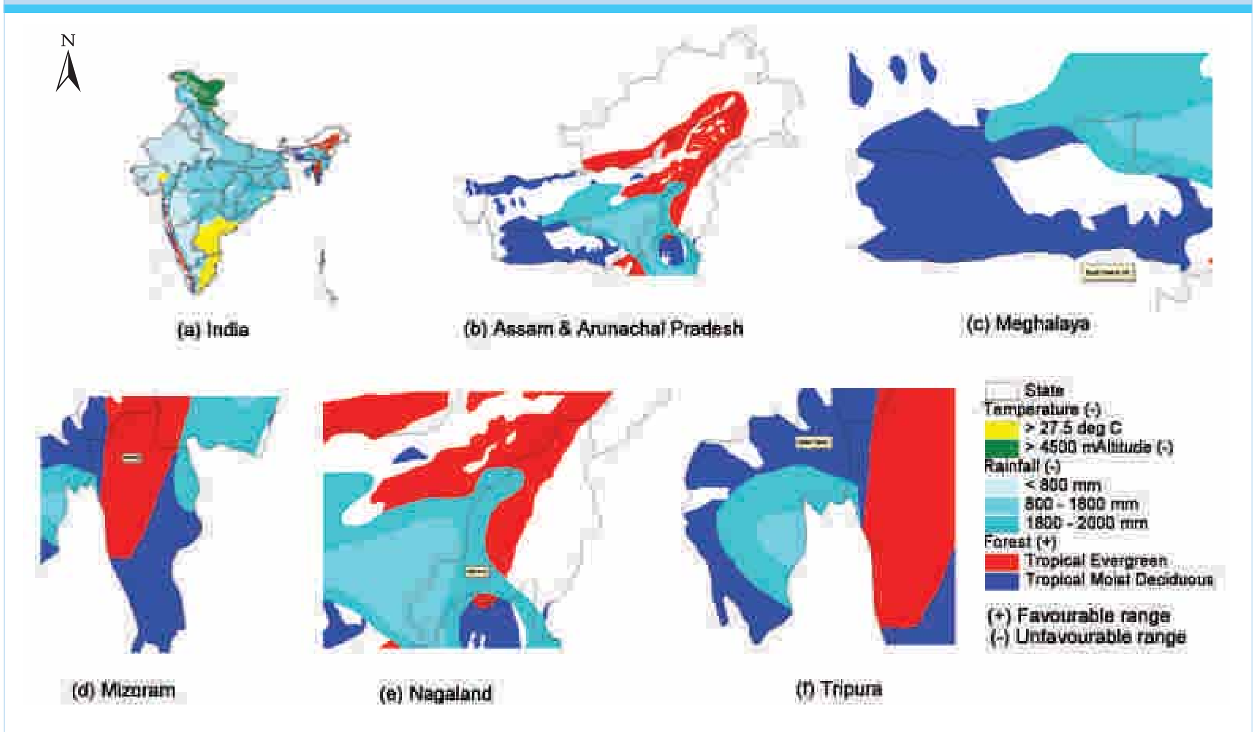


Figure 15 (a–f): GIS predicted areas favourable for An. dirus in (a) India; and (b–f) north-eastern states. An. dirus has been collected several times from all the north-eastern states except from Manipur. In all these areas this species has been found playing an important role in malaria transmission distribution of this species. The resultant map obtained by integrating the four thematic maps is shown in Figure 15a. The favourable areas for the species are shown in red – evergreen forest; and blue – deciduous moist forest. These are mainly located in north-east and in western districts of India. In spot surveys, *An. dirus* has been reported from north-eastern states and from Karnataka, Kerala, Tamil Nadu, Jammu & Kashmir and Andman & Nicobar Islands. It is observed that GIS based distribution overlaps the areas where the species has been reported earlier. Besides these areas, there are a few new areas where surveys have not been conducted and the species is likely to be found (Figure 15).

For validation, GIS predicted areas were compared with the reported distribution at micro level. In Assam, the large areas on north-east are found favourable for *An. dirus* through GIS (Figure 15b). This species has been reported several times from Dibrugarh, Cachar, Gokhal Khane, Nanai, Brahmaputra valley and Mariani. In western Assam, deciduous moist forest areas were found to be favourable for species occurrence and the species has been reported from Goalpara and Kamrup districts. Arunachal Pradesh envelops Assam from the north, east and a small portion on the west. The species has been reported from Assam border Tirap district, Nampong, and Changlang Tenga valley. GIS also maps some areas favourable on Assam border (Figure 15b).

In Meghalaya, deciduous moist forest on eastern and western side are favourable for *An. dirus* (Figure 15c). There are reports on the presence of *An. dirus* from East Khasi hills, Burnihat. The entire state of Mizoram is favourable for *An. dirus* and it has been reported from Aizwal and south Mizoram

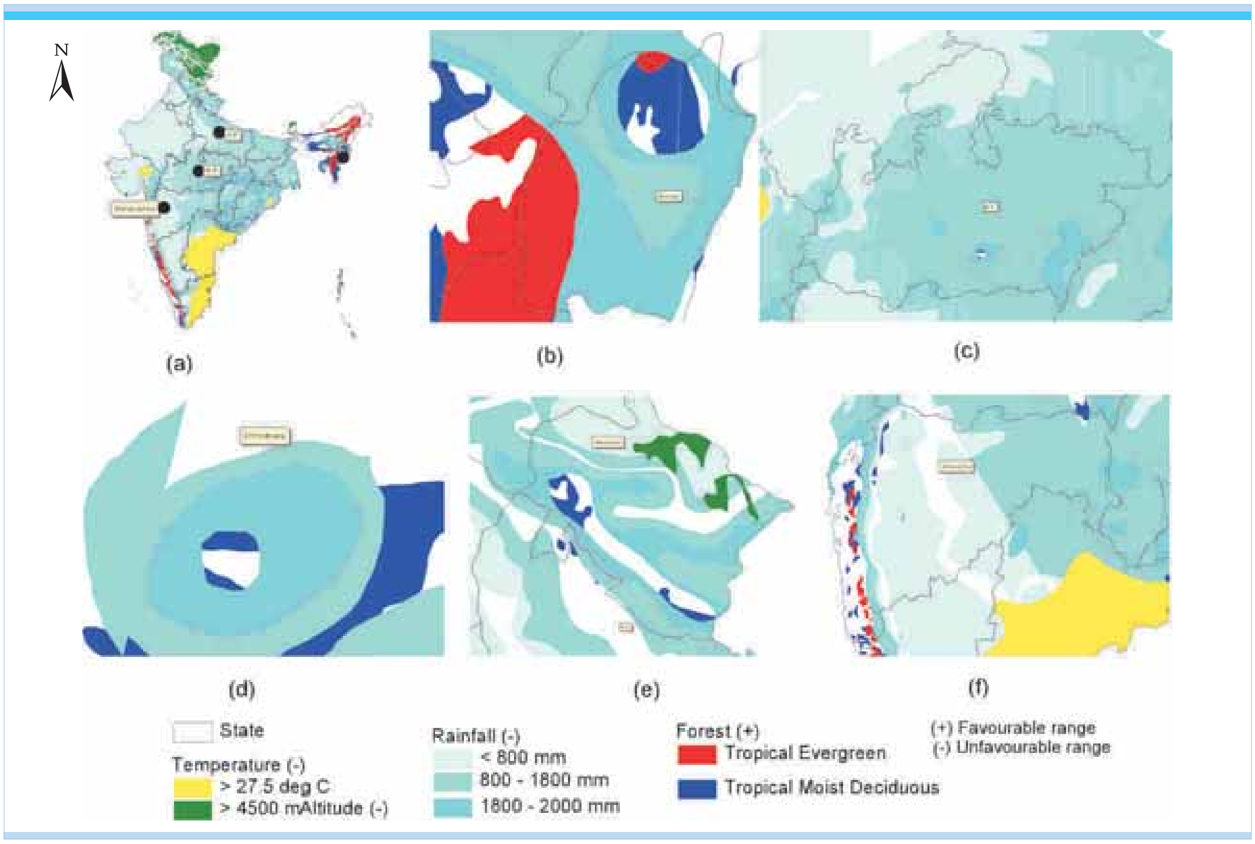


Figure 16 (a–f): GIS predicted new areas of *An. dirus* distribution in (a) India; (b) Manipur state; (c) Madhya Pradesh state; (d) Chhindwara district in Madhya Pradesh is blown up to zoom in small favourable portion in the district; (e) Uttar Pradesh and Uttarakhand states; and (f) Maharashtra state

(Figure 15d). In Nagaland, favourable areas are found in Kohima, Mohokchung, Mon and Wokh (Figure 15e). In Tripura, favourable areas are due to deciduous moist forest which forms as a broken semi circular ring on the western side (Figure 15f). The species has been reported from north Tripura, but in surveys conducted earlier in south Tripura (in 1955 and 1998) this species was not found. This may be because areas identified at micro level by GIS prediction may not be in conformance with political boundaries.

Anopheles dirus has been reported from Jammu & Kashmir, Andaman & Nicobar Island and Kerala. Distribution through GIS also depicts areas favourable in these states. In Karnataka, it has been reported from Bijapur, Chitradurga, Hassan, Shimoga, north Kanara, and Coorg, GIS reconfirms the reports from these areas. From West Bengal the reports of the species are from Jalpaiguri. Figure 15 shows that these areas are favourable for *An. dirus*. Besides new areas in Manipur in the north-east, there are receptive areas for *An. dirus* in other parts of the country—Madhya Pradesh, Uttar Pradesh, Uttarakhand and Maharashtra states (Figures 16 a–f). As per GIS predicted distribution, favourable areas calculated in different states is as follows: Mizoram–93%; Tripura–52%; Assam, Meghalaya, Manipur and Kerala–between 30 and 35%; Goa–25%; Nagaland–24%; Maharashtra, Andhra Pradesh, Uttar Pradesh, and Karnataka <10%.

2.3.4 *Anopheles fluviatilis* – a species of foothill areas

It is an efficient vector of malaria in hills and foothill areas of the country along with irrigated tract of Deccan plateau. It transmits disease along with *An. culicifacies* in U.P. *terai* and Orissa and with *An. minimus* in north-eastern region. It prefers to breed in slow moving water such as streams, field channels, seepage channels of dams and irrigation with grassy shades. It breeds in shallow wells, when usual breeding sites are washed out by heavy rains. It is distributed at heights from sea level to 2500 m, but mainly from 300 m to 1800 m. It has been reported as a vector from a few

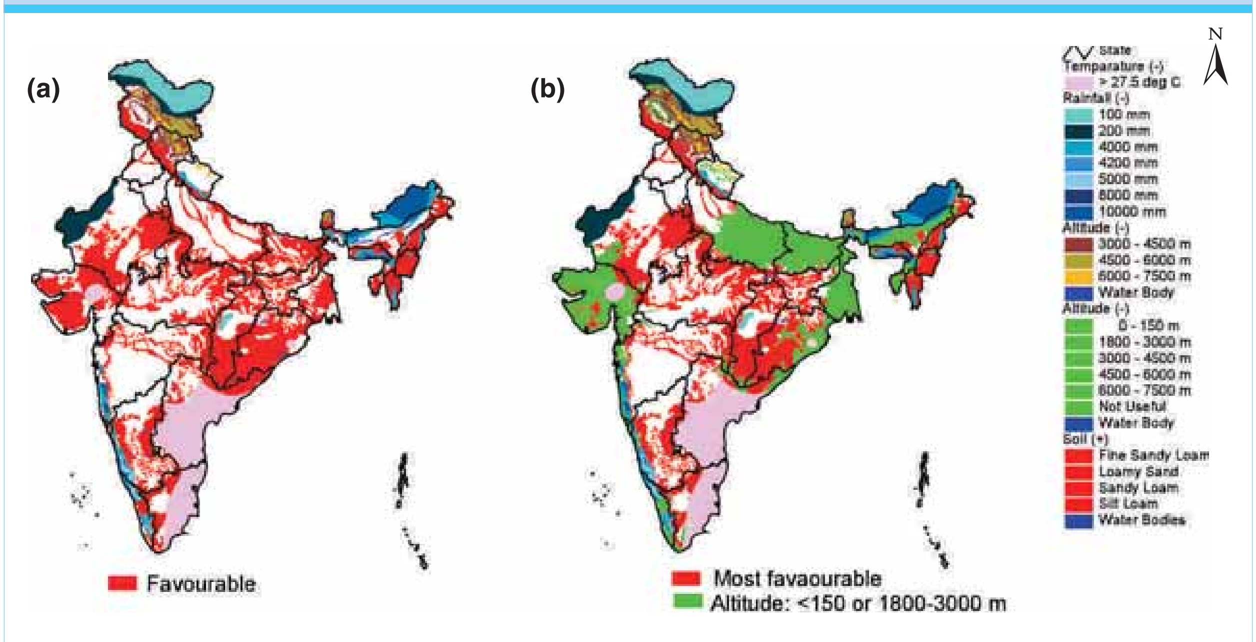


Figure 17 (a & b): GIS-based distribution of *An. fluviatilis:* (a) 0–3000 m altitude was taken as favourable; and (b) areas <150 m and >1800 m (not so favourable) were masked (green shades) to map the most favourable areas for the species meters above sea level to 1800 m altitude in Kashmir. Heavy rainfall is not suitable. Temperature between 20–30°C and relative humidity 60–80% are optimum. Sandy loam, fine sandy loam, loam, silt loam and clay loam soils are favourable. Keeping in view the above information of the parameters, thematic maps were prepared and by integrating these conditions GIS predicted map was developed (Figure 17). Figure 17(a) shows the predicted distribution of *An. fluviatilis* at 0–3000 m and 17(b) shows the most favourable distribution from 150–1800 m. The GIS predicted map when compared with the reported distribution showed a good spatial correlation. Since, *An. minimus* and *An. fluviatilis* have overlapping distribution, information collected during validation for the distribution of *An. minimus* was used for validating the distribution of *An. fluviatilis*.

An. sundaicus is a coastal species. It has disappeared from the mainland in the 1960s due to insecticidal pressure and is now found abundantly and widely in the Andaman and Nicobar Islands where it is the sole vector of malaria. It is generally a salt-water breeder. The major breeding places are swamps and pits along bunds (embankments) containing stagnant brackish water. It also breeds in salt water lagoons, creeks, wells, overhead tanks and fresh water pools in coastal areas. The most suitable breeding places are those in which sea water and fresh water mingle. It is also found in fresh water breeding places.

In Andaman and Nicobar Islands, the altitude ranges from sea level to 150 m, and annual mean temperature is about 25°C. Since very high rainfall is not suitable for vector immature stages, areas having ≤1600 mm rainfall were considered as favourable. As the sandy soil is the characteristic feature of coastal area, this soil was selected for the study. Integration of thematic maps of parameters with favourable range resulted in areas favourable for *An. sundaicus* shown in Figures 18a–c. Comparison of GIS analyzed map with the reported distribution showed a good spatial correlation. Since it is a coastal species, the comparison was restricted to coastal areas only. For validity of the results a blow up of the Orissa state was taken (Figure 19). The map shows Chilka lake falling in the GIS analyzed favourable zone and *An. sundaicus* was reported from this lake several times. Similarly, Vishakhapatanam of Andhra Pradesh state falls in GIS predicted favourable zone and the species was recorded earlier from this area. After DDT spray, this species has disappeared from both these areas.

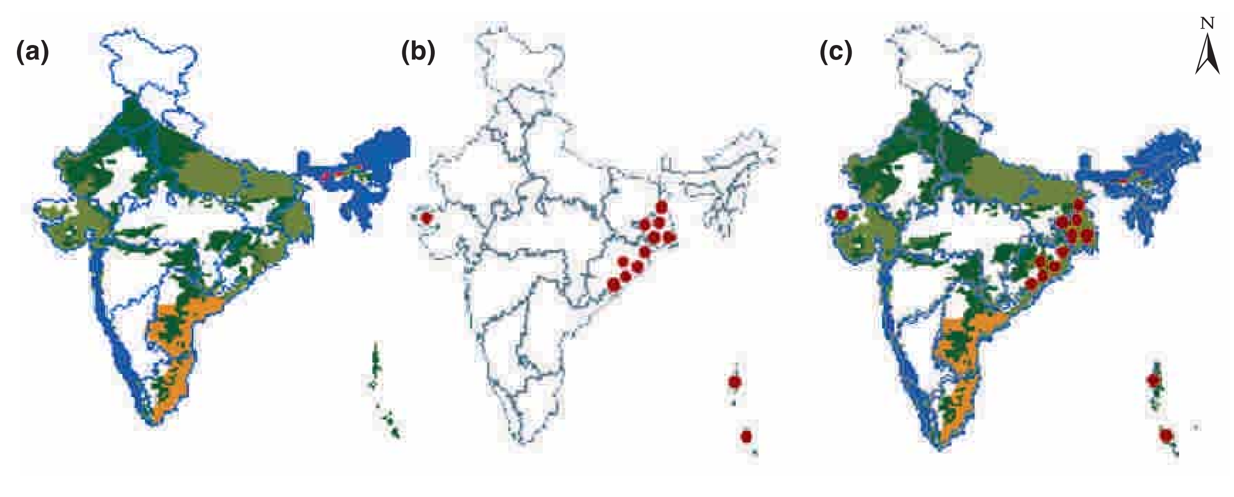


Figure 18 (a-c): *An. sundaicus* distribution; (a) Light green colour shows GIS predicted favourable areas for *An. sundaicus* in India; (b) Red dots represent the reported areas of *An. sundaicus* distribution in India; and (c) Overlaying of reported map on GIS predicted map for validation

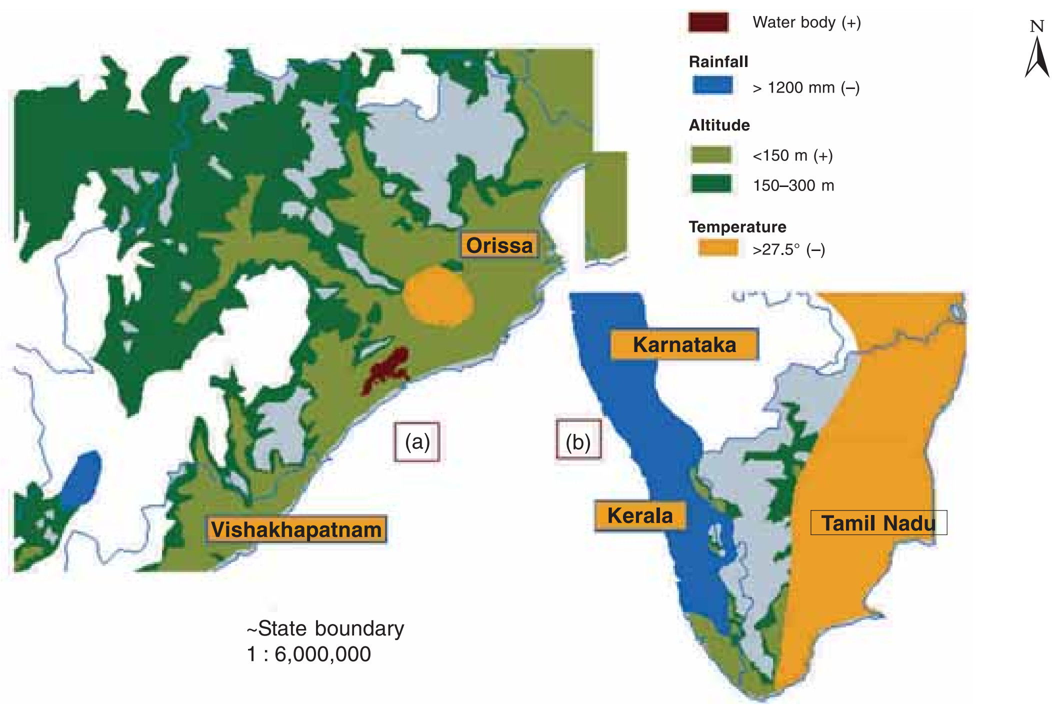


Figure 19 (a & b): GIS predicted (light green coloured) areas of *An. sundaicus* in (a) Orissa and Vishakhapatnam in Andhra Pradesh where the species has been reported several times; and (b) Kerala where this species has not been reported so far

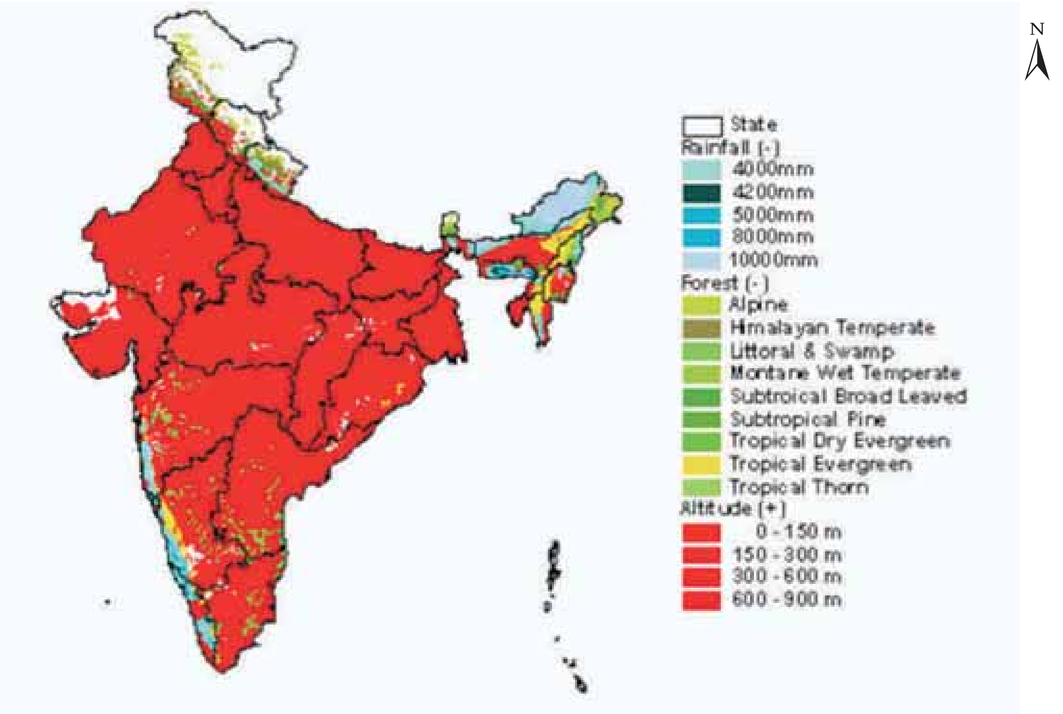


Figure 20: GIS predicted distribution of *An. stephensi* (subject to the condition that the area is urban or peri-urban)

On the south-western coast, GIS studies revealed that a part of south Kerala is favourable for *An. sundaicus*, therefore, precision surveys are required to confirm the presence of the species in this area.

2.3.5 *Anopheles stephensi* – a species of urban and peri-urban areas

Anopheles stephensi is found throughout the country except in northeastern region and Andaman and Nicobar Islands and at higher altitudes. This species is responsible for the transmission of malaria in urban/peri-urban areas of the country. The species is a domestic species as it breeds in intra- and peri-domestic containers such as tanks, cisterns, coolers, etc. and also wells. It has also been found breeding in irrigation channels and in rice fields. Distribution of *An. stephensi* is shown in Figure 20, subject to the condition that the area is urban/peri-urban. Altitude range from 0–900 m, temperature $>20°C$ and rainfall <2400 mm were taken as favourable for the area, that being an urban or peri-urban area. Besides mapping the distribution of major malaria vectors, other anopheline species found in India have been mapped using GIS technology. A compact disc (CD) has been produced consisting of an album with the objective to make a “Ready to Use Product”. This album consists of 58 maps, each showing the GIS predicted distribution of a species in India, along with the blow up map of GIS predicted district-wise favourable areas and the validation of GIS predicted distribution through reported surveys. A CD on request can be obtained from the National Institute of Malaria Research, New Delhi.

2.4 Delineation of Breeding Habitats and Landscape Features Suitable for *An. culicifacies* Abundance

The study was carried out by the National Institute of Malaria Research (the then Malaria Research Centre), Delhi and Regional Remote Sensing Service Centre, Bengaluru, Karnataka from 2000–03.

Remote Sensing (RS) technology through satellites has made possible to monitor land use features on the surface of earth over various time intervals. Karnataka lies between latitudes 12° 45′ and 14° 22′ N and longitudes 76° 24′ and 77° 3′ E. In this state, *An. culicifacies* is the major vector. Tumkur district in southern Karnataka is one of the malarious districts and in this district *An. culicifacies* was found breeding in contained water bodies, namely tanks, streams, and irrigation, step and draw-wells. Therefore, RS satellite image technology was used in Tumkur district with the following objectives: (i) to identify and characterize the breeding habitats of *An. culicifacies* that are detectable by remote sensing images (RS) and the transient water bodies that are not detectable by RS; (ii) to identify the presence of biotope suitable for thriving of adult *An. culicifacies* population in and around villages; and (iii) to find out the relationship between landscape features of the villages with the malaria endemicity.

Based on annual parasite incidence (API) of malaria from 1995–99, three Primary Health Centres, namely Bukkapatna with high malaria with API ranging from 4 to 26.4, Tovinkere with moderate Malaria with API ranging from 0.23 to 7.0 and Byalya, a non-malarious PHC with zero API in all the years (except for one *Pf* case in June 2001) were selected for the study (Figure 21). Ten villages were selected in each PHC for a detailed study.

Figure 21: Taluka-wise map of Tumkur district showing three Primary Health Centres selected for the study

***Principal Investigator*:** Dr. R.C. Dhiman, National Institute of Malaria Research, New Delhi
***Co-investigators*:** Dr. S.K. Ghosh, NIMR Field Station, Bengaluru and Shri P. Manavalan, Regional Remote Sensing Service Centre, Bengaluru

Entomological surveys for the presence of breeding habitats of mosquitoes, different breeding habitats positive for anophelines, densities of larvae per dip, emergence of adult anopheline mosquitoes, and man hour density of *An. culicifacies* and other malaria vectors in indoor resting places, were carried out in selected villages in January, May to July and December of 2000 and 2001, and in June of 2002 following standard methods. In this area, *An. fluviatilis* and *An. stephensi* are found but are not considered important as vectors of malaria. Surveys were carried out within 1.5 km radius from the centre of the village keeping in view the flight range of *An. culicifacies*. Surveys for adult resting mosquitoes in human dwellings and cattle sheds in each village were also made and adults collected were identified up to species level. Land use features, viz. water-bodies, types of plantation, barren land, hilly area etc.within the 1.5 km radius from the centre of the village were recorded. In this area, malaria is high from May to July and from December to January it is low. Active fever surveys for point prevalence of malaria cases were undertaken in all study villages during December 2001, January 2002 and June 2002.

Data of Indian Remote Sensing Satellite IRS 1C/D LISS III (Linear Image Self Scanning) with 23.5 metre resolution and PAN (Panchromatic) data with 5.8 metre resolution covering all the three PHCs were procured from the National Remote Sensing Agency (NRSA), Hyderabad for December 2000, May 2001 and December 2001/January 2002. False colour composite/hybrid colour composite images were generated in respect of villages of the three PHCs by merging LISS III and PAN products. Village-wise ground data on land use features in the 3 PHCs for December 2000, May 2001, December 2001/January 2002 and June 2002 were generated. Land use features from the point of mosquitogenic potential, i.e. on water bodies, rocks with and without vegetation, coconut/areca nut plantation and barren area were obtained by supervised classification in marked area of 1.5 km radius for May 2001 from the satellite images.

Habitats positive for *An. culicifacies*, the major vector in the area, breeding in May 2000 are given in Table 4. Tanks, streams, ponds, marshy areas, and irrigation and draw wells were the breeding sites identified in the three PHCs. In the satellite images, it was possible to delineate the major breeding habitats of *An. culicifacies* namely tanks, streams and ponds but irrigation and draw wells, and agriculture pits were not recognized.

In the month of May 2000 in Bukkapatna, i.e. the high malarious PHC, 70% (7/10) of tanks were positive for mosquito breeding while in the non-malarious/least malarious Byalya PHC 12.8% (1/8) were positive and in moderate malarious Tovinkere PHC, 50% (5/10) tanks were positive for mosquito breeding (Table 4). In this month, breeding habitats mainly tanks in the least malarious area dried up while those in high malarious area were all with water. Landscape features from IRS LISS III satellite data in December 2000 (Figure 22) indicated that in Bukkapatna, the proportion of water bodies, marshy area, moist soil and rocks with vegetation, which support mosquito breeding and adult survival, was more as compared to that in Tovinkere and Byalya PHCs.

Anopheles species collected and their man hour densities (MHD) in the surveys carried out in May and December of 2001 are given in Table 5. In May, *An. culicifacies* was found in all the villages of Bukkapatna PHC with MHDs ranging from 1–57, in Tovinkere PHC it was found in 6 out

Table 4. Habitats positive for *An. culicifacies* breeding in the 3 PHCs of Tumkur district, Karnataka (May 2000)

PHCs	Tanks	Streams	Ponds	Marshy area	Irrigation wells	Draw wells	Kunte
Bukkapatna	7/10	5/7	3/6	2/5	2/25	0/3	Nil
Tovinkere	5/10	6/6	0/7	0/1	0/32	0/4	0/3 (0)
Byalya	1/8	4/5	0/3	–	0/17	0/7	0/21(0)

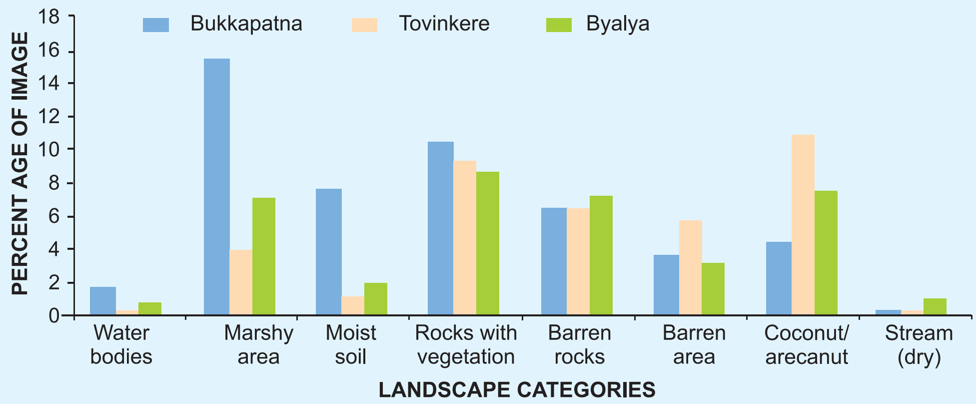


Figure 22: Land use features derived from satellite data of the villages under three catagories of PHCs in Tumkur district (data collected in December 2000)

of 10 villages with MHDs ranging from 1–47 and in Byalya the vector species was found in only 2 villages with MHDs of 1 and 3. In a few villages, *An. fluviatilis* was found in low densities. In December/ January months, except in Surenhally in Tovinkere PHC, and Pujarihally in Byalya PHC all the villages in the three PHCs had *An. culicifacies* in a sympatric association with either *An. fluviatilis* or *An. stephensi*. Densities of *An. culicifacies* were much higher in Byalya (1 to 71) than in Bukkapatna PHC (0.6 to 12.3) and Tovinkere PHC (4 to 54). In the month of May, villages in the three PHCs distinctly differed with reference to the presence of *An. culicifacies*, the major vector in the area while in December /January months no significant difference was found among the villages.

Analysis of satellite imageries of individual villages (Figures 23, 24 and 25) in May 2001 revealed that the presence of water in water bodies, permanent vegetation cover constituting coconut and eucalyptus plantations, and rocks and less barren scrubby area were some of the landscape features that showed relationship with *An. culicifacies* density in high malarious area. During May in Byalya PHC, water bodies were mostly dry. The village-wise statistics of landscape features particularly surface area of breeding habitats, vegetation cover for providing humidity, etc generated for May 2001 in villages of the three PHCs are given in Table 6. In order to consolidate the land use features, coconut/arecanut, rocks with vegetation and eucalyptus plantation were clubbed as permanent vegetation cover, and barren area and scrub/grassy area were clubbed together in Table 7.

As the malaria cases reach to a peak in April, May and June months and the entomological data distinctly differed in the three PHCs during the same period (Table 5), land use features detected in May 2001 were analyzed to establish the correlation. The pattern and the amount of rainfall in the three PHCs are shown in Figure 26. Rainfall was more in Tovinkere and Byalya PHCs as compared to that in Bukkapatna PHC. Rainy season in this area is from April to November with a peak from June to September. In November, all water bodies in all the three PHCs were full of water because of the rains in the preceding months. In May /June, even with the increase in temperature, the water bodies in Bukkapatna contained water, while in the other two less malarious PHCs, water dried up in most of the water bodies. The soil in Bukkapatna PHC in general had poor drainage, while in Tovinkere and Byalya the drainage was excellent resulting in percolation of water rapidly leading to dry water-bodies. Therefore, May/June months were found critical in assessing entomological and ecological parameters supporting *An. culicifacies* populations to delineate villages/PHCs. This suggested that

Table 5. Village-wise entomological data collected in May and December 2001 in the three PHCs

Study sites Villages in 3 PHCs	*Anopheles* species	Entomological data	
		MHD in May 2001	MHD in December 2001
BUKKAPATNA PHC			
Huildore	culicifacies	5	11.3
Rangnathpura	culicifacies	3	1.3
	fluviatilis	1	0
Kilaradahally	culicifacies	14	12.6
	fluviatilis	0	4
Bukkapatna	culicifacies	2	1.3
Maidenahally	culicifacies	48	2
	fluviatilis	0	1
Ramalingapura	culicifacies	57	4
	fluviatilis	2	5.3
Janakallu	culicifacies	43	3
	fluviatilis	0	2
Yeradakatte	culicifacies	4	0.6
Kuruburahally	culicifacies	3	3.3
	fluviatilis	0	5.3
S. N. Tanda	culicifacies	1	3.3
	fluviatilis	1	28
TOVINKERE PHC			
Birdenahally	culicifacies	2	9
Doggenhally	culicifacies	0	23
	fluviatilis	0	1
Mallekavu	culicifacies	2	28
	fluviatilis	0	4
Bendone	culicifacies	0	11
	fluviatilis	0	1
Marenayakanahally	culicifacies	26	2
	fluviatilis	1	0
Chikkanhally	culicifacies	47	54
	stephensi	1	2
Obenhally	culicifacies	15	5
	stephensi	0	1
Ajjenhally	culicifacies	1	4
	stephensi	0	3
Pakirappanpalya	culicifacies	0	12
Surenhally	culicifacies	0	0
BYALYA PHC			
Ejihally	culicifacies	0	47
Marabarahally	culicifacies	0	6
	fluviatilis	0	2
Chikkahosahally	culicifacies	3	61.3
Doddahosahally	culicifacies	0	4
Timmanhally	culicifacies	1	71
N. Nadakanahally	culicifacies	0	2
Pujarihally	culicifacies	0	0
Sankapura	culicifacies	0	1
Gondehally	culicifacies	0	8
Sogenhally	culicifacies	0	20.6

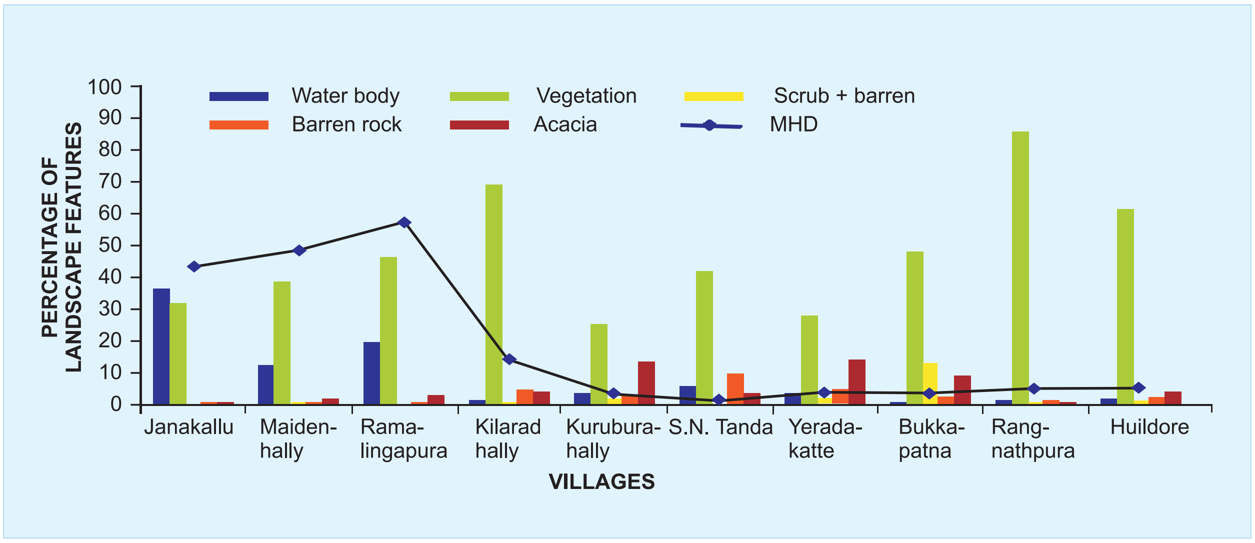


Figure 23: Bukkapatna PHC—Village-wise landscape features (from satellite images) and MHD of *An. culicifacies* in May 2001

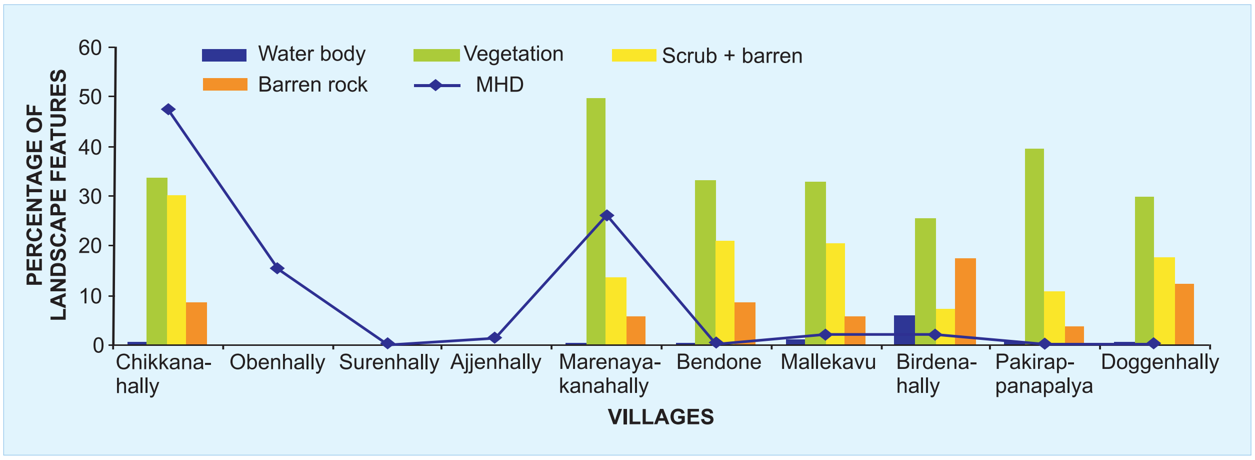


Figure 24: Tovinkere PHC—Landscape features and MHD of *An. culicifacies* in May 2001

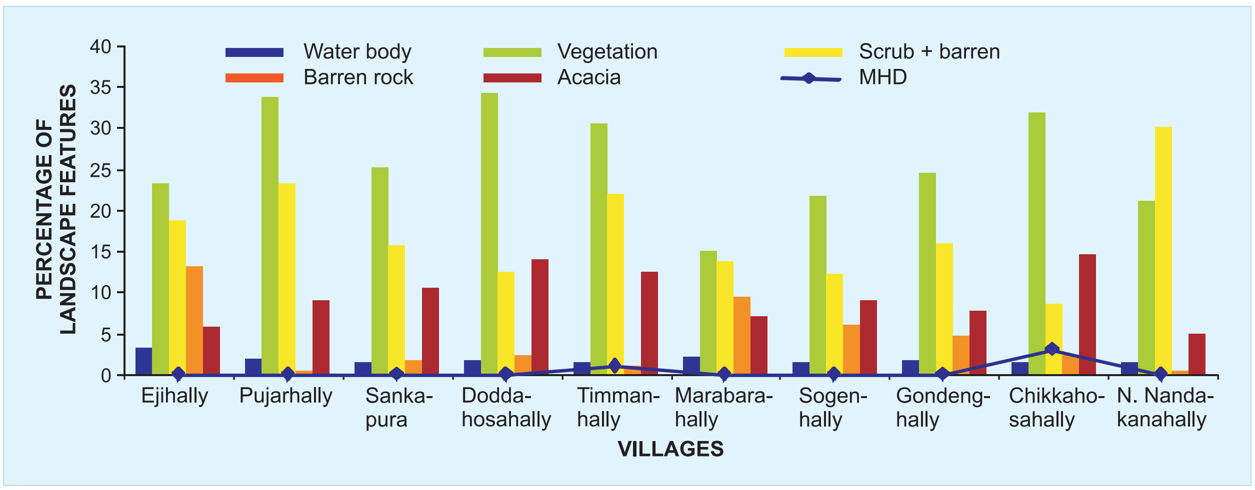


Figure 25: Byalya PHC—Landscape features and MHD of *An. culicifacies* in May 2001

Table 6. Statistics of land use features in villages of 3 PHCs of Tumkur district derived from satellite images of May 2001 and entomological data from ground surveys during the same time

Study sites	Percentage of landscape features											
Villages in 3PHCs	Water bodies	Barren area	Moist soil	Coconut/ arecanut plantation	Rocky area	Barren rock	Eucalyptus plantation	Human settle-ment	Acacia plantation	Agri-culture land	Grassy-fallow land	River sand
BUKKAPATNA PHC												
Huildore	1.73	0.06	11.72	8.64	13.44	2.58	39.06	1.92	3.92	11.97	1.08	–
Rangnathpura	0.82	0	1.49	3.64	21.21	1.13	60.87	0.38	0.58	3.17	0.34	–
Kilaradahally	0.64	0.01	5.11	5.35	15.32	4.42	48.36	1.67	3.58	10.92	0.26	–
Bukkapatna	0.36	0.58	1.4	25.5	6.53	2.28	15.61	6.9	8.97	14.73	12.32	–
Maidenahally	11.97	0.09	0.15	7.74	30.36*	0.13	0.06	13.02	1.44	1.2	0	–
Ramalingapura	19.18	0	0.06	23.84	22.07*	0.82	0.24	11	2.56	0.99	0.72	–
Janakallu	35.78	0	4.7	8.76	22.61*	0.76	0.1	10.59	0.46	0.64	0	–
Yeradakatte	3.33	0.75	7.27	7.1	5.37	4.76	15.58	9.25	13.71	25.64	0.4	–
Kuruburahally	3.2	1.62	10.5	5.92	5.55	2.74	13.42	5.84	13.49	30.06	0.05	–
S.N. Tanda	5.38	0.19	25.48	9.12	9.3	9.68	23.52	1.88	3.44	5.42	0.66	–
TOVINKERE PHC												
Birdenahally	5.85	1.15	16.49	10.04	2.12	17.41	13.19	17.56	–	6.03	6.06	–
Doggenhally	0.32	1.91	16.9	8.65	1.47	12.12	19.51	11.15	–	8.95	15.59	–
Mallekavu	1.03	3.53	16.03	8.82	1.55	5.71	22.51	10.37	–	10.11	16.91	–
Bendone	0.2	3.66	15.16	3.68	2.02	8.37	27.36	10.09	–	9.39	17.19	–
Marenayakanahally	0.15	2.35	15.53	5.82	12.56	5.55	31.23	5.51	–	9.16	11.11	–
Chikkanhally	0.5	8.43	6.24	0.26	1.57	8.32	31.69	9.71	–	5.92	21.54	–
Obenhally	na											
Ajjenhally	na											
Pakirappanpalya	nil	0.53	21.4	11.63	3.02	3.61	24.79	8.23	–	13.63	10.14	–
Surenhally	na											

Table 6 contd...

(Table 6 contd...)

Study sites Villages in 3PHCs	Percentage of landscape features											
	Water bodies	Barren area	Moist soil	Coconut/ arecanut plantation	Rocky area	Barren rock	Eucalyptus plantation	Human settle-ment	Acacia plantation	Agri-culture land	Grassy-fallow land	River sand
BYALYA PHC												
Ejihally	3.2	7.11	1.06	2.57	2.74	13.1	17.86	20.66	5.86	4.91	11.7	8.83
Marabarahally	2.15	2.2	0.49	3	1.47	9.47	10.6	26.9	7.03	4.43	11.59	20.26
Chikkahosahally	1.52	1.77	1.83	10.22	11.45	2.46	10.17	19.15	14.68	12.25	6.8	6.56
Doddahosahally	1.7	3.37	1.86	12.86	11.37	2.33	9.96	12.82	14.08	11.64	9.13	7.42
Timmanhally	1.54	0.64	2.49	8.53	11.51	1.18	10.83	20.27	12.41	4.98	21.25	3.67
N. Nadakanahally	1.47	0.27	9.14	4.51	5.12	0.35	21.08	17.97	4.93	2.29	29.94	1.37
Pujarihally	1.93	0.71	2.87	3.67	7.78	0.49	22.24	20.74	9.11	5.48	22.62	1.5
Sankapura	1.44	2.69	1.17	9.67	6.21	1.7	9.24	20.06	10.55	11.15	12.95	11.2
Gondehally	1.75	6.16	0.54	9.96	4.55	4.75	9.99	14.95	7.8	12.65	9.65	15.35
Sogenhally	1.49	2.71	1.3	5.78	5.22	6.02	10.66	21.46	9.11	8.14	9.54	17.85

MHD—Man hour density

Table 7. Consolidated land use features derived from satellite data in villages of three PHCs

PHCs	Percentage of land use features					
	Water bodies	Permanent vegetation cover	Scrubs and barren	Barren rock	Acacia	Malaria vectors and MHDs
Bukkapatna	0.36 – 35.78	24.89 – 85.72	0 – 12.9	0.13 – 9.68	0.46 – 13.71	Ac 1 – 57 Af 0 – 2
Tovinkere	0.15 – 5.85	25.53 – 49.61	7.21 – 29.97	3.61 – 17.41		Ac 0 – 47 As 0 – 1 Af 0 – 1
Byalya	1.44 – 3.2	15.07 – 34.19	8.57 – 30.21	0.35 – 20.33	4.93 – 14.68	Ac 0.3

Ac – *An. culicifacies*, Af – *An. fluviatilis*, As – *An. stephensi*, MHD – Man hour density.

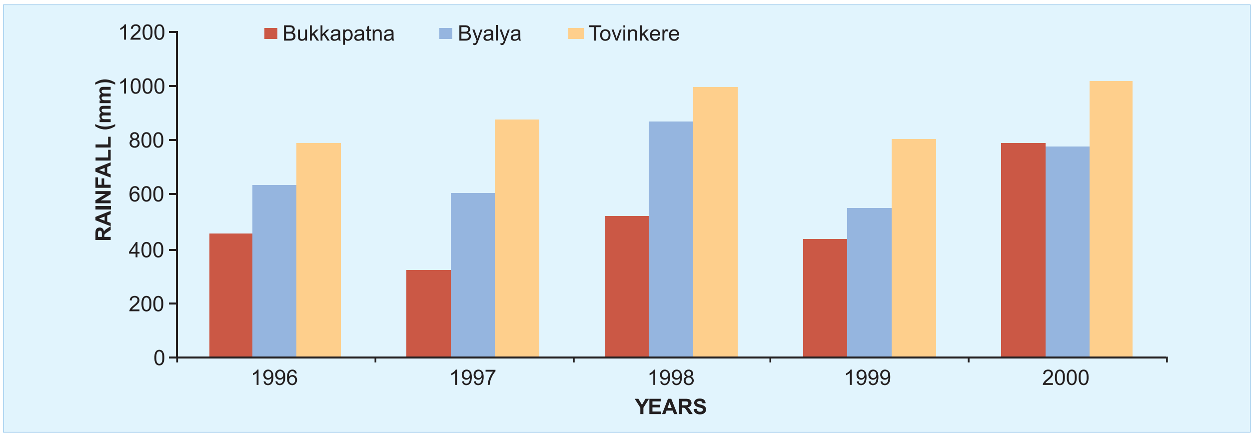


Figure 26: Rainfall pattern in the three PHCs in Tumkur district

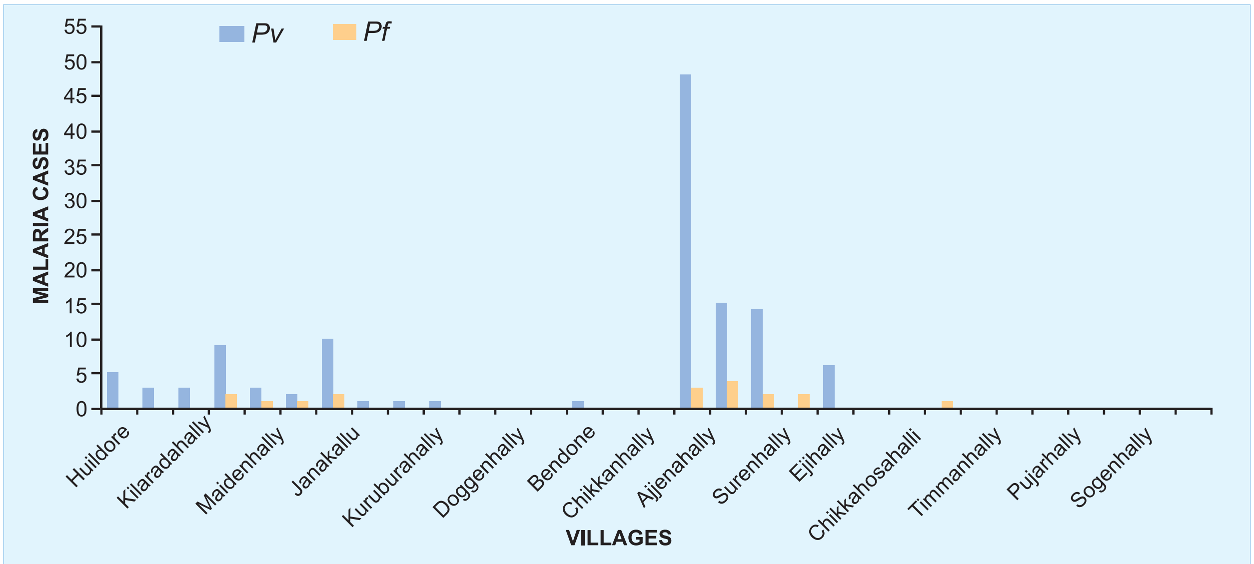


Figure 27: Malaria incidence in individual villages in the three PHCs in June 2001

examination of landscape features especially water bodies, soil type, and permanent vegetation cover, etc. that support *An. culicifacies* populations in the month of May/June are decisive in classifying a village/PHC as malarious or non-malarious. Variation in *An. culicifacies* densities and landscape features among the villages within the PHCs, suggested village-wise analysis. Permanent vegetation versus vector density gave negative correlation when the 10 villages in Bukkapatna PHC were considered as a group (Table 7). But when the extent of permanent vegetation in the five villages that recorded the highest vector density – Maidenahally, Janakallu, Ramalingapura, S.N. Tanda and Yerdakatte were considered for establishing relationship with the vector density, the correlation coefficient (*r*) was 0.99.

In Bukkapatna PHC, Janakallu, Maidenahally, Ramalingapura, S.N. Tanda and Yerdakatte could be labeled as high risk villages while Kilaradahally, Kuruburahally, Bukkapatna, Rangnathpura and Huildore as low risk malarious villages. In Tovinkere PHC, Chikkanhalli, Obenhalli and Birdenahalli were found to have the landscape elements suitable for high malaria while Doggenhalli and Marenayakanahalli had low potential for malaria. In non- malarious/low malarious Byalya PHC, villages Ejihally and Marabahalli may have the malaria transmission potential because of the presence of water-bodies like tanks and streams. It needs to be seen whether permanent vegetation cover beyond 1.5 km radius influences the density of vector species and malaria endemicity.

This analysis was supported by the malaria data. The slide positivity rate (SPR) did not vary between Bukkapatna and Tovinkere PHCs when data were collectively considered for the whole PHC (10.52 and 14.2 respectively in June 2001, and 13.04 and 14.28 in June 2002). June was chosen for malaria survey to give a one-month time lag for malaria transmission to set in after suitable vector-conditions were found in May. Village-wise incidence of malaria in selected villages of the three PHCs in June 2001 showed distinct differences among the study villages (Figure 27). In Bukkapatna area, all the villages were having malaria cases while in Tovinkere PHC malaria cases were seen in 4 villages and in Byalya PHC only one village recorded malaria cases.

The generation of Normalised Difference Vegetation Index (NDVI) values for different dates (Figure 28) also indicated difference in NDVI values in three PHCs warranting the need for villages level analysis of NDVI values for determining the relationship with malaria endemicity.

Remote sensing was used to delineate *An. culicifacies* breeding sites and identify land use features favourable for vector abundance. The study has brought out clearly that there is heterogeneity among the villages even within a PHC both with respect to landscape features and in malaria incidence. This is in line with the differential malarial endemicity generally observed and confirms that malaria

(a) (b)

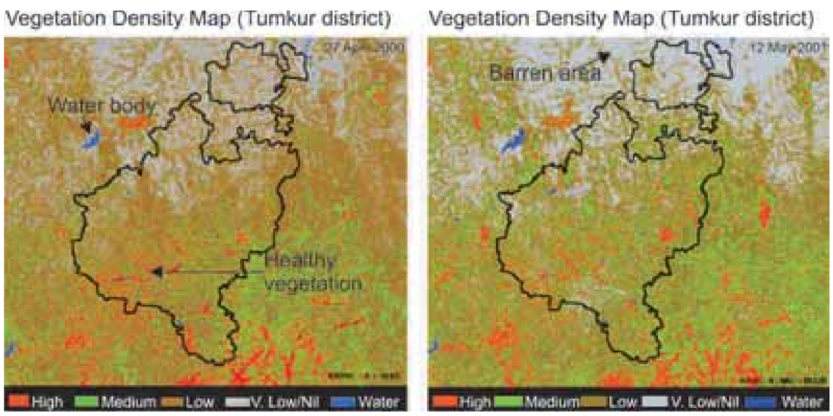


Figure 28: Vegetation Index (Normalised difference vegetation index) derived from IRS 1 C data of 27 April 2000 (a); and 12 May 2001(b). The values are from –1 to 1. Higher positive values indicate more vegetation cover while negative values indicate water. Barren area in grey colour is more in (b)

(a) (b)

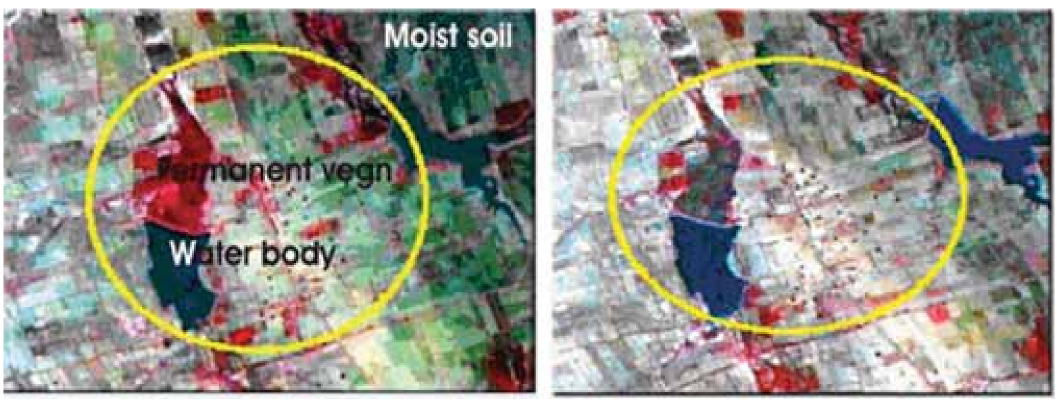


Figure 29: Image of Yerdakatte village in Bukkapatna PHC generated from LISS III and PAN sensors of IRS 1 C satellite on (a) May 2001; and (b) January 2002. Difference in the extent of more water in tank on right side of the image is clearly visible in (b). Vegetation cover is more and healthier in (a)

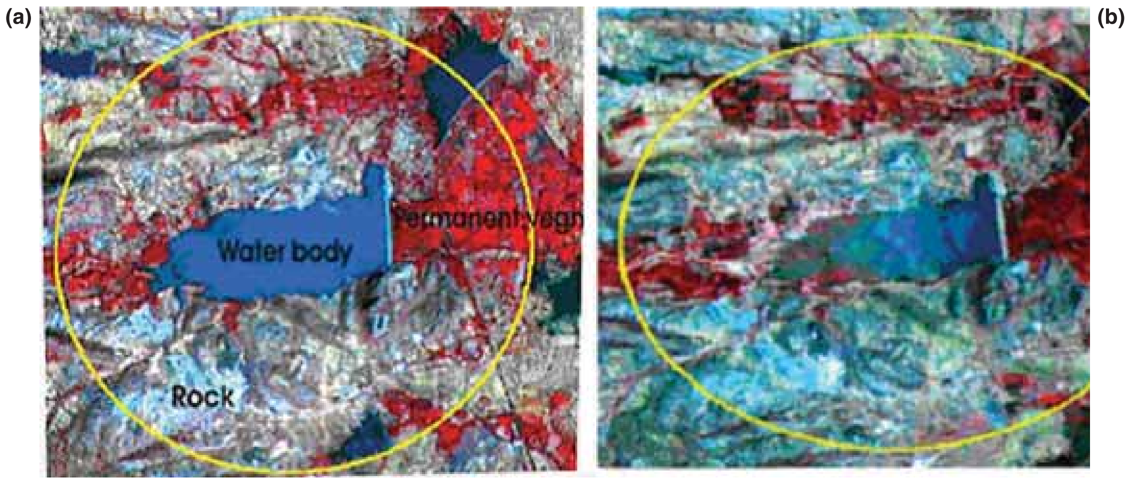


Figure 30: Image of Birdenahalli village in Tovinkere PHC generated from LISS III and PAN sensors of IRS 1 C satellite on (a) May 2001; and (b) January 2002. Growth of vegetation in the bottom of tank is visible in (a). Difference in extent of more water in both the tanks is clearly visible in (b). Vegetation cover is more and healthier in (b)

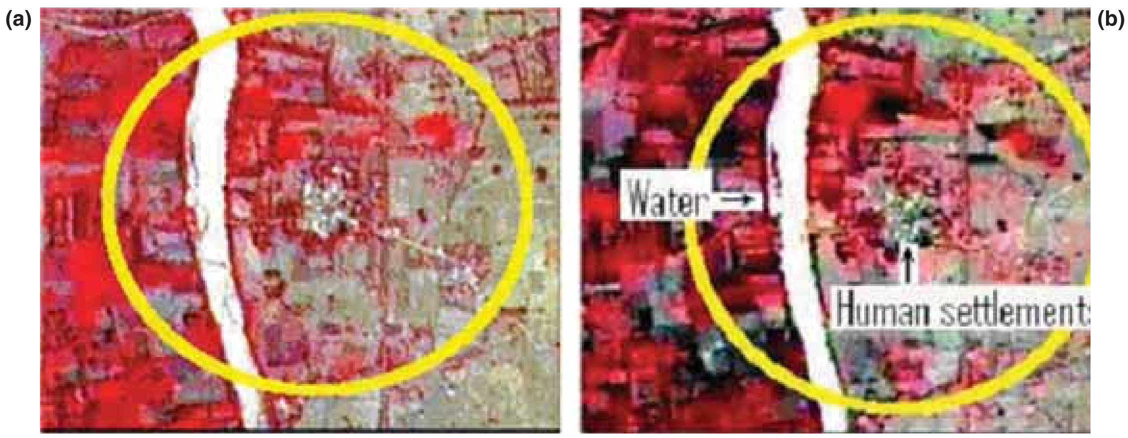


Figure 31: Image of Sankapura village in Byalya PHC generated from LISS III and PAN sensors of IRS 1 C satellite on (a) May 2001; and (b) January 2002. No water body is visible in the image except an almost dry river. A minor trace of polluted water in river in (a); and slightly fresh water in (b) is visible

is a local and focal disease. A comparison of landscape features in villages of the three PHCs showed both qualitative and quantitative differences in the satellite images taken in May 2001 and January 2002 (Figures 29, 30 and 31). This suggests that the remote sensing tool can be used to monitor village-wise land use features relevant for vector population densities, vegetation, NDVI values and water-bodies and to classify a village as malarious or non-malarious suitable for village-level stratification for prioritization and micro planning for malaria control.

National Institute of Malaria Research received 'Geospatial Excellence Award' for contributions made in GIS for vector-borne diseases control in International Geospatial Conference 'Map World Forum' on 12 February 2009. The award is granted to meritorius projects which have made significant and measurable contributions towards the development of new geospatial technology practices to substantially reduce project costs and brings in efficiency in the workflow.