Mapping and Distribution of Malaria Vectors and other Indian Anophelines using GIS and RS

There are 58 species of Indian anophelines out of which six—*Anopheles culicifacies, An. fluviatilis, An. stephensi, An. dirus, An. minimus* and *An. sundaicus* are the major vectors of malaria in different ecological settings in India. A GIS-based technique has been develolped to map Indian anophelines including malaria vectors. Thematic maps for ecological parameters which mainly govern the distribution of the species such as forest cover, rainfall, altitude, soil type and temperature published by National Thematic Mapping Organization (NATMO), Govt. of India on 1:6,000,000 scale were digitized (Fig. 5). Reported distribution was taken as baseline information. A software was developed to workout favourable conditions for existence of different species. Favourable conditions for continuous variables consisting of all values between minimum and maximum, whereas for discrete variables, individual values were pooled. A mathematical model was developed to extract the range of each parameter and integration. Digitization, overlaying and analysis was done using ESRI GIS software Arc/Info NT 8.1 and Arc View 3.2. Validation was done using reported distribution and field verification.

Anopheles sundaicus—A Species of Coastal Area

An. sundaicus is a coastal species and breeds in brackish water. Presently, it is confined only to Andaman & Nicobar Islands where it is the sole vector of malaria. In A & N Islands, the altitude ranges from sea level to 150 m, and the annual mean temperature is about 25°C. Since very high rainfall is not suitable for immature stages of the vector, areas having $\geq$1600 mm rainfall were considered as unfavourable. Sandy soil is the characteristic of coastal area, therefore, this soil was selected for the study. Integration of favourable themes resulted in areas favourable for *An. sundaicus* as shown in Fig. 6a (Srivastava *et al*

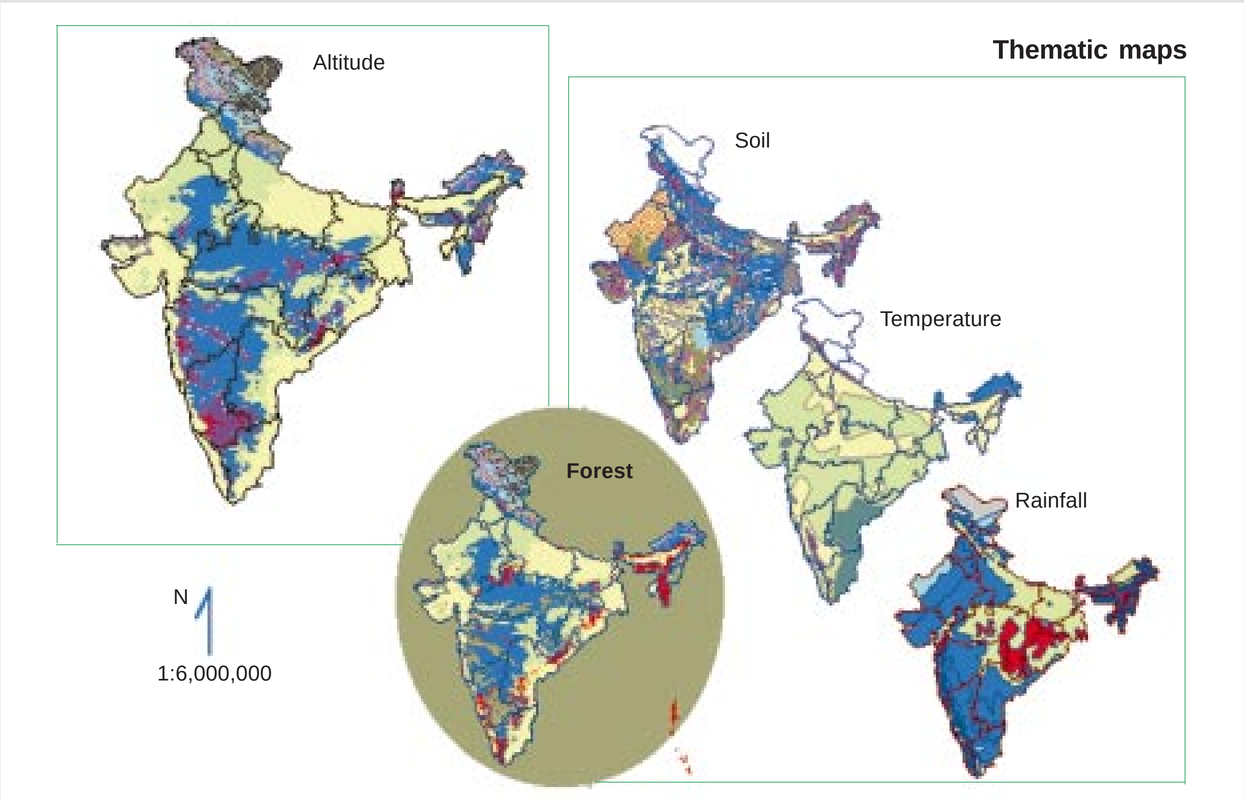

Fig. 5: Thematic maps of ecological parameters, namely altitude, rainfall, forest, soil and temperature plates of Land Resources Atlas of India, NATMO, Govt. of India (1996) in the scale of 1:6,000,000 were digitized by using Arc/Info NT 8.1 on Summagraphic A00 size digitizer

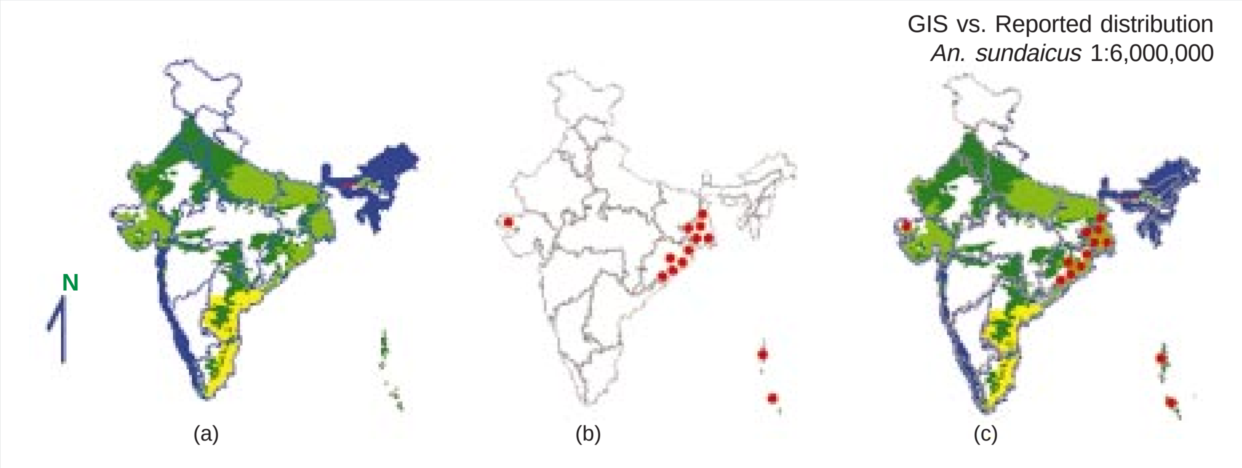

Fig. 6: (a) Map showing GIS-predicted favourable areas for *An. sundaicus* in India (light green colour); (b) Reported distribution of *An. sundaicus* in India; and (c) Validation of GIS-predicted areas favourable for *An. sundaicus*

1997, 1998). Comparison of GIS analyzed map with reported distribution (Fig. 6b) revealed a good geospatial correlation. In Fig. 6c, dots represent the actual sites where the species has been reported overlaid on GIS analyzed map which clearly reveals validity of results. Since it is a coastal species, the comparison was restricted to coastal areas only. For validity of the results a blowup of the Orissa state was taken (Fig. 7). It shows Chilka lake falling in GIS analyzed favourable zone and *An. sundaicus* was reported from this lake several times. In Visakhapatnam of Andhra Pradesh state which falls in favourable GIS zone the species was recorded earlier. On southwestern 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 this species.

Anopheles dirus—A Species of Deep Forested Areas

An. dirus is one of the most efficient vectors of malaria in forested areas of northeastern India. It

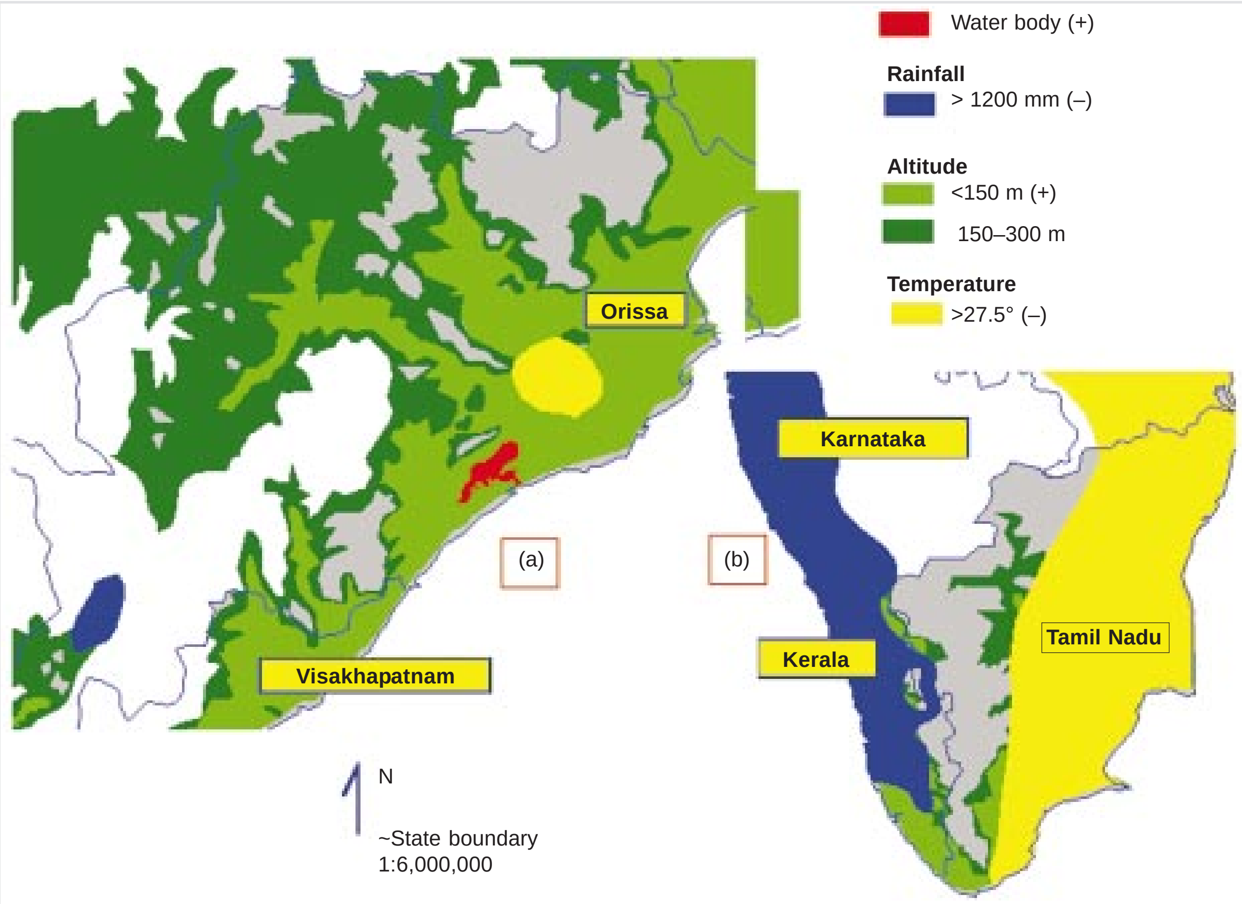

Fig. 7: GIS predicted areas of *An. sundaicus* in (a) Orissa, where the species has been reported several times; and (b) Kerala, no reports from this area

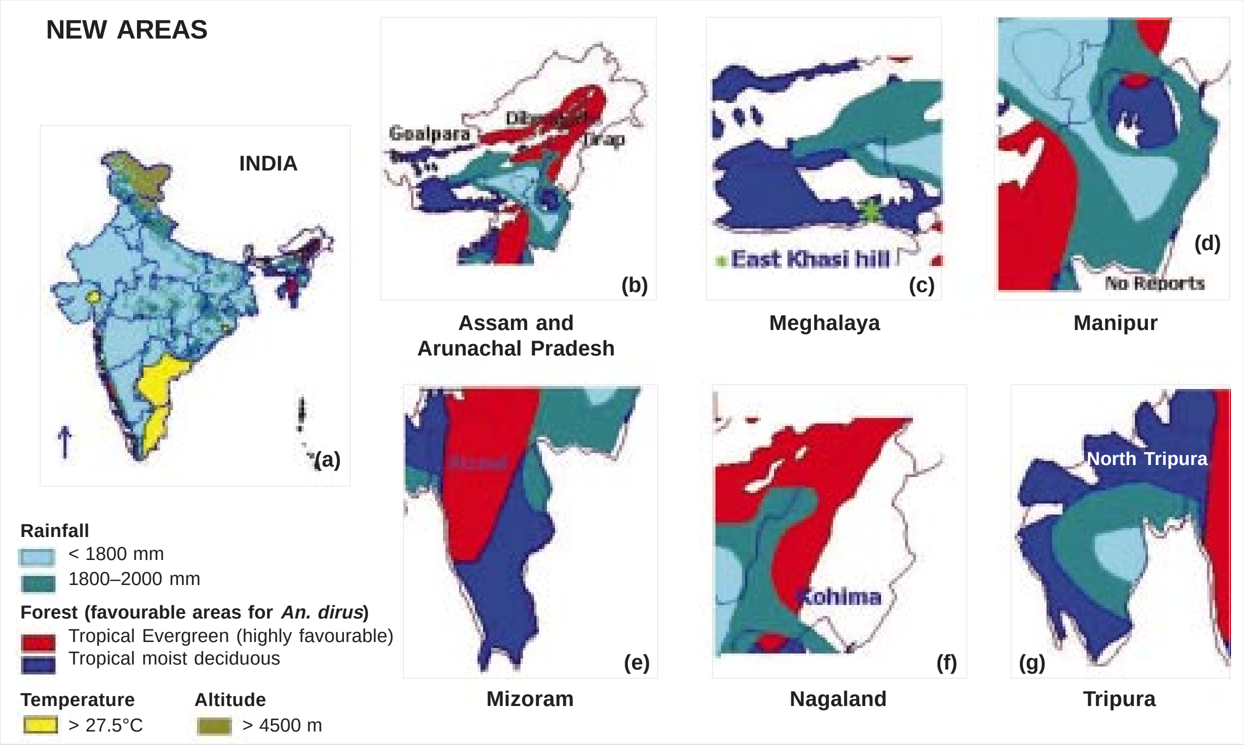

Fig. 8: GIS-predicted areas favourable for *An. dirus* in (a) India; and (b–g) northeastern states

breeds in pools, unused wells, borrow pits, hoof prints and drains covered with foliage in deep-forested areas. The resultant map obtained by integrating the four thematic maps of forest cover, rainfall, temperature and altitude is shown in Fig. 8a. The favourable areas for *An. dirus* are shown in red — evergreen forest and blue—deciduous moist forest. These are mainly located in northeast and western districts of India. In spot surveys, *An. dirus* has been reported from northeastern 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 (Srivastava and Nagpal 2000; Srivastava *et al* 2001). Besides these areas, there are some new areas where surveys have not been conducted and the species is likely to be found (Fig. 8a). For validation GIS-predicted areas were compared with reported distribution at micro level. In Assam, the large areas on northeast were found favourable for *An. dirus* through GIS (Fig. 8b). 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 envelopes Assam from the north, east and small portion on west. The species has been reported from Tirap district, Nampong, Changlang Tenga valley situated near Assam border. GIS also maps some areas favourable on Assam border (Fig. 8b). In Meghalaya, deciduous moist forest on eastern and western sides are favourable for *An. dirus* (Fig. 8c). There are reports from east Khasi hills, Burnihat. In Manipur, there are no reports of *An. dirus* prevalence (Fig. 8d) The entire state of Mizoram is favourable for *An. dirus* and it has been reported from Aizawl and south Mizoram (Fig. 8e). In Nagaland, favourable areas were found in Kohima, Mohokchung, Mon and Wokh, the species was reported from western side of Kohima (Fig. 8f). In Tripura favourable areas are due to deciduous moist forest, it forms a broken semi-circular ring on the western side (Fig. 8g). The species has been reported from north Tripura.

An. dirus has been reported from Jammu & Kashmir, A & N Islands and Kerala. Distribution through GIS also depicts areas favourable in these states. In Karnataka, it has been reported from Bijapur, Chitradurga, Hassan, Shimoga and north Kanara and Coorg, where GIS reconfirms the reports from these areas. From West Bengal, the reports of the species are from Jalpaiguri. Fig. 8 also shows that these areas are favourable for *An. dirus*. Besides new areas in Manipur falling in Indo-China zone, there are receptive areas for *An. dirus* in Madhya Pradesh, Uttar Pradesh and Maharashtra states falling in Indo-Iranian zone (Fig. 9 a–e).

Anopheles minimus—A Species of Forest-fringe Areas

An. minimus has been the most important vector of malaria along the foothills of Himalaya from Uttar Pradesh to northeast in India. The resultant map after integration of thematic maps of soil, forest cover, rainfall, temperature and altitude using GIS shows the areas favourable for *An. minimus* (Fig. 10).

GIS-predicts favourable areas not only in northeast but also in Uttarakhand, Bihar, Chhattisgarh, Madhya Pradesh, Orissa, Maharashtra, Kerala and

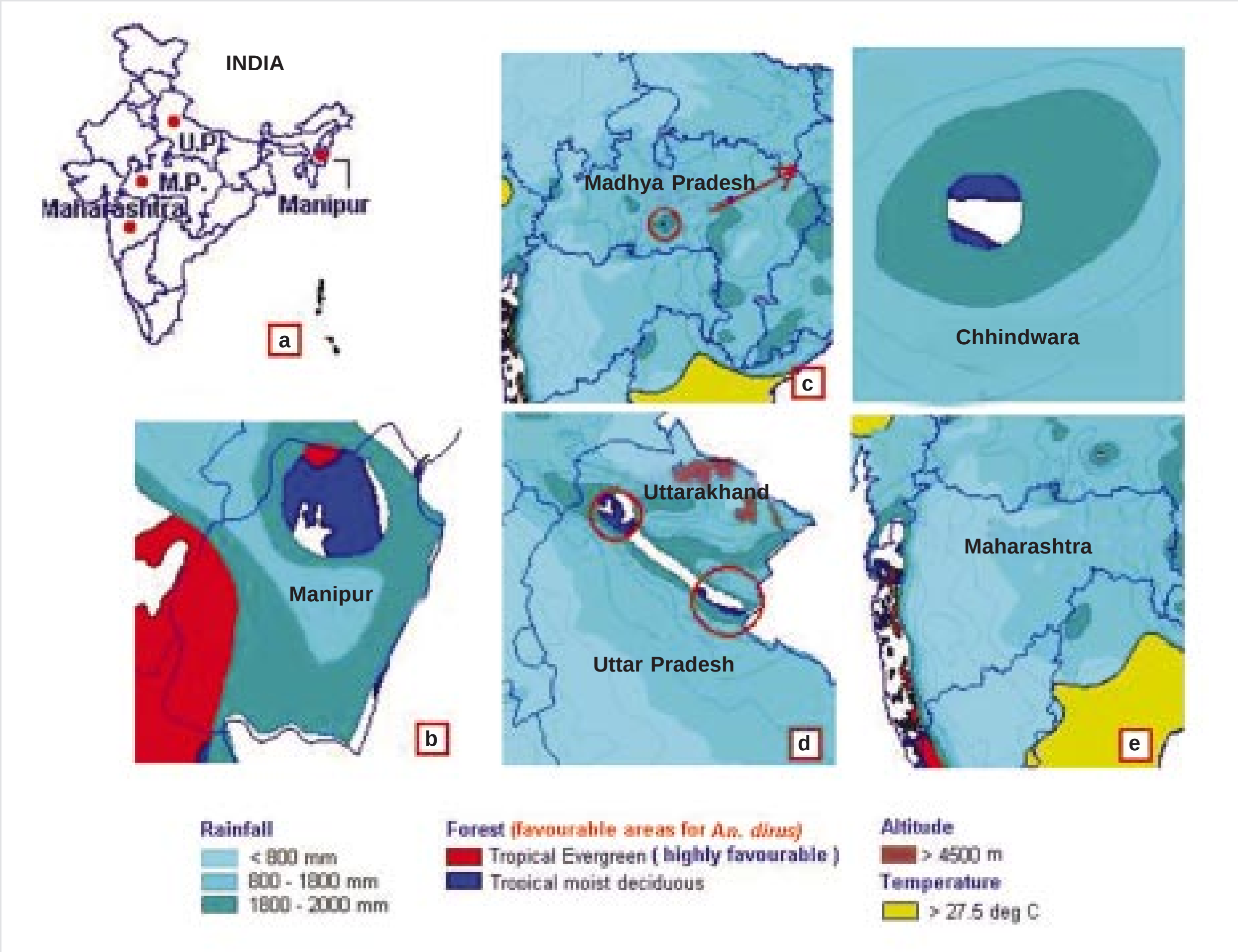

Fig. 9: GIS-predicted new areas for distribution of *An. dirus*: (a) states in India; (b) Manipur; (c) Madhya Pradesh—Chhindwara district is blownup to zoom in small favourable portion of the district; (d) Uttarakhand and Uttar Pradesh; and (e) Maharashtra

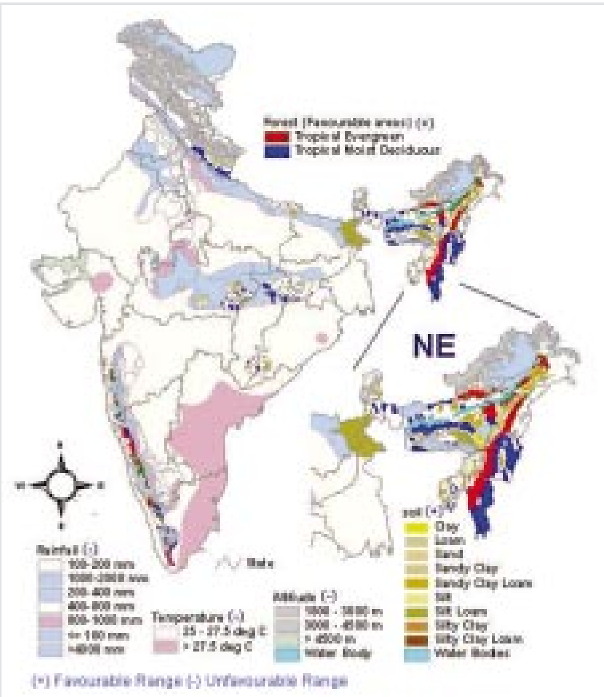

Fig. 10: GIS-predicted favourable areas for *An. minimus* distribution in India, shown in red and blue colours. Inset shows details of *An. minimus* distribution in malaria endemic states

Karnataka (Fig. 11 a–e). It reveals that except Andhra Pradesh all other states have the favourable areas for *An. minimus* distribution from where the species was recorded prior to 1960. In addition, some new areas are also exhibited in Kerala, Maharashtra, Himachal Pradesh and Sikkim.

The results were validated by reported distribution and carrying out precision field surveys at nine locations in four states, namely Uttarakhand, West Bengal, Assam and Meghalaya (Fig.12 a–b) and *An. minimus* was collected from all the locations. In two districts, namely Champavat (earlier Nainital) of Uttarakhand and Dhubri of Assam, the species was reported to have disappeared after 1950s in the former, and in the latter, it was not reported in earlier entomological surveys. In both the places *An. minimus* was encountered besides validation of GIS prediction, reappearance of *An. minimus* at Banbasa (Champavat) and the first report from Dhubri was established. Amazingly, GIS-predicted precisely the location in these districts to conduct entomological surveys and the species could be found there. Favourable areas for *An. minimus* in each state were also delineated using GIS and it was found that northeastern states of India are the most favourable and Mizoram has about 90% of its area favourable

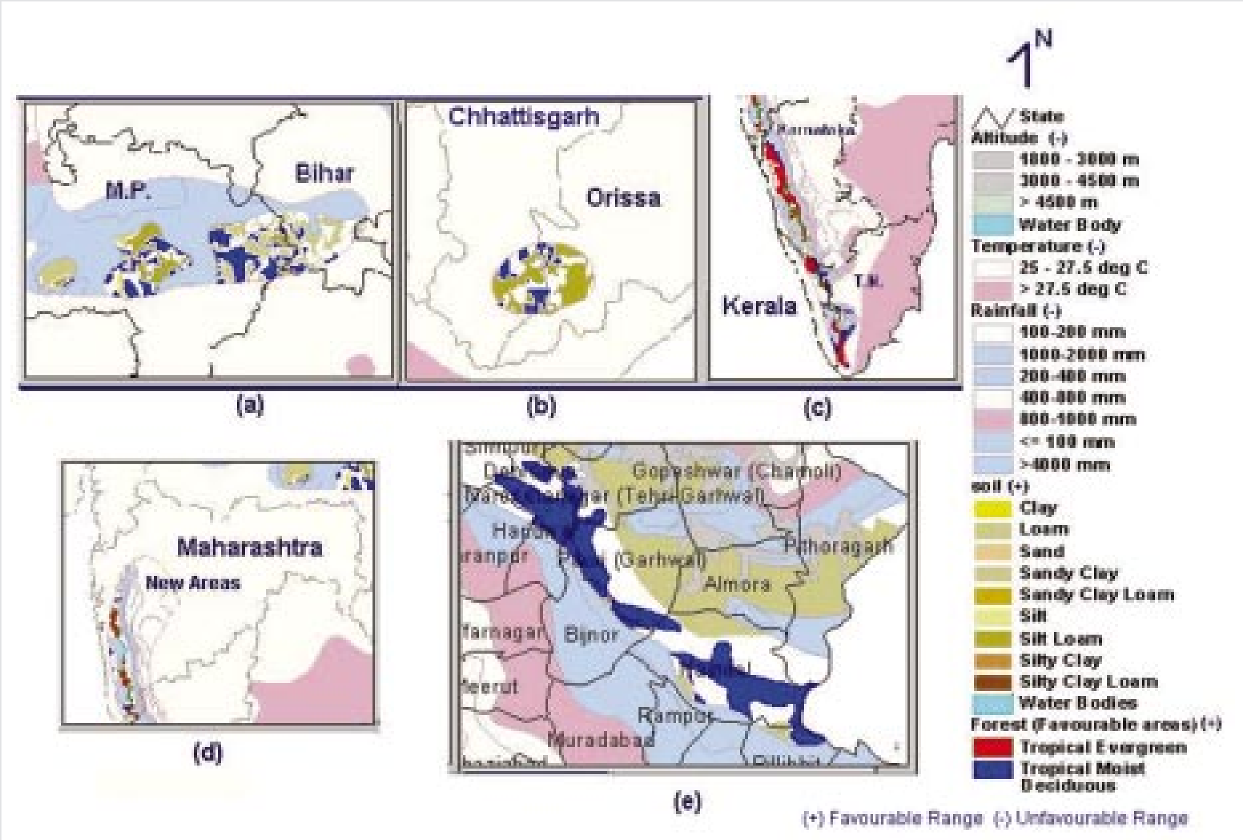

Fig. 11 a–e: GIS-predicted distribution of *An. minimus* in non-endemic areas and also in new areas

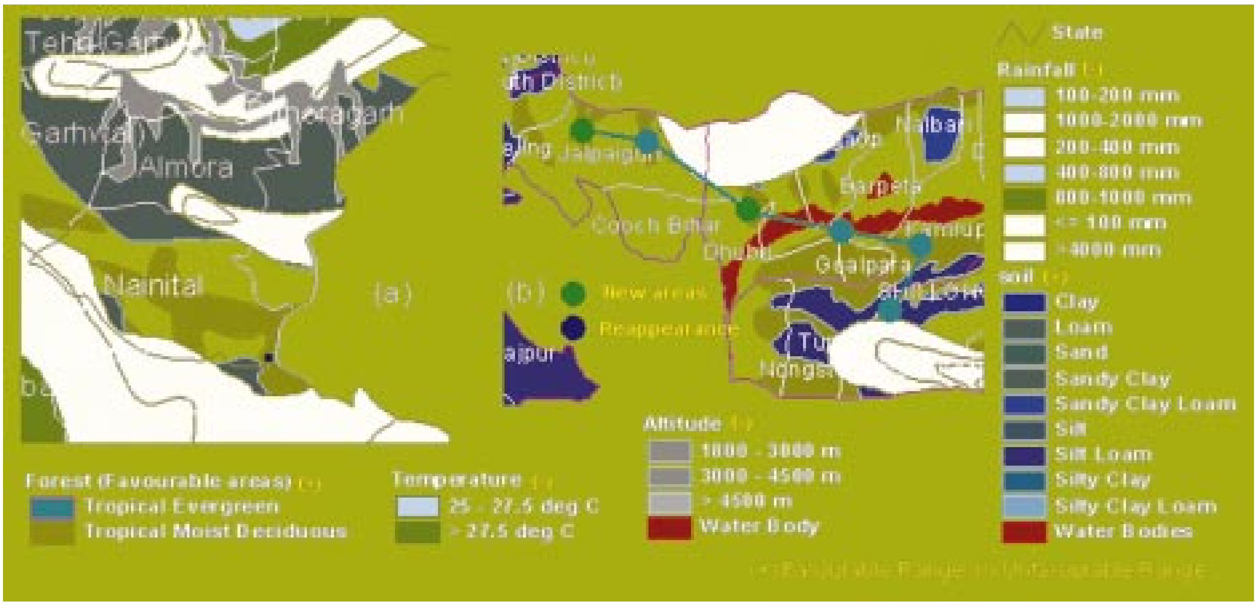

Fig. 12 a–b: Validation spots in GIS-predicted distribution areas of *An. minimus*. Red dots show areas where the species has been reported, pink dots show new areas

for *An. minimus*. There are a few favourable areas in Kerala and Maharashtra where the species could be found in these areas. However, till date no reports of *An. minimus* prevalence are available.

The technique can delineate the areas favourable for any species of flora and fauna, and is very useful for precision surveys. The technique is fast and can be easily duplicated in other parts of the country/ world. In any disease, once the vector distribution is known species-specific control measures can be formulated in a cost-effective manner.

Other Indian Anophelines

Besides mapping of vector distribution, database consisting of ecological parameters suitable for breeding, survival and longevity for non-vector

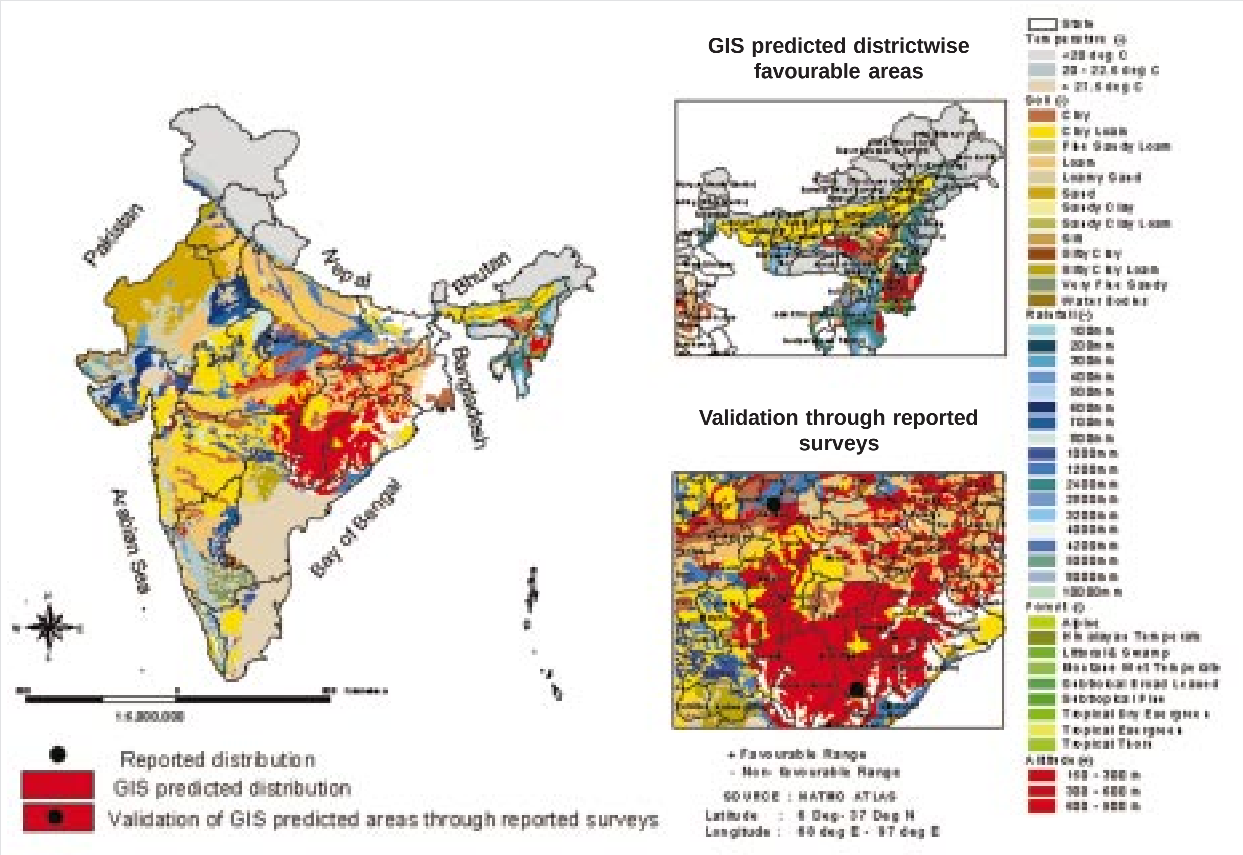

Fig. 13: GIS-predicted distribution of *An. sergentii* in India, a blowup of northeastern states and validation through reported distribution is also depicted in insets

species has been generated. Thematic maps prepared for vector distribution were used, using the software and the mathematical model developed, species-specific conditions were worked out, extracted, overlaid and integrated, the resultant maps showed favourable areas of respective species distribution. Reported areas have been overlaid to validate the GIS-predicted results. The results are reconciling well with the reported distribution. The work on 28 species in subgenus *Cellia* namely, *An. kochi, An. balabacensis, An. elegans, An. karwari, An. tessellatus, An. splendidus, An. pulcherrimus, An. jamesii, An. pseudojamesi, An. annularis, An. pallidus, An. philippinensis, An. nivipes, An. jeyporiensis, An. sergentii, An. moghulensis, An. subpictus, An. sundaicus, An. vagus, An. varuna, An. aconitus, An. majidi, An. maculatus, An. willmorei, An. theobaldi*, *An. dthali, An. multicolor* and *An. turkhudi* has been completed (Fig. 13). A compact disk (CD) has been prepared consisting of distribution of all Indian anopheline species, this is continuously being updated including more species, to be used as a training module.

Application of Remote Sensing (RS) at Village-level to Delineate the Breeding Habitats of *An. culicifacies*

With the advent of finer resolutions in Indian Remote Sensing Satellites, a pilot study was initiated in Tumkur district of Karnataka to delineate the breeding habitats of *An. culicifacies*, the major malaria vector, and to find out the suitable biotope for highly malarious/low malarious areas. Three Primary Health Centres (PHC) with highest, moderate and least malaria were selected for detailed study. Ten villages in each PHC were surveyed for entomological and ecological studies in peak and low malaria transmission seasons. False colour composite images from IRS1C LISS III and PAN data were generated and classification of land-use features was done village-wise (with buffer zone of 1.5 km radius, keeping in view the flight range of vector mosquito) into various land-use categories for peak and low malaria transmission seasons. It was found that delineation of water tanks, rivers, streams, ponds, marshy areas and some irrigation wells not covered by vegetation, was possible. The landscape features critical to malaria endemicity in May were found as water bodies, coconut/areca nut plantation, marshy areas, moist soil, rocks with vegetation and less barren area (Fig. 14). The study indicates that mapping of major breeding habitats of malaria vector and landscape features determining endemicity in similar ecotype is possible through satellite remote sensing technique. In India, the application of remote sensing technique in the field of malaria started in 1992. In this study the data from Indian remote sensing satellites IRS 1A and B with 36.5 meter

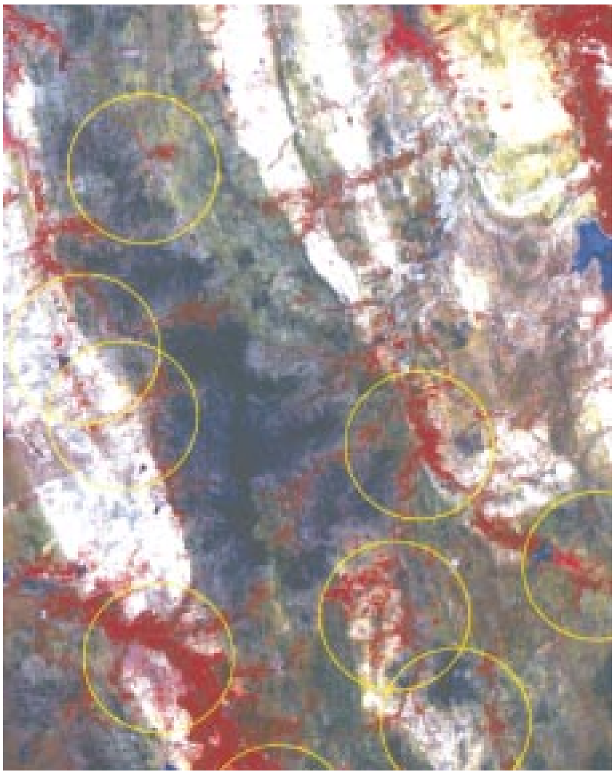

Fig. 14: IRS ID hybrid colour composite of Bukkapatna area of Tumkur district

resolution was used. It could be possible to detect water bodies, village boundaries, vegetation, barren areas *etc*. The smaller breeding habitats which are preferred by *Anopheles* mosquitoes were not detectable. With the advent of satellites with higher resolution (5.8 meter) estimation of mosquito larval production was also attempted.

The application of satellite remote sensing was attempted in inaccessible area of Car Nicobar with digital terrain modeling (Dhiman *et al* 2000). A study using a remote sensing and geographic information system was carried out in Car Nicobar, an island in the Bay of Bengal, to target mosquitogenic condition, particularly of *An. sundaicus*. Satellite data (IRS – 1B LISS II) provided a synoptic view of water bodies of inaccessible areas, marshy areas and coconut plantation as the possible breeding habitats preferred by *An. sundaicus*. A contour map and a digital terrain model helped in the prediction of areas prone to waterlogging. Integration of ground surveys, remote sensing and GIS provided comprehensive information in a short time, which would otherwise have been difficult to display and interpret.

Realizing that anopheline breeding is confined to smaller aquatic habitats and spatial distribution of habitats within the source of blood meal have important bearing on the transmission potential at village-level, the detection of landscape features at village-level was also attempted (Dhiman 2002) in three PHCs of Tumkur district (Karnataka) by selecting 10 villages in each category of high, moderate and no (least) malarious PHCs. Ground surveys for geographic reconnaissance of breeding habitats, larval density per dip, man hour density of adult *An. culicifacies* and other anophelines and ecological changes in landscape features were recorded in low (December/January) and peak transmission seasons of malaria. False colour composite was developed from IRS 1C/D LISS III and PAN data and classification was done for generating statistics for different land-use categories, like water bodies, coconut /areca nut plantation, moist land, barren areas, agricultural plantation rocks with and without vegetation, etc.

It was found that tanks, ponds and streams are easily detectable by remote sensing while irrigation wells (which were found supporting mainly *An. barbirostris*) were rarely detectable. Presence of water in water bodies, rocks with vegetation, coconut/ areca nut plantations and less barren area were found as the landscape elements critical to malaria endemicity. It was found that remote sensing could be used for the detection in ecology of an area at village-level resulting into reduction/increase in malaria endemicity .

After tsunami attack in Car Nicobar Island, post-tsunami malariogenic conditions were mapped vis-a'-vis entomological, ecological and parasitological data using IRS P6 with LISS IV sensor having 5.8 m resolution in three bands. Presently, in order to make the use of satellite remote sensing operational, a study is underway in problematic districts of Karnataka.

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