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 — *An. culicifacies, An. fluviatilis, An. stephensi, An. dirus, An. minimus* and *An. sundaicus* are major vectors of malaria in different ecological settings. A GIS based technique has been evolved to map Indian anophelines including malaria vectors. Thematic maps for ecological parameters which mainly govern the distribution of the species—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. 4). 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 consist 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.

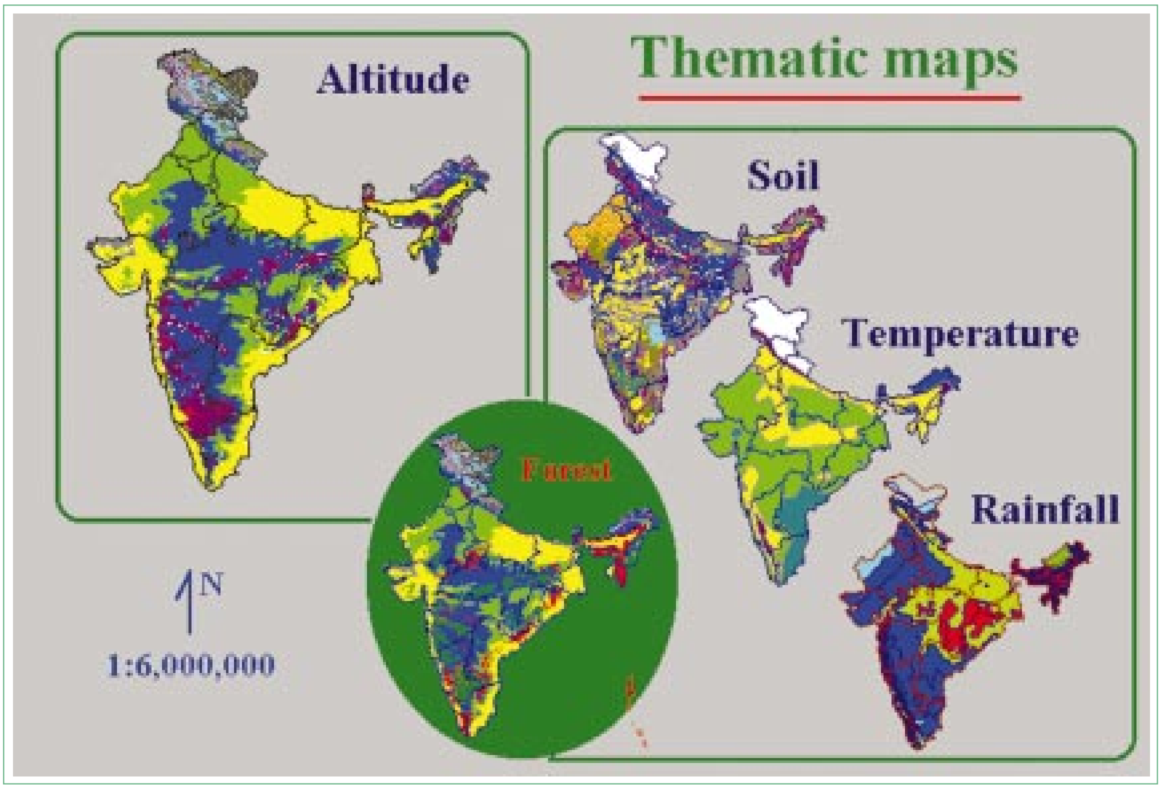

Fig. 4: **Thematic maps of ecological parameters namely altitude, rainfall, forest, soil and temperature plates of Land Resources Atlas of India, NATMO, Govt. of India (1996) in the scale of 1:6,000,000 were digitized by using Arc/Info NT 8.1 on Summagraphic A00 size digitizer**

An. 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 annual mean temperature is about 25°C. Since very high rainfall is not suitable for immature stages of the vector, areas having ≥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. 5a (Srivastava *et al*., 1997, 1998). Comparison of GIS analyzed map with reported distribution (Fig. 5b) revealed a good geospatial correlation. In Fig. 5c, 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. 6). 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.

An. 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 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. 7a. 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

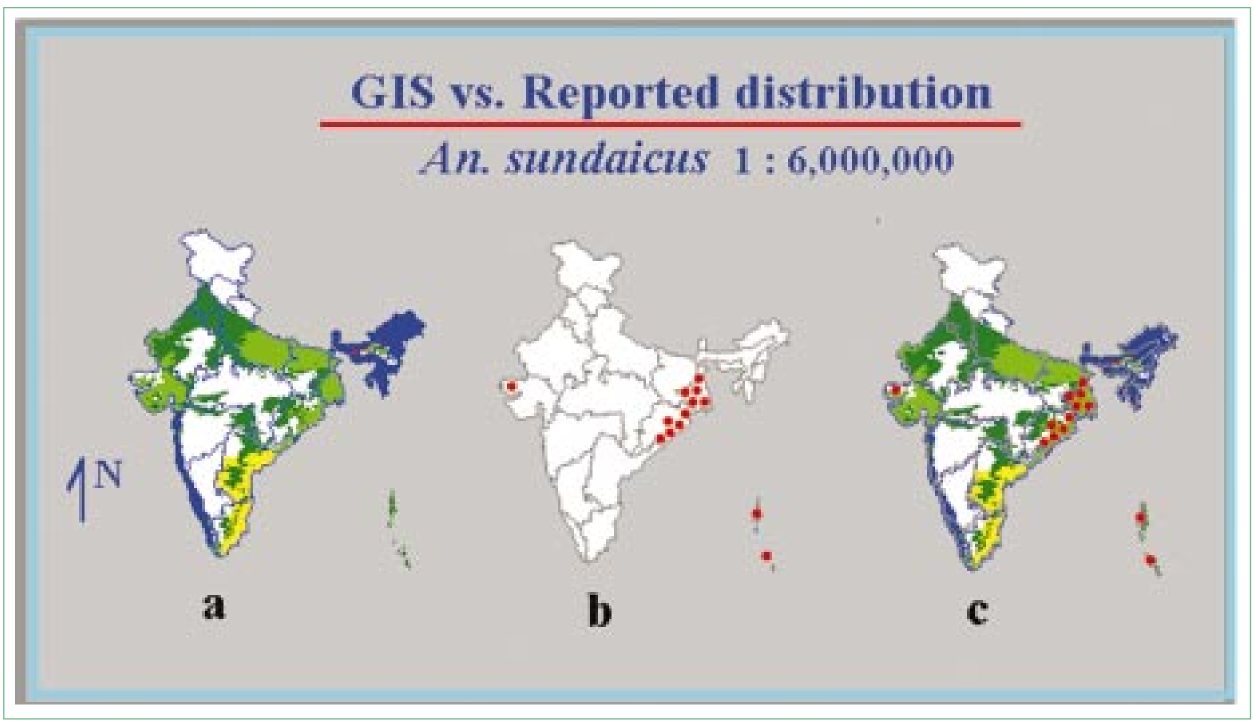

Fig. 5: **(a) Light green colour shows GIS predicted favourable areas for *An. sundaicus* in India; (b) Reported distribution of *An. sundaicus* in India; and (c) Validation of GIS predicted areas favourable for *An. sundaicus***

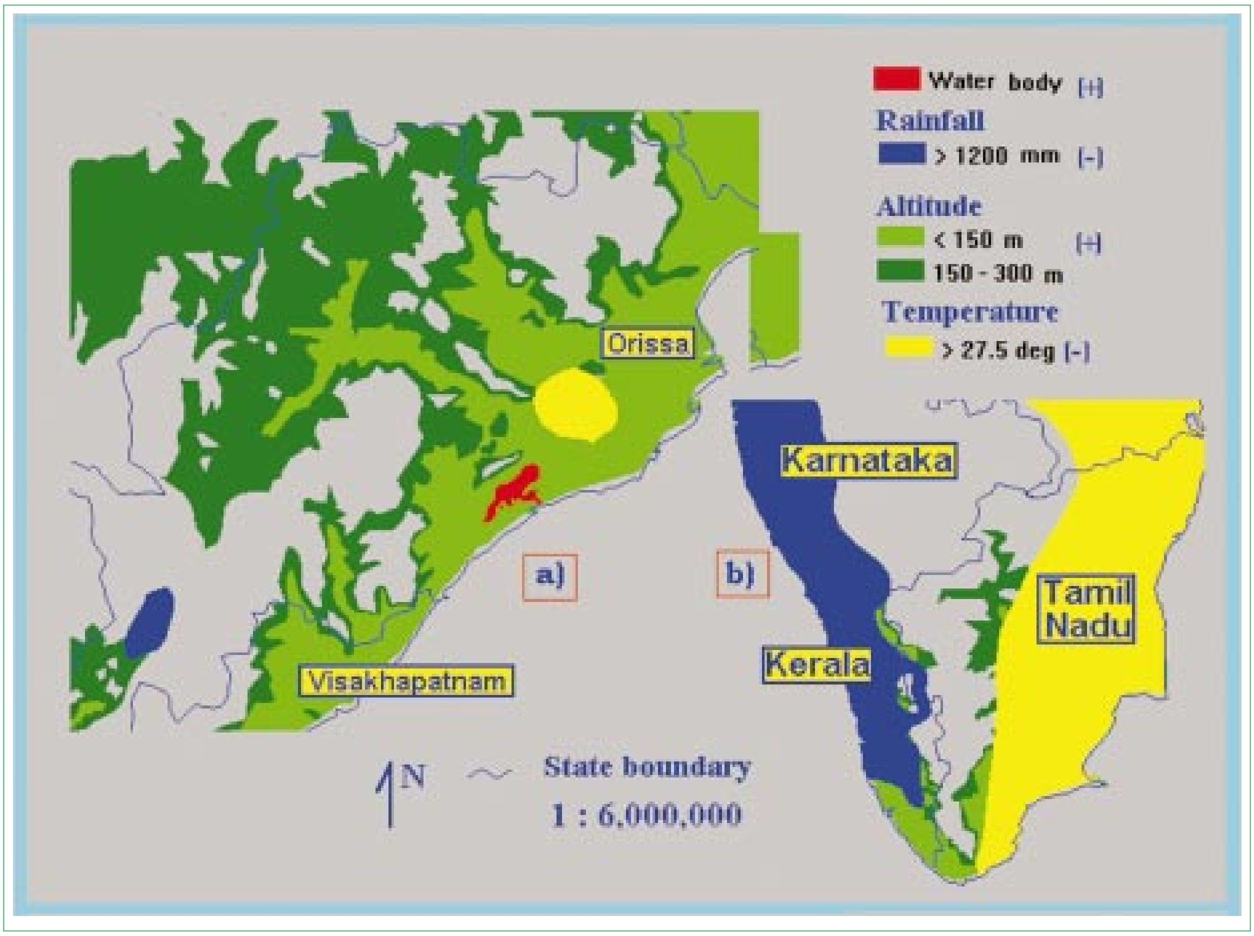

Fig. 6: **GIS predicted areas of *An. sundaicus* in (a) Orissa, where the species has been reported several times; and (b) Kerala, no reports from this area**

areas, there are some new areas where surveys have not been conducted and the species is likely to be found (Fig. 7a). 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. 7b). 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. 7b). In Meghalaya deciduous moist forest on eastern and western sides are favourable for *An. dirus* (Fig. 7c). There are reports from east Khasi hills, Burnihat. The entire state of Mizoram is favourable for *An. dirus* and it has been reported from Aizawl and south Mizoram (Fig. 7e). In Nagaland favourable areas were found in Kohima, Mohokchung, Mon and Wokh, the species was reported from western side of Kohima (Fig. 7f). In Tripura favourable areas are due to deciduous moist forest, it forms a broken semi circular ring on the western side (Fig. 7g). The species has been reported from north Tripura.

Anopheles 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. 7 also shows that these areas are favourable for *An. dirus*. Besides new areas in Manipur falling in Indo-Chinese zone, there are receptive areas for *An. dirus* in states of Madhya Pradesh, Uttar Pradesh, and Maharashtra falling in Indo-Iranian zone (Fig. 8a–e).

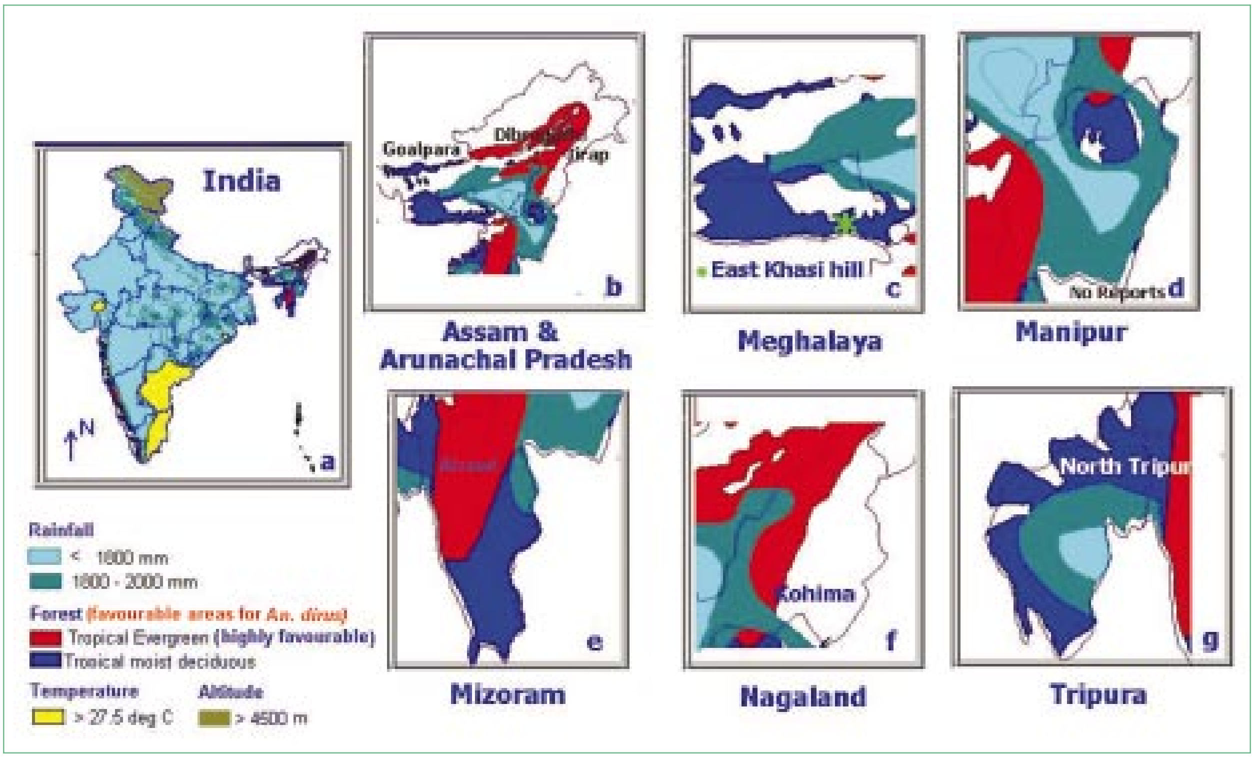

Fig. 7: **GIS predicted areas favourable for *An. dirus* in (a) India; and (b–g) northeastern states**

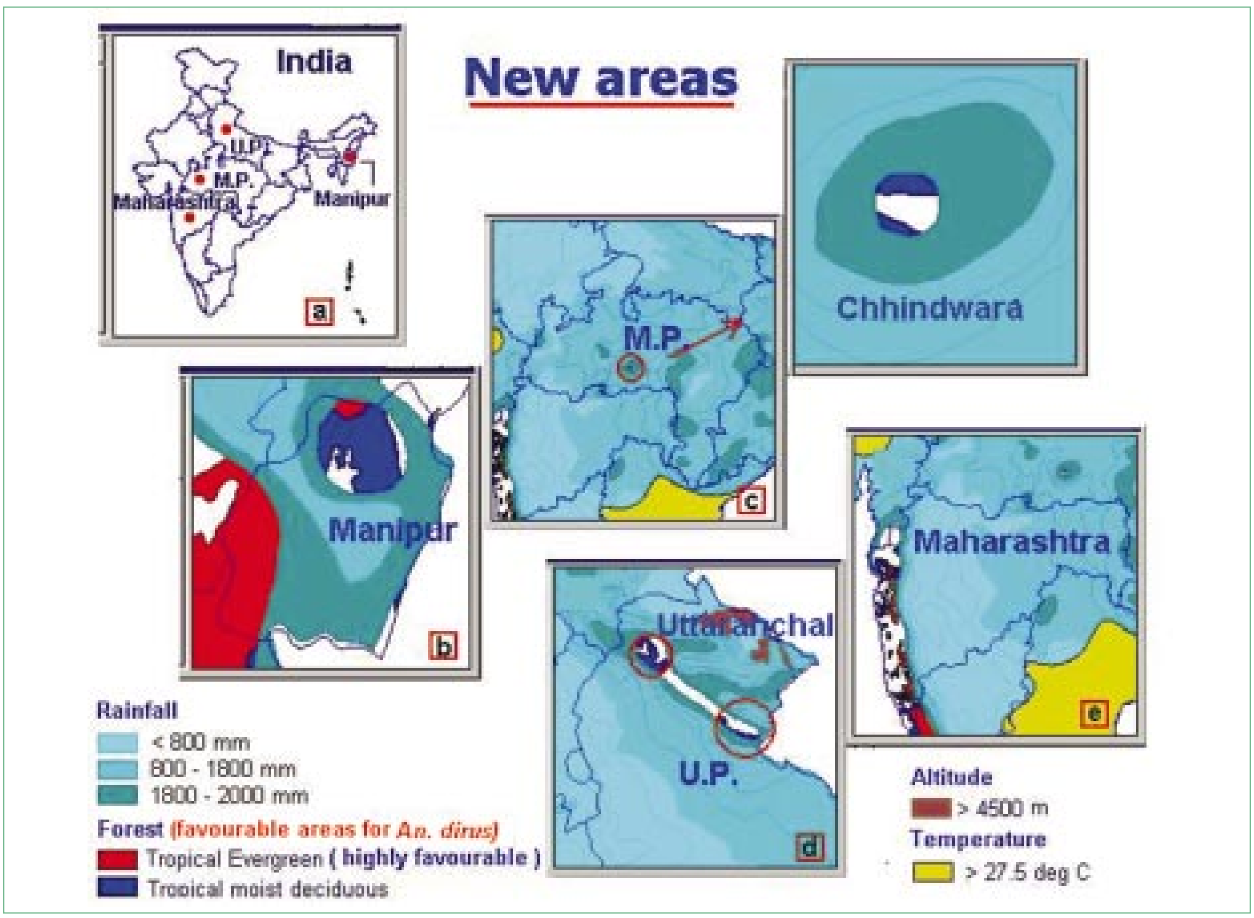

Fig. 8: **GIS predicted new areas for distribution of *An. dirus*: (a) states in India; (b) Manipur; (c) Madhya Pradesh—Chhindwara district is blownup to zoom in small favourable portion of the district; (d) Uttar Pradesh and Uttaranchal; and (e) Maharashtra**

An. 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. 9).

GIS predicts favourable areas not only in northeast but also in Uttaranchal, Bihar, Chhattisgarh, Madhya Pradesh , Orissa, Maharashtra, Kerala and Karnataka (Fig. 10 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 in nine locations of four states namely, Uttaranchal, West Bengal, Assam and Meghalaya (Fig.11 a–b) and *An. minimus* was collected from all the locations. In two districts, namely, Banbasa, District Champavat (earlier Nainital) of Uttaranchal and Dhubri district of Assam, in the former, the species was reported to have disappeared after 1950s, and in later, it was not reported in earlier entomological surveys. In both the places *An. minimus* was encountered besides validation of GIS prediction,

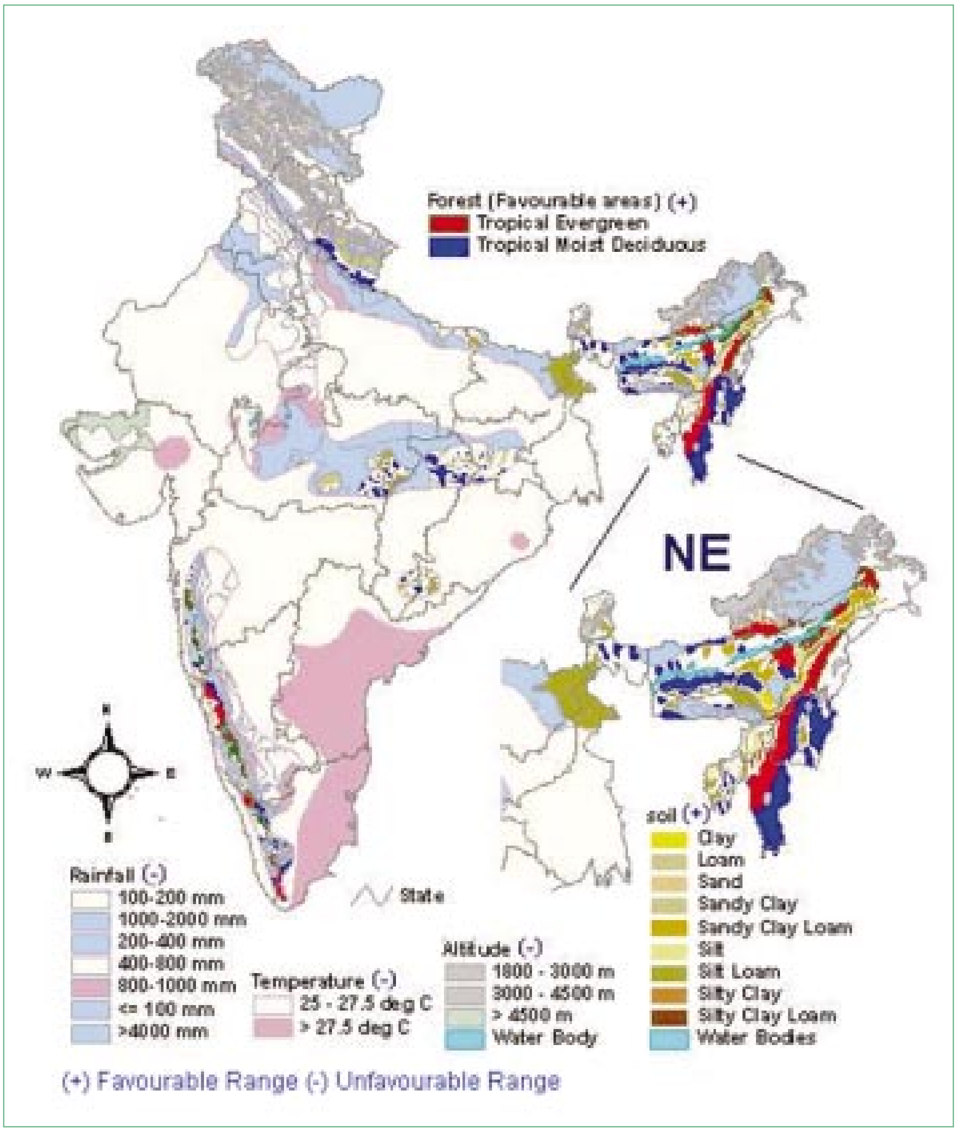

Fig. 9: **GIS predicted favourable areas for *An. minimus* distribution in India, shown in red and blue colour. Inset shows details of *An. minimus* distribution in malaria endemic states**

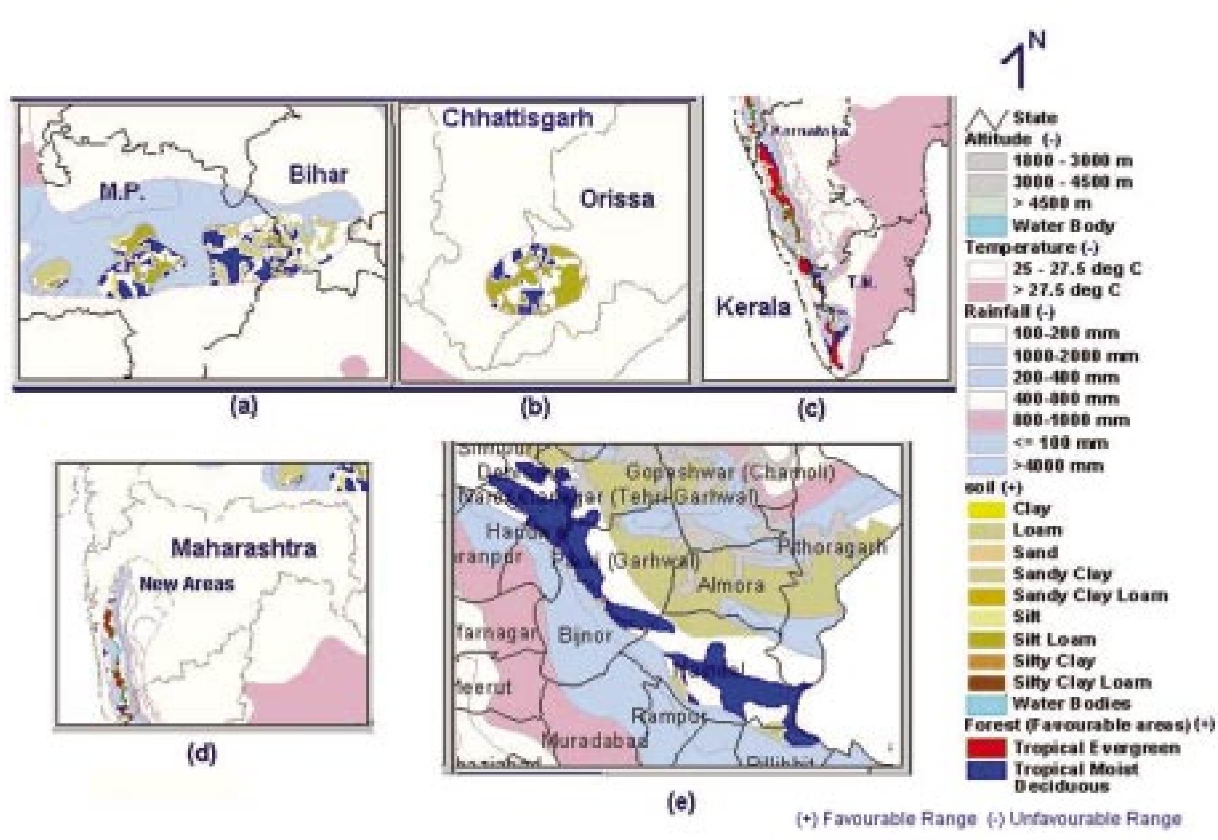

Fig. 10: **GIS predicted distribution of *An. minimus* in nonendemic areas and also in new areas**

reappearance of *An. minimus* at Banbasa and 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, Mizoram has about 90% of its area favourable for *An. minimus*. There are a few favourable areas in Kerala and Maharashtra where till date no reports of *An. minimus* prevalence are available but the species could be found in these areas.

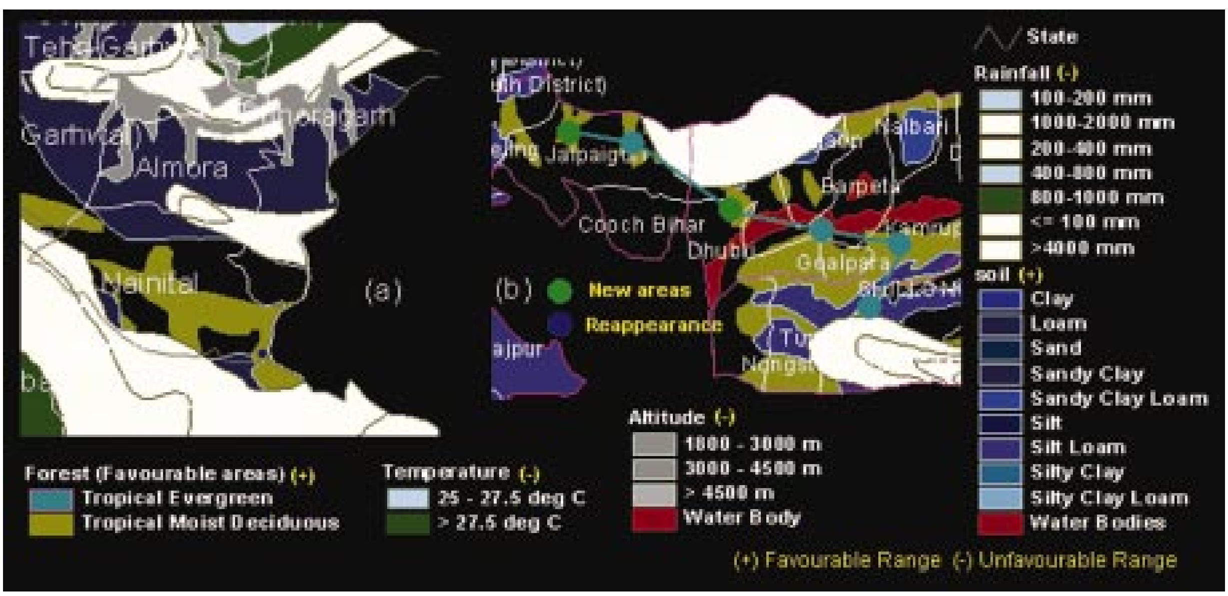

Fig. 11 a–b: **Validation spots in GIS predicted distribution areas of *An. minimus*. Red dots show areas where the species has been reported, pink dots show new areas**

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 cost-effective manner.

Other Indian Anophelines

Besides mapping of vector distribution, database consisting of ecological parameters suitable for breeding, survival and longevity for nonvector 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 the 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. 12). The work on 24 species in subgenus *Anopheles* is in progress. A compact disk (CD) is being 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 *Anopheles culicifacies*

With the advent of finer resolutions in Indian Remote Sensing Satellites, a pilot study was initiated in Tumkur

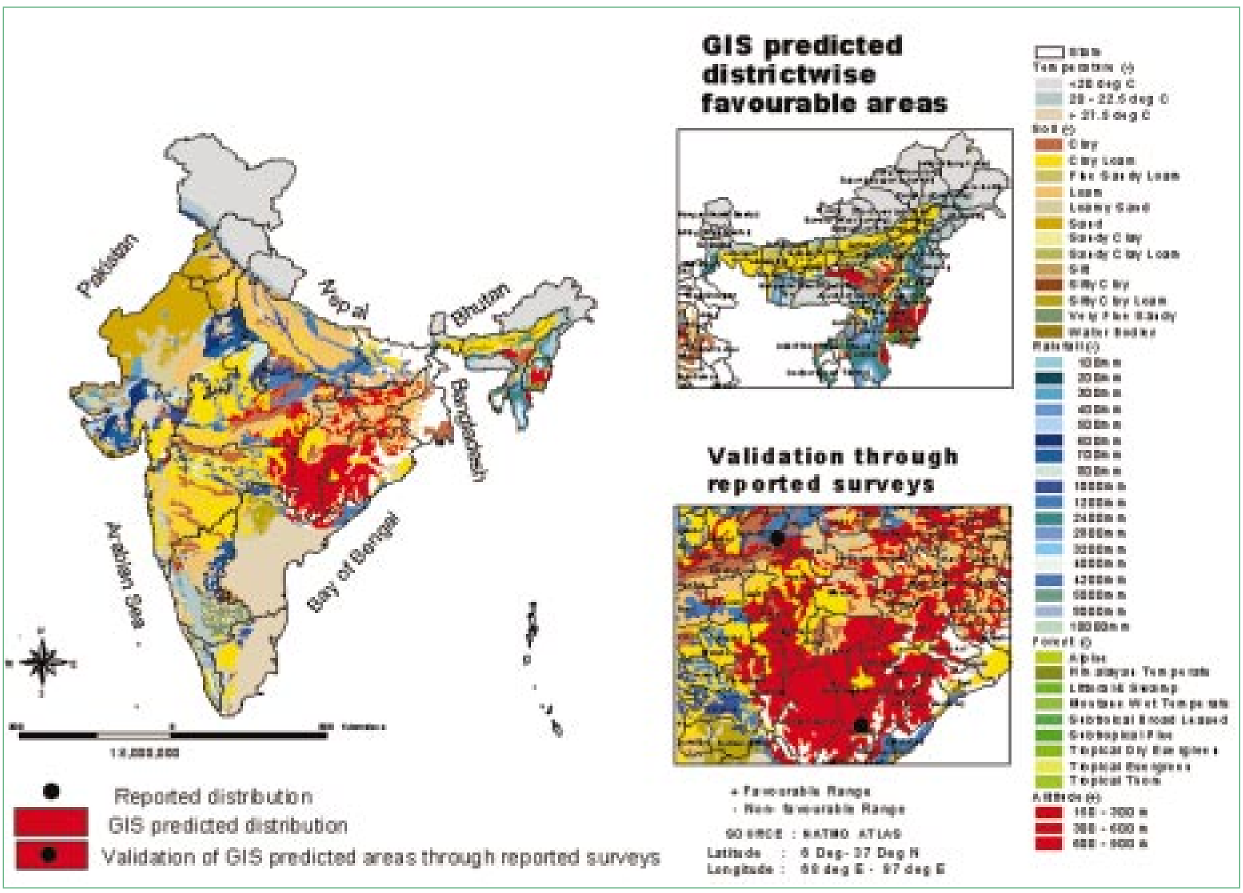

Fig. 12: **GIS predicted distribution of *An. sergentii* in India, a blowup of northeastern states and validation through reported distribution is also depicted in insets**

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 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 lean 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. 13). 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. n

Fig. 13: **IRS ID hybrid colour composite of Bukkapatna area of Tumkur district**