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 developed 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 >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.)
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
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Anopheles dirus — A Species of Evergreen Forests

An. dirus has been the most important vector of malaria along the foothills of Himalaya from Uttar Pradesh to northeast in 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. 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 Andaman & 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 Khadi hills, Burnhni. In Manipur, there are no reports of An. dirus prevalence (Fig. 8d). 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, Chitrardurga, 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 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.

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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.

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

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.
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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...
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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. moqhulensis, 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
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 mosquito-malariaic 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 malarionic 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 under way in problematic districts of Karnataka.