Predictive habitat modelling for forest malaria vector species *An. dirus* in India – A GIS-based approach

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***Anopheles dirus* is found in deep-forested areas where manual surveys are very difficult because of inaccessibility. Geographic Information System (GIS) and a Boolean operator have been used to map areas where the species is likely to be found. Being a forest-based species, thematic maps of forest cover, altitude, rainfall and temperature were prepared. Overlaying and integration of thematic maps were done using Arc/Info NT and analysis by Arc/view 3.1 (GIS ESRI) software. The results were validated through reported distribution and were found correct. The technique can cover vast and inaccessible areas, fast and easily duplicable in other parts of the world. Once the vector distribution is known, species-specific control measures can be formulated.**

GLOBALLY malaria clinical cases are reported as 300–500 million and 1.5–2.7 million deaths annually. The increasing trend of environmental change is dramatically changing malaria distribution pattern at local and as well as global scales. Malaria situation is worsening with large-scale epidemics and increasing mortality. There have been immense efforts to correlate malaria and the environment as the latter influences development of both parasite and vector (http://www.who.ch/). In spite of several reports of vector distribution from India, large areas still remain unexplored, specifically deep-forested areas where manual surveys are very tedious due to difficult accessibility[1–3]. The distribution of vector is mainly governed by suitable environmental conditions for breeding, survival and longevity. Many parameters associated with environmental change can now be remotely-sensed using remote sensing technologies and combined with geographic information system (GIS) can describe local and landscape-level features influencing disease and vector distribution. Recently, using GIS distribution of *Anopheles sundaicus*, we have described a coastal malaria vector species and the results were found to be very encouraging[4]. In the present study an attempt has been made to map the distribution of *Anopheles dirus* (Peyton Harrison, 1979) using GIS. Thematic maps of ecological parameters, namely forest cover, altitude, rainfall and temperature toposheets published by Survey of India were digitized. Using GIS favourable range of each ecological parameter for *An. dirus* was identified and extracted out from the digital maps. Boolean operator was used to integrate the maps of favourable range of each ecological parameter to depict areas where the species is likely to be found. The study revealed many new areas besides the reported distribution.

An. dirus is one of the most efficient vectors of malaria in north-eastern India. It breeds in pools, disused wells, borrow pits, hoof prints and drains covered with foliage in deep-forested areas[3]. It enters houses or cattle sheds for feeding, but leaves soon thereafter. This species maintains a high man–mosquito contact. In Arunachal Pradesh, perennial malaria transmission was maintained in spite of DDT spraying and there was an increase in transmission between 1964 and 1969. Similar situations also prevail in other forested areas[5]. In India an estimated 50 million people living mainly in deep-forested and forest fringe areas are exposed to this species along with *An. minimus* and *An. fluviatilis*[6]. The species is highly anthropophilic and endophagic, occurs in high numbers and may constitute up to 60% of catches, effective flight range is about 1.5 km. It usually feeds late at night with peak biting activity from midnight till 03.00 h (ref. 7). The GIS predicted distribution of *An. dirus* in different parts of India is presented here.

Materials and methods

The most influencing environmental parameters for the distribution of *An. dirus* happen to be forest cover, altitude, rainfall and temperature. Hence, for GIS-predicted distribution, digital thematic maps of these four ecological variables were prepared.

Algorithm for identification of favourable range of ecological parameters and integration of thematic maps for An. dirus distribution

From each reported area lower and upper limits (forest cover ($j = 1$), altitude ($j = 2$), rainfall ($j = 3$) and tempe-

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rature ($j = 4$)) were identified and denoted as Z_{mj} and Z_{nj}. From the sets of lower and upper bounds denoted as $\{Z_{mj}\}$ and $\{Z_{nj}\}$ least lower and highest upper bounds, denoted as Z_{lj} and Z_{hj} were identified for each variable and the range was defined as

$$\text{Range} = \{\text{least lower bound } (Z_{lj}), \text{ highest upper bound } (Z_{hj})\}, \quad (1)$$

where forest cover ($j = 1$), altitude ($j = 2$), rainfall ($j = 3$) and temperature ($j = 4$). Location of each value of each parameter on ground is defined by X_{IJ} and Y_{IJ}, attribute information is taken as the third value, i.e. Z_{IJ} value in 3D Cartesian coordinate system. Spaces were combined using the Boolean operator ∩ (intersection) out of ∩ (inter-

section) and ∪ (union). The favourable areas for distribution of the species were extracted using the following mathematical model.

$$\bigcap_{j=1,2,3,4} \{(X_{lj}, Y_{lj}, Z_{lj}) < \bigcup_j (X_j, Y_j, Z_j) < (X_{hj}, Y_{hj}, Z_{hj})\}, \quad (2)$$

where (X_j, Y_j, Z_j), $j = 1$–4 denote all geographic locations having favourable values of the habitat variables; forest, temperature, rainfall and altitude, respectively.

Digital thematic maps of altitude, forest, temperature and rainfall were prepared using Survey of India topo-sheets in the scale 1 : 6,000,000. Forest map was digitized using plate 7, *Land Resources Atlas of India*, Govt of India (1996). which includes forest cover of 1993 correc-
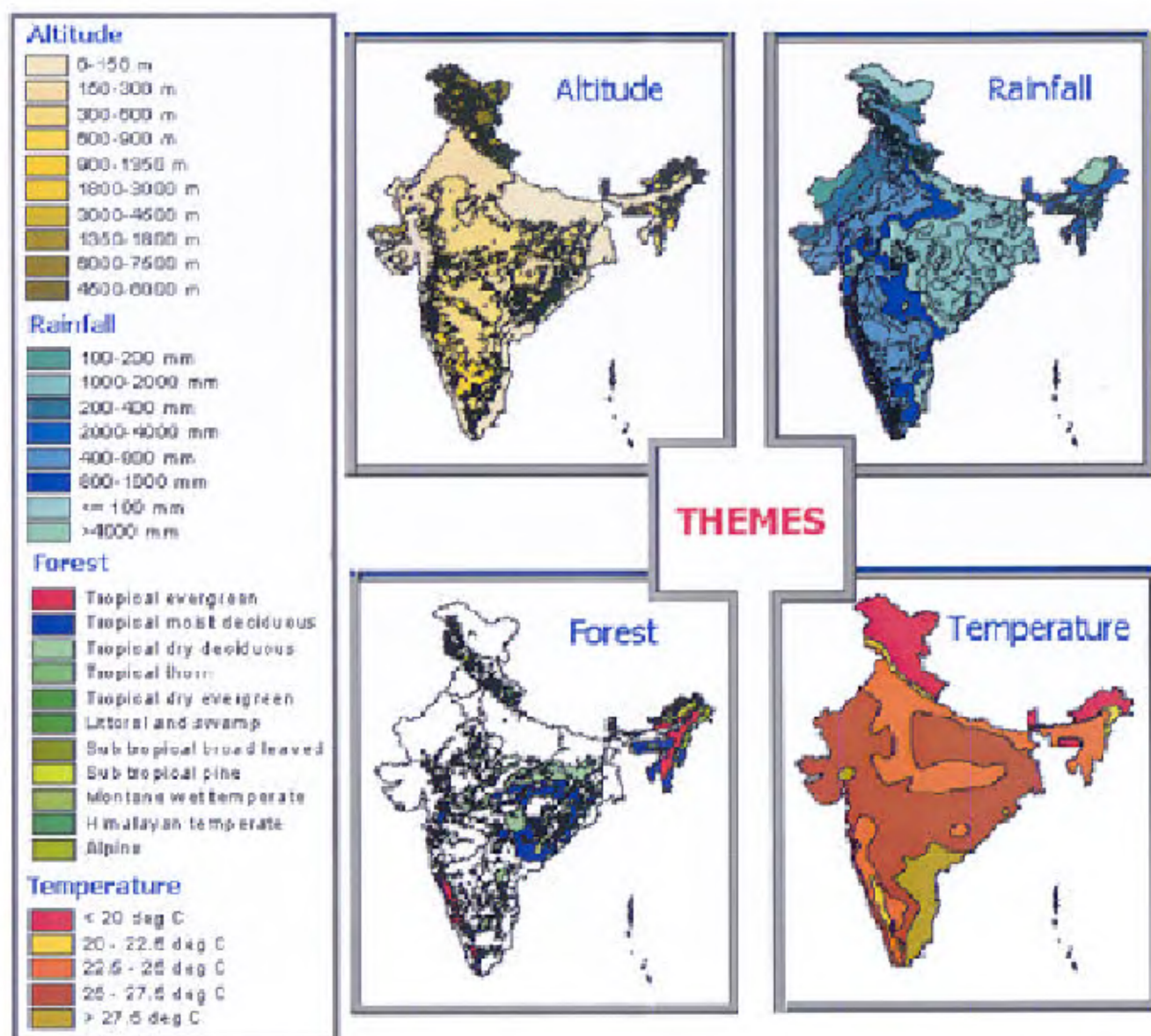

Figure 1. Thematic maps of altitude, rainfall, forest and temperature prepared digitizing Survey of India topo-sheets in the scale of 1 : 6,000,000 by using ARC/Info NT on Summagraphic A00 size digitizer. These maps were overlaid and integrated using ARC/View 3.1 to predict habitats favourable for *An. dirus* in India.

ted using remote sensing information. Temperature and rainfall maps were digitized using plate nos 3 and 4 of *Water Resource Development Atlas of India*, published by Govt of India (1996). These maps were overlaid, integrated and analysed using GIS software Arc/Info NT and Arc View 3.1. (Environmental Science Research Institute, USA). GIS is a computer-assisted system which facilitates inputting, processing, analysing, integrating and presentation of both spatial and non-spatial information.

Forest: *An. dirus* is reported to be found in evergreen-forested areas. Out of all climatic conditions, rainfall plays a vital role in forested areas and hence forest classification mainly rests on rainfall. Areas where rainfall is > 2500 mm along with average daily temperature of 25°C are categorized as tropical wet evergreen forests. Moist deciduous evergreen forest areas have rainfall > 1500–500 mm. Using eq. (1) two types of forests, namely evergreen tropical wet and moist deciduous forests were identified as favourable areas for the distribution of *An. dirus* (Figure 1).

Altitude: Vector species prefer to establish their population at various heights where optimum ecological requirement for their survival is satisfied. Survey of India map showing ten categories of altitude from sea level to 7500 m was used in the study. Since eq. (1) reveals the species-favourable range from sea level to the height of 4000 m, favourable altitude range was taken up to 4500 m taking into account Survey of India classification (Figure 1).

Temperature: Mosquito species have different temperature threshold levels. Besides mosquito survival and longevity, duration of sporogony in mosquito is temperature-dependent. At temperature lower than 20°C, duration of sporogony in mosquito is prolonged beyond 30 days, i.e. more than the average mosquito's lifespan and hence active malaria transmission does not take place. At extreme temperatures, longevity of mosquitoes is drastically reduced. A temperature map consisting of 5 categories from < 20°C to > 27.5°C was used. Temperature 20 to 27.5°C was brought out as favourable range for the species by eq. (1) (Figure 1).
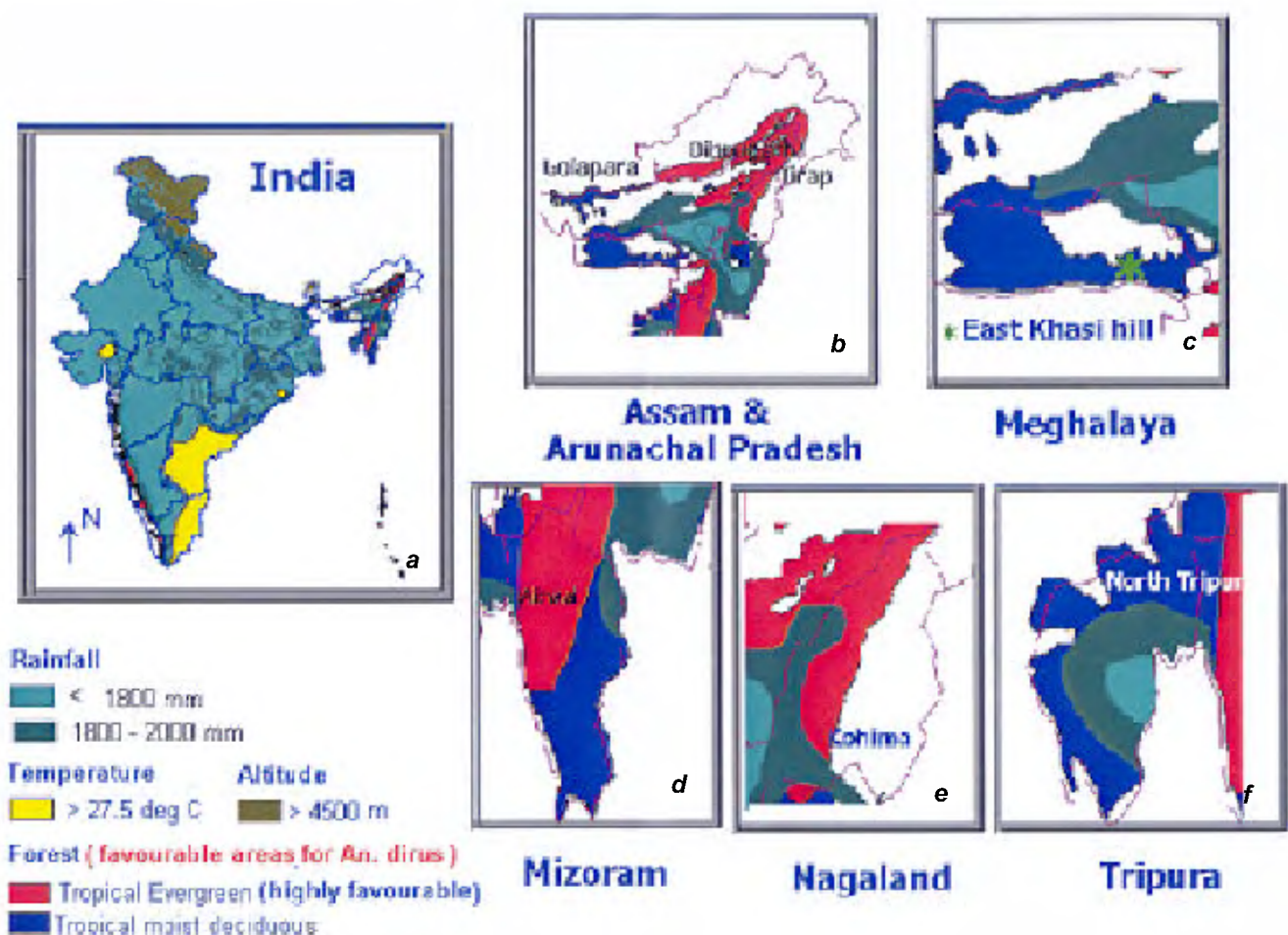

Figure 2.   GIS-predicted areas favourable for *An. dirus* in (*a*) India; and (*b–f*) North–eastern states. Earlier reports reveal that *An. dirus* has been collected several times from these areas, except Manipur and plays an important role in malaria transmission.

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Rainfall: For most of the species the number of breeding sites is proportional to amount of rainfall and its pattern. Extreme conditions restrict mosquito proliferation, low rainfall creates less number of breeding habitats, high rainfall flushes mosquito eggs. In this study, 10 categories of rainfall ranging from < 100 mm to > 3200 mm were considered and using eq. (1), rainfall > 2000 mm which is also the phenomenon of the evergreen tropical wet and moist deciduous forests was taken as favourable zone (Figure 1).

Results and discussion

The resultant map obtained by integrating the four thematic maps using the above mathematical model is shown in Figure 2 *a*. The favourable areas for *An. dirus* are shown in red – evergreen forest and blue – deciduous moist forest. These are mainly located in the north-east and 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 Andaman & Nicobar Islands. It is observed that GIS-based distribution overlaps the areas where the species has been reported earlier. Besides these areas there are some new areas where surveys have not been conducted and the species is likely to be found (Figure 2 *a*). For validation GIS-predicted areas were compared with reported distribution at micro level; the results are discussed below.

In Assam, the large areas on north-east are found favourable for *An. dirus* through GIS (Figure 2 *b*). The species has been reported several times from Dibrugarh[8–10], Cachar[11,12], Gokhal Khane[13], Nanai[14,15], Brahmaputra valley[16] and Mariani[17]. In western Assam deciduous moist forest areas were found to be favourable for species occurrence and the species has been reported from Goalpara[18–20] and Kamrup district[21].
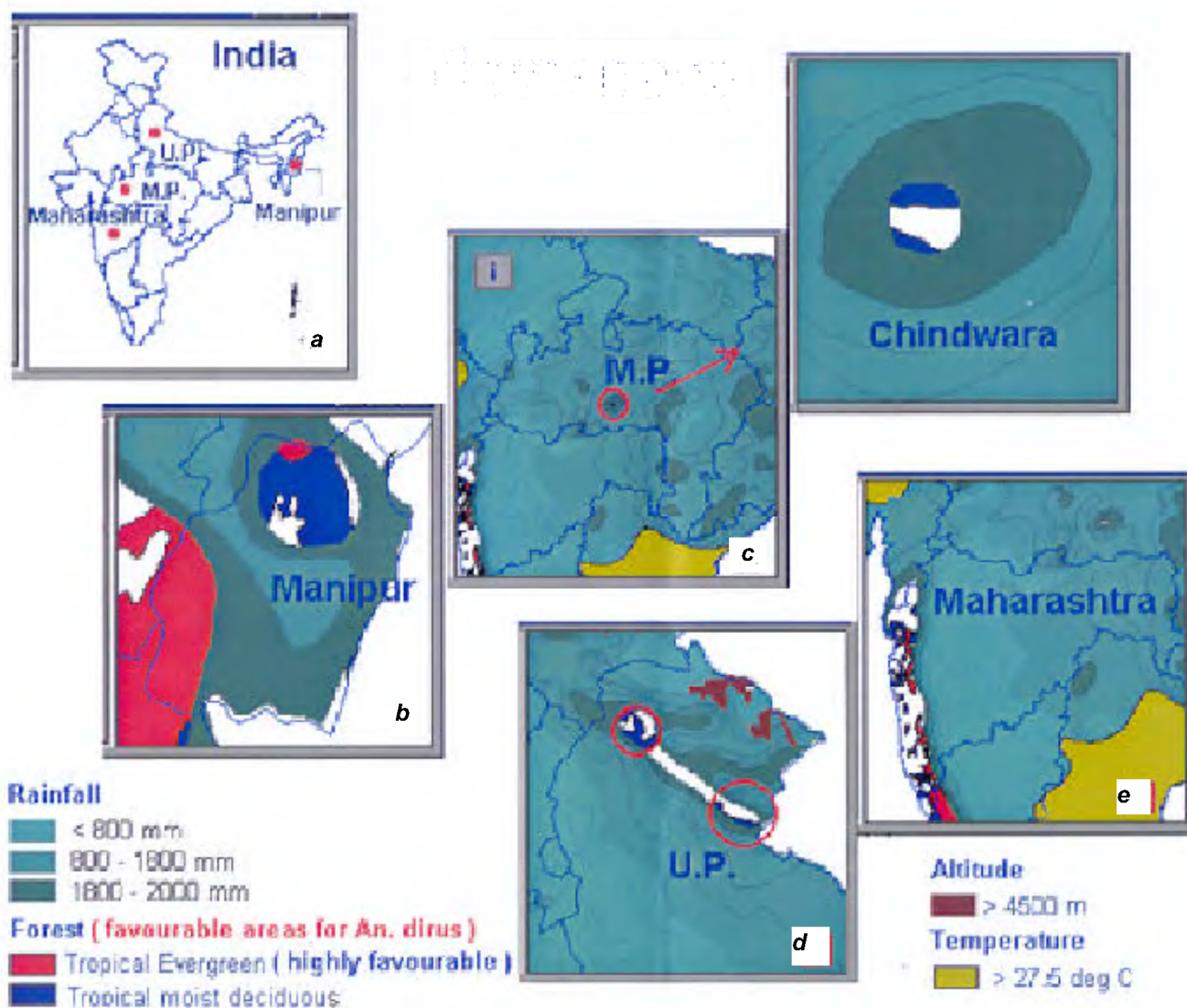

Figure 3. GIS-predicted new areas for distribution of *An. dirus* (*a*) States in India; (*b*) Manipur; (*c*) Madhya Pradesh, Chindwara district is blown up to zoom in small favourable portion of the district; (*d*) Uttar Pradesh, and (*e*) Maharashtra.

Arunachal Pradesh envelopes Assam from the north, east and a small portion on the west. The species has been reported from Assam border Tirap district[5,22–26], Nampong[24] and Changlang Tenga valley[26]. GIS also maps some areas favourable on Assam border (Figure 2 *b*).

In Meghalaya deciduous moist forest on eastern and western sides are favourable for *An. dirus* (Figure 2 *c*). There are reports from East Khasi hills, Burnihat by Rajagopal[27]. The entire state of Mizoram is favourable for *An. dirus* and it has been reported from Aizawl and south Mizoram[28–31] (Figure 2 *d*). In Nagaland favourable areas are found in Kohima, Mohokchung, Mon and Wokh; the species was reported from western side of Kohima[32] (Figure 2 *e*). In Tripura favourable areas are due to deciduous moist forest; it forms a broken semi circular ring on the western side (Figure 2 *f*). The species has been reported from north Tripura[33]. But during surveys conducted by Misra and Dhar[34] in 1955 and Anil Prakash et al.[35], in 1998 in south Tripura, *An. dirus* was not encountered. It may be pointed out that in GIS maps the distribution at micro level and these boundaries have no conformance with political boundaries.

An. dirus has been reported from Jammu & Kashmir[36], Andaman & Nicobar Island[37–40] and Kerala[41]. 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[42–49]. From West Bengal the reports of the species are from Jalpaiguri[50–52], Figure 2 shows that these areas are favorable for *An. dirus*.

The Indian sub-continent is divided into two epidemiological zones, namely Indo-Chinese and Indo-Iranian. These two zones are under the influence of two groups of vector species. North-eastern states are under the influence of Indo-Chinese species, namely *An. dirus* and *An. minimus*. Rest of the country is under the influence of Indo-Iranian species, namely *An. culicifacies*, *An. stephensi* and *An. fluviatilis*. *An. dirus* has made its role in the hilly tracts of western parts of the country, also falling in Indo-Iranian zone, namely Karnataka and western Tamil Nadu. This is substantiated by GIS mapping as well (Figure 2). Besides new areas in Manipur falling in Indo-Chinese zone, there are receptive areas for *An. dirus* in Madhya Pradesh, Uttar Pradesh and Maharashtra, falling in Indo-Iranian zone (Figure 3 *a–e*).

In each state, per cent favourable area with respect to (i) total state area, and (ii) total area favourable for *An. dirus* as per GIS-predicted distribution is calculated using the software. In respect to state area, maximum area of about 93% is found favourable in Mizoram followed by Tripura (52%). In Kerala, Assam, Meghalaya and Manipur favourable area ranges between 30 and 35% of the total state area. In Goa and Nagaland, the favourable area is estimated as 25 and 24%, respectively. Per cent favourable area in Maharashtra, Andhra Pradesh, West Bengal,

Uttar Pradesh, Madhya Pradesh and Karnataka is below 10. With respect to total favourable area in India for *An. dirus* Assam (22.58%) tops the list followed by Karnataka (16%) and Mizoram (15%). In Maharashtra, Manipur, Meghalaya, Tripura, Arunachal Pradesh, Nagaland and Tamil Nadu, 3 to 10% areas are favourable, whereas states like Uttar Pradesh, Goa, West Bengal and Madhya Pradesh have less than 1% favourable area.

In the hilly district of Thailand, where drug resistance was first originated and later covered the entire country has been attributed to *An. dirus*[53]. In India first record of drug-resistant *P. falciparum* malaria is from Karbi Anagong district of Assam. This mutant drug-resistant strain is reported to be spread by *An. dirus*, supported by *An. minimus* in Assam and its neighbouring states. The present study reveals large areas favourable for *An. dirus* in north-eastern states. In areas of drug failure, more emphasis needs to be given to vector control. GIS-based distribution can pinpoint areas of occurrence of *An. dirus* at micro level, where species-specific environmental-friendly control measures can be strengthened. Such studies are of great help in decision-making required for modified plan of control strategy. The technique is specially useful in mapping vast and inaccessible areas and easily duplicable in other parts of the world.

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