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Review Article

Distribution of Malaria Vectors in India: An Update

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A B S T R A C T

Malaria continues to be a major public health concern in India and is targeted for elimination aligning with the sustainable development goal (SDG) by 2030. In spite of significant progress in reducing the disease burden, the challenges in malaria elimination still exist mainly because malaria transmission in the country is under the grip of nine established vectors. Among these, the primary vectors are *Anopheles (An) culicifacies, An. stephensi, An. minimus, An. fluviatilis, An. baimaii and An. epiroticus.* The vectors of secondary importance are *An. annularis, An. varuna, and An. philippinensis.* These vector mosquitoes show different bionomics, especially in resting and feeding behaviour resulting in different transmission dynamics. In addition to the established 6 primary and 3 secondary vectors, a few more *Anophelines* have also been incriminated and established to transmit malaria in localized areas. However, the validation through multicentric studies is yet to be done, therefore under the national programme, only these 9 vectors are considered. Historic data from 1934 onwards has indicated the prevalence of different *Anophelines* in different geographical areas and has established the malaria vectors based on the sporozoite incrimination. This necessitates the mapping of the geographical dominance of these vectors to facilitate entomological surveillance and their response to vector control measures. This paper is an update on the distribution of 9 malaria vectors in India in different time periods based on historical data, publications and entomological reports.

Keywords: *Anopheles*, Malaria, Mosquito, Vector-Borne Diseases, India

Introduction

Malaria incidence in India shows a wide range of distribution due to different geo-ecological and regional diversity. Multi-ethnicity and wide distribution of malaria vectors are the key factors for variation in endemicity. The control or elimination strategies are framed mainly to interrupt local transmission along with early detection and treatment of the cases. The main tool for transmission interruption is vector control, which needs detailed studies on vector prevalence, its behaviour and response to vector control measures. The prevalence of vectors in any given area and its mapping are the prerequisites for formulating any vector control strategy. Malaria being local and focal in nature requires tailored strategies feasible for the given area. The multiple vector transmission dynamics of malaria in India have been documented even in the pre-independence period. Out of the 58 Anopheline species,[1]

different vectors have been incriminated at different points of time in different areas. The 9 established malaria vectors, namely: *Anopheles (An) stephensi, An. culicifacies, An. minimus, An. fluviatilis, An. baimaii (*earlier known as *An. dirus), An. epiroticus (*earlier known as *An. sundaicus), An. annularis, An. varuna,* and *An. philippinensis,* have also been documented in different periods.[2–7] It was highlighted by Singh et al.[5] that in the past 10 years, mapping of malaria vectors was done at the global level but in India, such mapping was not attempted. They reviewed the published literature for mapping the five primary malaria vectors only excluding *An. epiroticus*. The regular reports from different entomological zones under the programme were not included in their reviews as these were not published. Therefore, an update on malaria vectors in India is essential to be documented.

The available literature revealed that during the pre-independence period, Christophers originally described 42 species and 10 varieties of mosquitoes in India, while studying the mosquitoes of the Indian subcontinent comprising India, Pakistan, Bangladesh, Nepal and Sri Lanka. However, in 1933, the record was updated by him to 51 species and 7 subspecies in India. Christophers tabulated these species and varieties in the Indian area and grouped them by their geographical distribution. While describing the *Anophelines* in India, he also categorized the *Anophelines* of adjoining areas under Indian, Western and Southeast Asia regions.[1,8] Subsequently, the studies by different Scientists revealed the prevalence of different malaria vectors in different geographic regions.

Malaria Vectors in India and Their Current Distribution

In India, the mapping of the areas for occurrence of 9 established vectors has been done from time to time. The malaria vector's maps (Figure 1) published in the book "Epidemiology and control of malaria in India" by NMEP,[9] were used for later publication.[4]

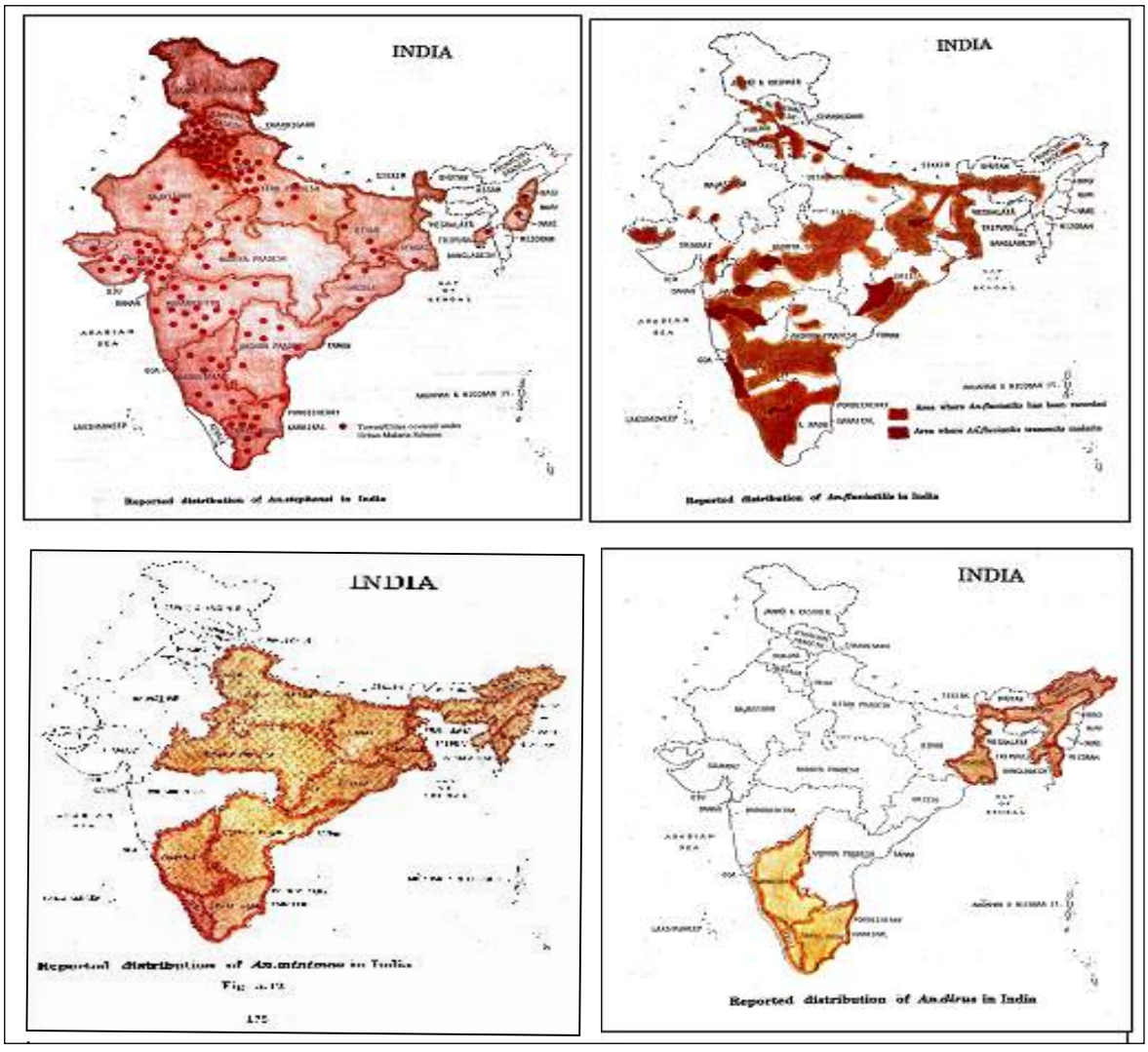

Figure 1. Maps showing Malaria Vector's influence in India

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Malaria in the north-east India is transmitted by three primary vectors, namely *An. minimus*, An. baimaii and *An. fluviatilis*[10] aided by a few secondary vectors such as *An. nivipes*[11] and possibly *An. maculatus*[1]. Besides these established vectors, the presence of *An. maculatus* complex was reported in northeastern states and its presence was crucial because of its role as a vector across the border. *An. subpictus*, suspected to play a role as a malaria vector, was incriminated for the presence of *P. vivax* and *P. falciparum* in both salivary glands and mid-guts in Goa, India.[12] However, the need for multicentric studies across the country to establish it as a malaria vector was recommended by the authors in their scientific publication. Regular data under the programme, especially on the prevalence of malaria vectors is collected by the NCVBDC from the States and Zonal Entomological Team. Based on the data of Zonal and State Entomological teams, and published or unpublished reports of research institutions, the details about established malaria vectors in India have been described in this article.

Anopheles culicifacies Giles 1901

An. culicifacies is a major vector of malaria in rural areas in India contributing to almost 70% of malaria cases in India.[13–16] *An. culicifacies* have been documented in nearly every district of western, southern, and central India since the year 2000.[5] Its presence across 420 districts out of 630 in the country and its increasing presence in northeastern states was reported.[5,17–20] According to Sharma and Dev,[21] this species is found throughout the whole mainland, except for the islands of Andaman & Nicobar and Lakshadweep, and at elevations between 1000 and 2000 meters above mean sea level in the Nilgiris highlands and Kashmir, respectively.

The *An. culicifacies* species has been identified as a complex of five sibling species in India, namely A, B, C, D, and E.[16,22–24] Species B was reportedly the most widespread and commonly found across the country, with its prevalence being highest in southern India, eastern Uttar Pradesh, north Bihar, and the northeastern states but was reported to be a non or poor vector of the malaria parasite.[25] In western and eastern India, both species B and C coexist, while species A and B are sympatric in the northwest region, and species A, B, and C are present in central and southern India, along with species D. The relative proportions of these species vary with geographic location and seasons, as reported in Alwar, where species B increased following the monsoon, while species D remained stable throughout the year and species C was found in low density. The reports indicated the presence of species B in Jabalpur, Chindwara, and Hoshangabad. Species C was found in Hoshangabad only; species D was identified in Narsinghpur and Khandwa, and sibling species E was found in Mandla, Chindwara, and Hoshangabad. The presence of species E in the Madhya Pradesh region was the first report, highlighting focused attention on vector control strategies. It was also reported that in southern Tamil Nadu, species B and E coexisted.[3,4,24,26,27]

Singh et al.[5] mapped the distribution of *An. culicifacies* for the pre-eradication period (1927–1958) based on surveys undertaken by Covell[28] and Puri[29,30]. The mapping was also done for the post-eradication period (1959–1999) and (2000-2015) based on the review of the literature and published reports (Figure 2).

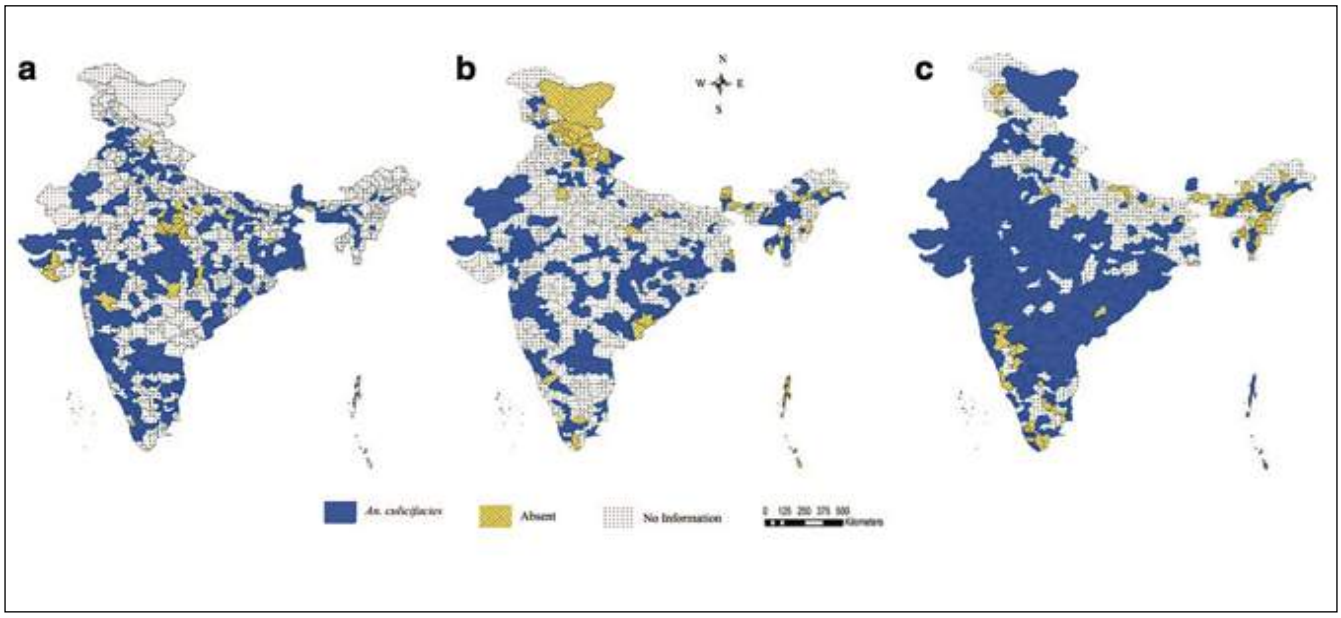

Figure 2.Mapping of *An. culicifacies* (a: 1927-1958; b: 1959-1999; c: 2000-2015) based on review by Singh et al., 2017

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Anopheles minimus Theobald 1901

An. minimus has been reported as one of the main malaria vectors[31,32] in the northeastern states of India[33]. This was the predominant malaria vector in the oriental region, however, in India, it was recorded in the foothills of the Himalayas from Uttar Pradesh to the northeast of India.[4,7,34–41] Dash et al.[3] using GIS predicted that the northeastern states, Uttarakhand, Bihar, Chhattisgarh, Madhya Pradesh, Orissa, West Bengal, Himachal Pradesh, Sikkim, Maharashtra, Kerala, Andhra Pradesh, and Karnataka of India are the most favourable areas for *An. minimus*.

The presence of *An. minimus* was earlier reported by Covell[28] in 16 districts of northeastern states of India which was later followed by Puri[29,30] who reported its distribution from 56 districts of 15 states of India. Rao[1] also documented the presence of *An. minimus* in the northeastern Himalayan region, however, Ananthaswamy et al.[42] reported its presence from southern India.

Based on the documented reports, the district-wise presence of *An. minimus* from 1927 to 1958, 1959 to 1999, and 2000 to 2015 have been mapped by Singh et al.[5] (Figure 3). During the post-eradication period, various studies further reported the distribution of *An. minimus* mainly from northeastern states, with the disappearance from the Himalayan region, West Bengal, and parts of southern India due to the vector's susceptibility towards DDT.[17,43] The use of DDT for malaria control and deforestation had a significant impact on the distribution of *An. minimus* which declined or disappeared entirely from certain regions in India such as the Terai region of Uttarakhand (formally Uttar Pradesh), eastern Odisha, North-East Frontier Agency (NEFA) (Arunachal Pradesh), East-Central India, Himalayan region and large parts of Assam following these changes.[4,34,35,44–48]

An. minimus species complex comprises three sibling species: A, C, and E. The species A, formally recognized as *An. minimus* sensu stricto (s.s.), is distributed in India. The other two sibling species are known as species C (*An. harrisoni* Harbach & Manguin) and species E (*An. yaeyamaensis* Somboon & Harbach).[4,49]

Anopheles fluviatilis James 1902

An. fluviatilis was named by James because the larvae were collected from fluvial water (clear water stream with grassy margins). *An. fluviatilis* is a primary malaria vector in forested areas of central and eastern India and the Himalayan foothills.[4,50–54] The species breeds in slow-moving streams, seepage and irrigation channels. Though this species feeds on both animals and humans, it prefers human hosts. *An. fluviatilis* showed peak activity between 2100 and 2400 hours in the forest area in Uttarakhand. However, it was not found in landing collections in the dam and plain areas. In the Sardar Sarovar Project site in Gujarat, the landing rate of *An. fluviatilis* was 0.28/man/night.[3] It plays the role of an efficient vector with *An. culicifacies* in Terai of Uttar Pradesh, Uttarakhand and in northeastern states.[34,55]

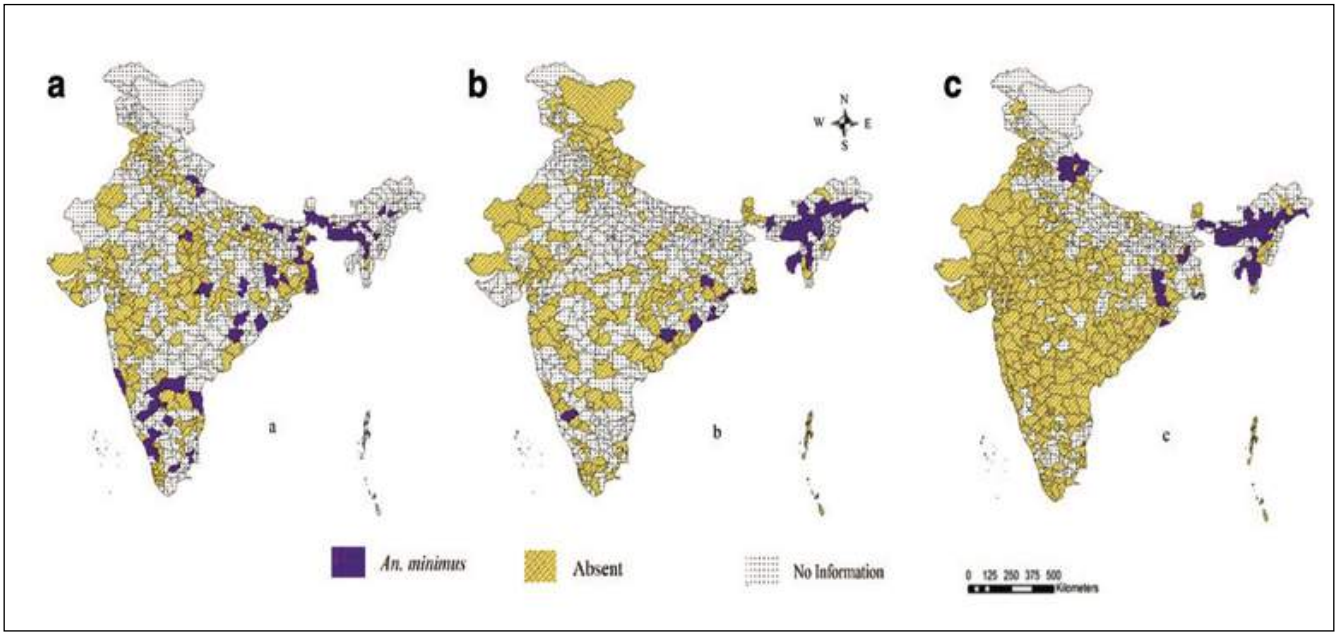

Figure 3.Mapping of *An. minimus* (a: 1927-1958; b: 1959-1999; c: 2000-2015) based on review by Singh et al., 2017

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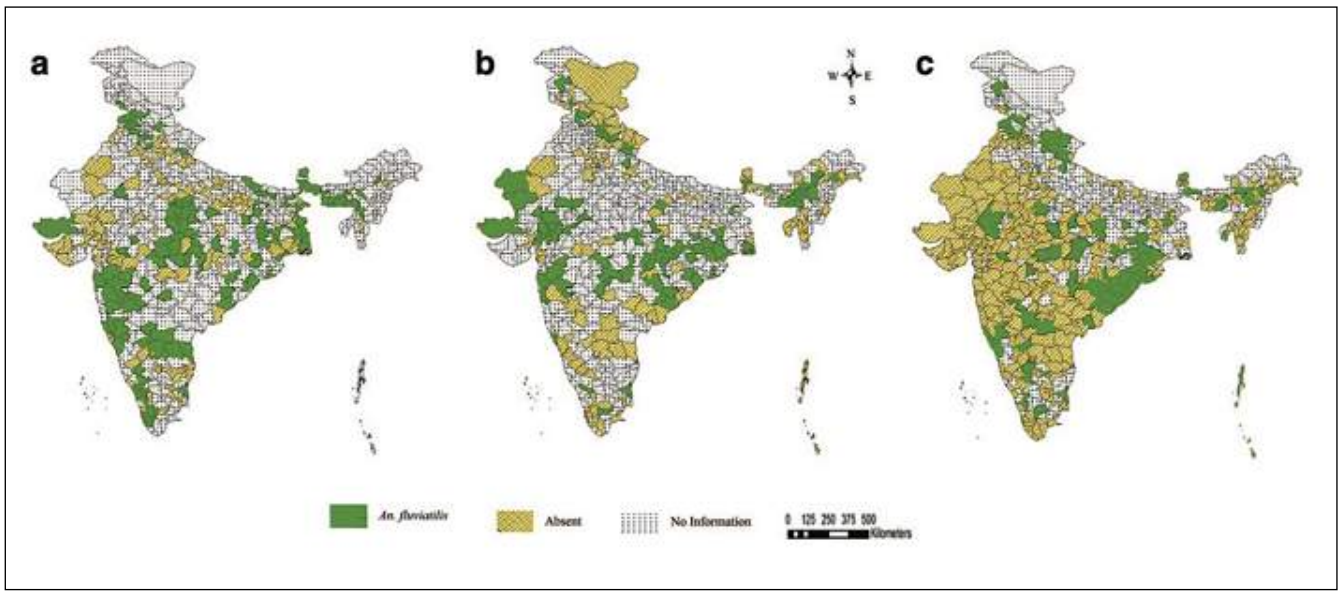

Figure 4.Mapping of *An. fluviatilis* (a: 1927-1958; b: 1959-1999; c: 2000-2015) based on review by Singh et al., 2017

Historical data compilation[5] revealed the distribution of *An. fluviatilis* was reported from 88 districts to 117 districts in 1948, including Western Ghats, central India, Odisha, West Bengal, and northern states.[29,30] The distribution for the period during 1927-1958; 1959-1999 and 2000 to 2015 was mapped (Figure 4).[5] It was also documented that the distribution of *An. fluviatilis* was reduced or absent in the Deccan Plateau, Western Ghats, West Bengal, and southern India, but increased in the Chota Nagpur Plateau, Odisha, and northeastern states, however, few reports indicated the presence of non-vector sibling species of *An. fluviatilis* in Rajasthan, parts of Haryana and Karnataka.[53–57] The current distribution of An. fluviatilis is mainly in forested and foothill areas of India.

An. fluviatilis consists of three sibling species (S, T, U) and one form (V), distinguishable cytogenetically.[4,58,59] Three haplotypes in species T and an additional taxon as 'V form' in India were identified in district Hardwar of Uttarakhand state.[61,62] While both sibling species T and U are poor vectors, they have shown the ability to support normal sporogony in laboratory feeding experiments.[4] The sporozoite rate of 1.49% in Kamrup district, Assam suggested that *An. fluviatilis* might have played an active role in the transmission of malaria when *An. minimus* disappeared from the area.[34] In the Odisha state of India, sibling species S was reported as a malaria vector and indoor resting whereas sibling species T was reported to be mostly zoophilic resting in cattle sheds but sibling U had limited distribution.[57]

Anopheles baimaii

An. baimaii (previously known as Anopheles dirus) is one of the most efficient vectors of malaria in the northeastern states of India. It breeds in pools, disused wells, borrow pits, hoof prints and drains covered with foliage in deep forested areas. *An. dirus* enters houses or cattle sheds for feeding but leaves immediately after the feed. This species is highly anthropophilic. *An. dirus* consists of several efficient human malaria vector complexes that are found in the sylvatic environment of the Southeast Asian region, including India.[63,64]

An. dirus is a complex of 7 sibling species viz., *An. dirus* or *An. dirussensustricto* (s.s.) (species A), *An. cracens* (species B), *An. scanloni* (species C), *An. baimaii* (species D), *An. elegans* (species E), *An. nemophilous* (species F), and *An. takasagoensis. An. baimaii* and *An. elegans* out of these are found in India, with distinct distribution and epidemiological significance.[4] Populations of *An. baimaii* and *An. dirus,* which were previously misidentified in India, are closely related and provide insights into their evolution and expansion in geological time scales.[65,66] *An. baimaii* is a highly efficient malaria vector and widely abundant in northeastern states, contributing to 50% of the reported cases annually.[4,51]

Singh et al.[5] have mapped (Figure 5) the distribution of *An. dirus* in India for a period from 1927 to 1958,1959 to 1999; and 2000 to 2015 indicating that persistently its distribution was limited in northeastern states of India except a few spots in Karnataka of southern India after 2000 but its presence in south India needed verification.

Anopheles stephensi Liston 1901

An. stephensi is an important urban malaria vector first incriminated in Mumbai, Maharashtra in 1911. It has also been found and incriminated in other urban areas such as Kutch (Gujarat), Chennai (Tamil Nadu) in 1938,

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Broach (now Bharuch) town in 1967 and Ahmedabad City in 1943.[3,67,68] *An. stephensi* has three variant forms, the type, intermediate and mysorensis which are differentiated by egg length, its width and the number of ridges on the egg float.[3,5,56,59] An. stephensi is most prevalent during the rainy season (June-August) which coincides with the malaria transmission period.[4] It breeds in various domestic containers viz., overhead tanks, cisterns, groundwater tanks, wells, desert coolers and water stored in construction sites. These sites are usually common in urban areas and therefore it is also known as an urban malaria vector. This species is mainly responsible for malaria outbreaks in construction project sites, and it has a longer flight range with a high degree of contact with humans. In rural areas, it prefers to bite animals and rest outdoors. Its peak biting activity is recorded between 22:00 to 24:00 hours but varies seasonally. It is an invasive species and can enter new towns and settlements.[3,4,70]

The distribution of *An. stephensi* in India for three different periods i.e., 1927-1958; 1959-1999; and 2000-2015 was mapped.[5] The compilation clearly indicated the presence of *An. stephensi* across many cities in India during the pre-eradication period, however, from 1959 to 1999 (post-eradication period), *An. stephensi* was mainly reported in parts of Rajasthan while being absent in major parts of Central and Southern India which may be attributed to less documentation (Figure 6). Considering the malaria situation in urban areas (stephensi transmitted malaria), an Urban Malaria Scheme (UMS) was launched in the year 1971 which was expanded gradually and covered 131 towns under UMS.

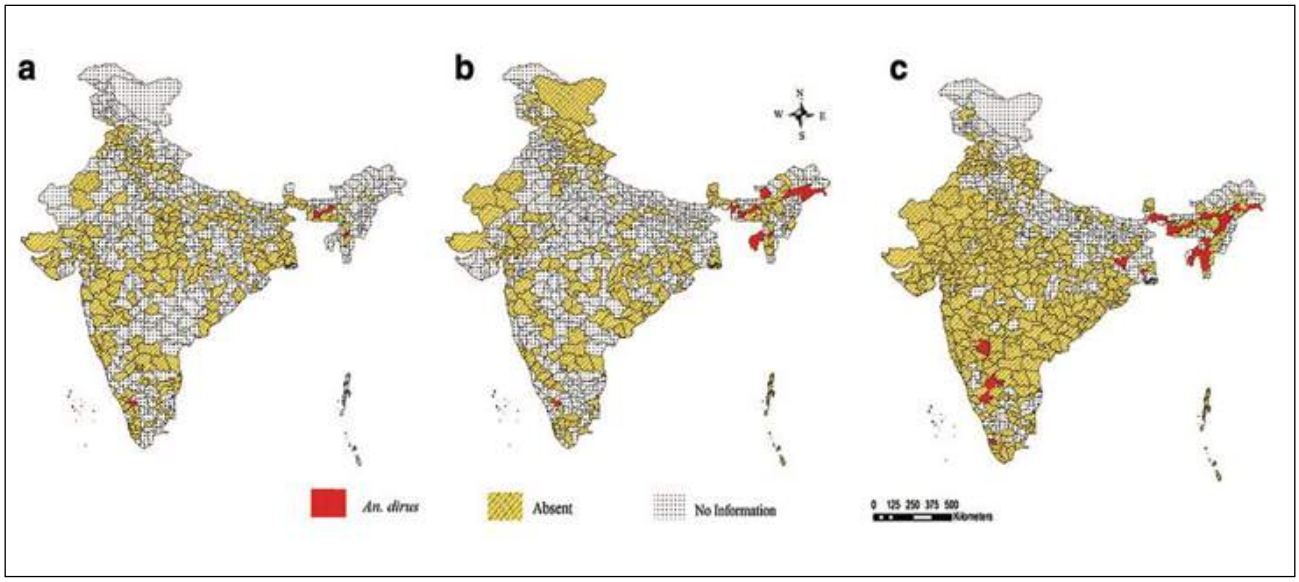

Figure 5.Mapping of *An. dirus* (a: 1927-1958; b: 1959-1999; c: 2000-2015) based on review by Singh et al., 2017

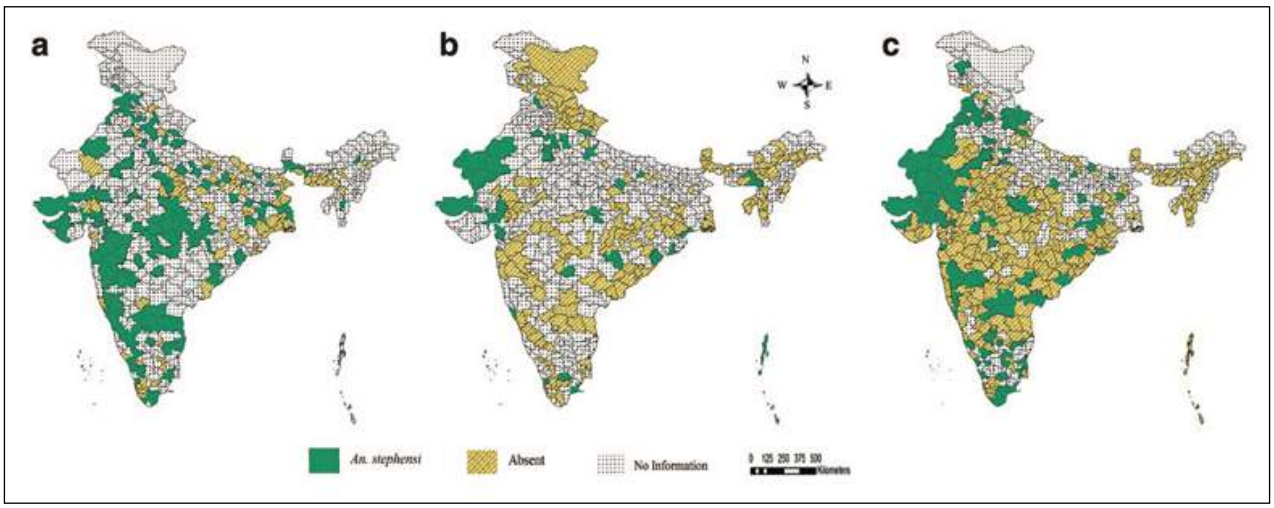

Figure 6.Mapping of *An. stephensi* (a: 1927-1958; b: 1959-1999; c: 2000-2015) based on review by Singh et al., 2017

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Presently, An. stephensi has been reported from 243 districts in the country, except for Mizoram, Arunachal Pradesh, Nagaland, Sikkim, Tripura and Manipur states. With the rapid pace of urbanization, the distribution of An. stephensi may extend to water-deficient rural areas and dominate the rural vector *An. culicifacies*.

Anopheles epiroticus Linton & Harbach 2005 (previously known as *Anopheles sundaicus* Rodenwaldt 1925)

Anopheles epiroticus Linton & Harbach 2005 previously known as *Anopheles sundaicus* Rodenwaldt 1925 is considered as a potent malaria vector in coastal areas of India. It breeds usually in brackish water but sometimes in freshwater.[71–73] The earlier studies in India have reported its distribution in Andhra Pradesh, Odisha, Tamil Nadu and West Bengal.[74,75] This species was found resting indoors in human dwellings in coastal Orissa and Andamans.[28,74] Currently, the species is restricted to Andaman & Nicobar Islands.[76] Its outdoor resting behaviour, preference to bite man as compared to cattle and breeding in swamps, pits along the margin of bunds (with stagnant brackish water), lagoons, creeks, wells, overhead tanks and freshwater pools in coastal areas were reported in Andaman and Nicobar Islands.[77,78]

An. sundaicus comprises four sibling species,[72] designated as *An. sundaicus* sensu stricto (s.s), *An. epiroticus* s.s. (formerly, *An. sundaicus* species A)[79], *An. sundaicus* species D[80,81] and *An. sundaicus* species E[82]. All of them act as predominant malaria vectors depending on the location.[83]

Anopheles annularis Van der Wulp 1884

An. annularis is the malaria vector of secondary importance in India. It is widely distributed in West Bengal, Nagaland, Tripura, Assam, small parts of Chhattisgarh, Madhya Pradesh, Maharashtra, Gujarat, Tamil Nadu, Andaman, and Jharkhand, Orissa, however, lesser distribution is recorded in western India.[3,7,24,84,85]

An. annularis is a species complex consisting of two sibling species A and B, differentiated by their banding pattern on chromosome arm 2. Studies revealed the prevalence of *An. annularis* sibling species A in districts Alwar (Rajasthan); Ghaziabad and Shahjahanpur (Uttar Pradesh); Sonepat (Haryana); Sundargarh and Koraput (Orissa); and Kamrup (Assam). Whereas, species B has been reported only from Shahjahanpur and Ghaziabad districts in Uttar Pradesh state where it was found sympatric with species A. Blood samples of both species A and B had bovine blood strongly indicating that these species are primarily zoophagic.[3]

Anopheles varuna Iyengar 1924

An. varuna is a secondary malaria vector in India which has been reported from the northeastern states of Arunachal Pradesh, Assam, and Meghalaya Manipur, Mizoram, except Nagaland, Odisha, Kerala, Tamil Nadu, Andhra Pradesh, Jharkhand, Chhattisgarh, Madhya Pradesh and forest fringe areas of Lakshadweep Island.[3,7,24,71,86,87]

It breeds in rainwater pools, ponds, rice fields, irrigation channels, wells, slow-moving streams etc. This species rests indoors but also reported resting outdoors. Its peak biting is between 24.00 to 02.00 hours. It is zoophagic in nature but also feeds on humans while in abundance. Its flight range is about 1 km.[7]

Anopheles philippinensis Ludlow 1902

An. philippinensis is a vector of secondary importance in the transmission of malaria reported from West Bengal, Assam, Arunachal Pradesh, Nagaland, Meghalaya, Manipur, Mizoram and Tripura in the country.[3,11,16,24,88] An. philippinensis and *An. nivipes* belong to the Annularis Group in the Neocellia series, having very similar morphology but slight differences in wing characters which also sometimes overlap. Due to this reason, *An. nivipes* is considered as a synonym of *An. philippinensis.*

The species breeds in tanks, swamps, ditches, rice fields, leaf axils, shaded lake margins and water bodies with vegetation. Though it rests in cattle sheds and human dwellings, it bites both outdoors and indoors throughout the night with two biting peaks from 20.00 to 22.00 and 02.00 to 04.00hrs. Its flight range is up to 0.8 km.[7]

Conclusion

Based on the above review of the literature regarding different malaria vectors, it is evident that our knowledge of malaria vectors in India is mainly based on entomological surveys conducted during the pre-DDT era which had been supplemented in different years subsequently. The distribution of malaria vectors prior to the DDT era is indicated in Figure 7.

The ecological changes and insecticide pressure have impacted the vector's behaviour and their area of influence. Increased receptivity for An. stephensi due to rapid urbanisation, the absence of *An. minimus* from Odisha due to insecticide pressure, spreading of *An. culicifacies* due to changing irrigation patterns, channelisation of water flow, changes in water table, increased water logging, changes in salinity, seepage etc., were cited as a few examples resulting in ecological succession of malaria vectors during the last 4–5 decades. The changes influencing malaria vectors in India due to ecological succession were documented by Nagpal and Kalra[89] and have been indicated in Figure 8.

The distribution of malaria vectors in India is an important factor to consider in the context of malaria elimination. Malaria in India is transmitted by 9 established vector species of Anopheles mosquitoes, however, at different

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times one or two more vectors were suspected in different regions.[12,90] *An. jeyporiensis* and *An. subpictus* have been indicated as playing the role of malaria vectors but under the programme and also in various publications, only 9 vectors have been indicated.[4,5,7] Similarly, Singh et al.[91] in a biodiverse setting like Meghalaya indicated that *An. minimus* and *An. baimaii* were rare, while four other species (*An. maculatus*, *An. pseudowillmori, An. jeyporiensis*, and *An. nitidus*) were abundant. They suggested that rice fields might be contributing to the observed abundance of *An. maculatus* and An. pseudowillmori, which could be playing a role in malaria transmission, either independently due to their high abundance, or in combination with *An. baimaii* and/ or *An. minimus*. They have also mentioned continuing the monitoring of mosquito species composition in relation to changes in land use and land cover (LULC) and bionomics of such species which are relevant to malaria transmission and vector control. Among the established 9 vectors, some are more prevalent and efficient in transmitting malaria than others. The prevalence of these vectors varies widely depending on various factors, such as geography, climate, and socio-economic status of the population. Effective malaria control measures in India, therefore, need to consider the specific Anopheles vector species present in different regions of the country and implement targeted strategies to combat malaria transmission. This could involve measures such as insecticide-treated bed nets, long-lasting insecticidal nets (LLINs), indoor residual spraying, and larval source management. A greater understanding of the distribution of Anopheles vectors in India is vital for successful malaria elimination efforts and therefore the vector's prevalence data generated by zonal entomological teams established under the national programme has been compiled in addition to published records for mapping the updated distribution of malaria vectors in India evidencing that still India is under the influence of six primary and three secondary malaria vectors. The updated state-wise distribution of 9 malaria vectors is depicted in Figure 9.

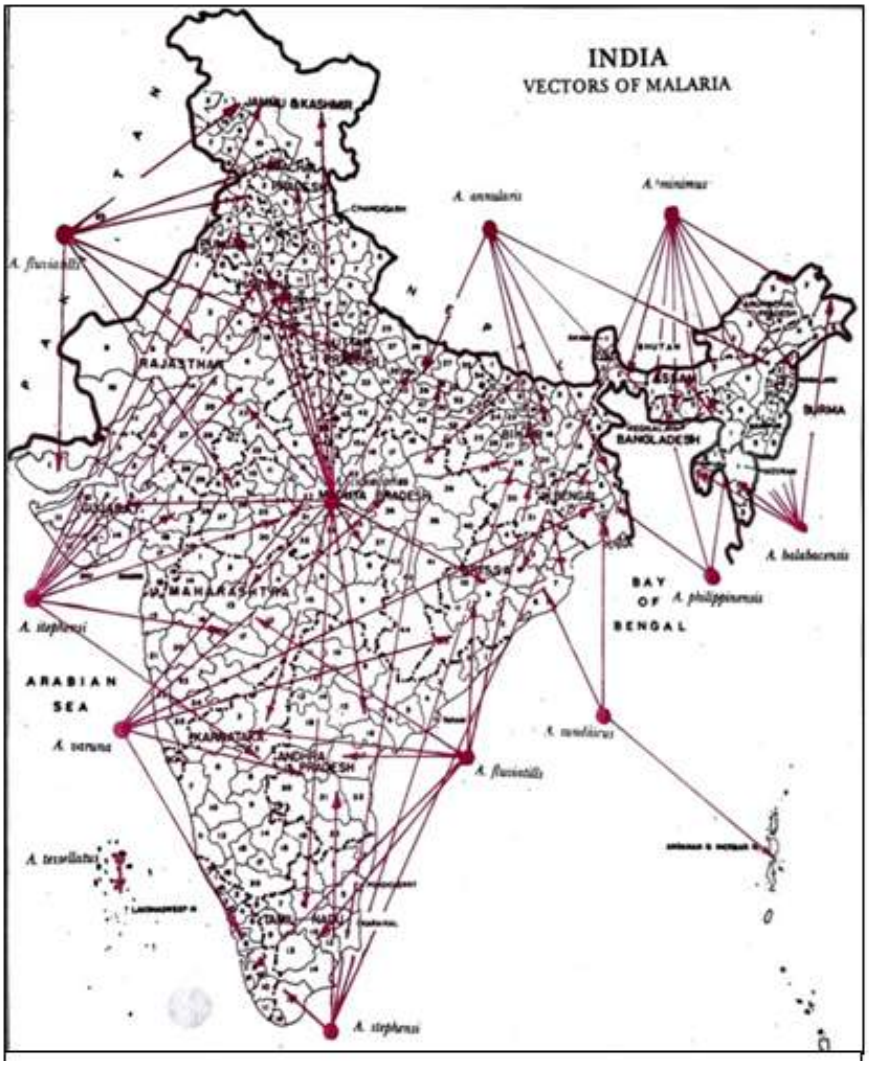

Figure 7.Vectors of Malaria in India (1948), (Source Nagpal and Kalra 1997; Sharma et al., 1996)

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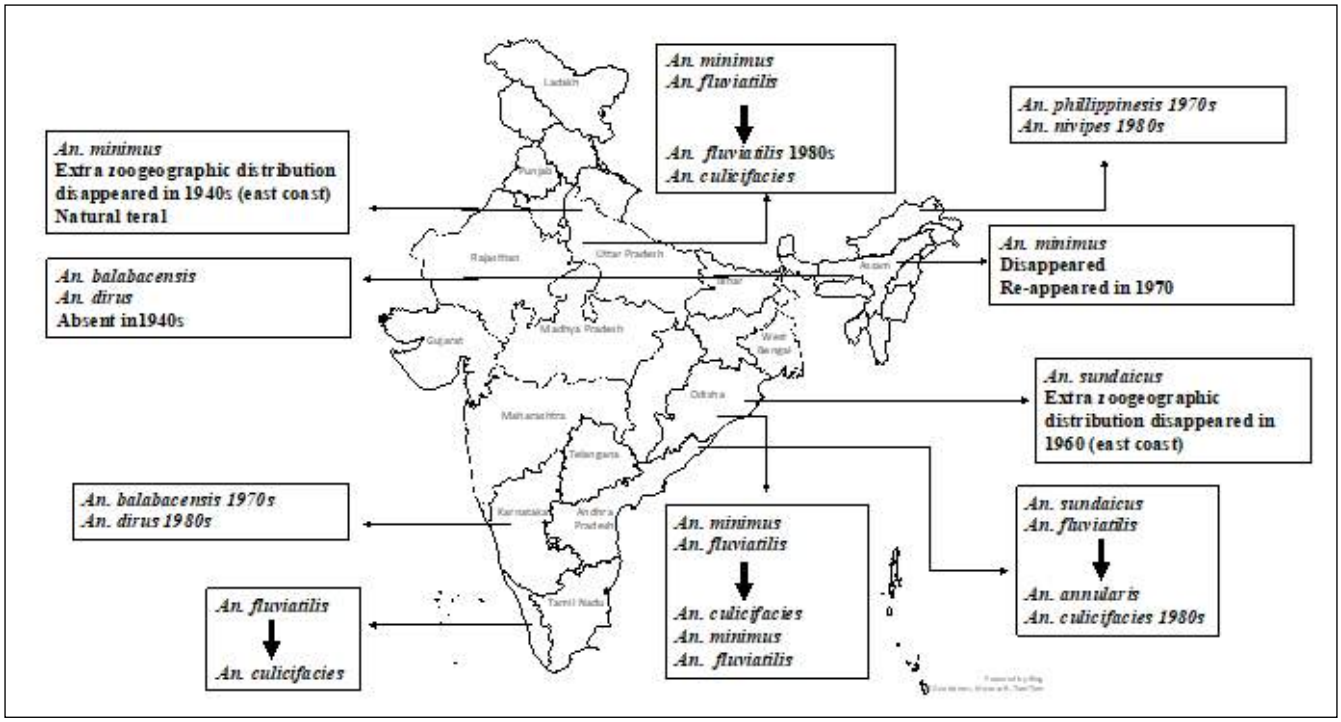

Figure 8.Ecological Succession of Malaria Vectors (Source Nagpal and Kalra 1997)

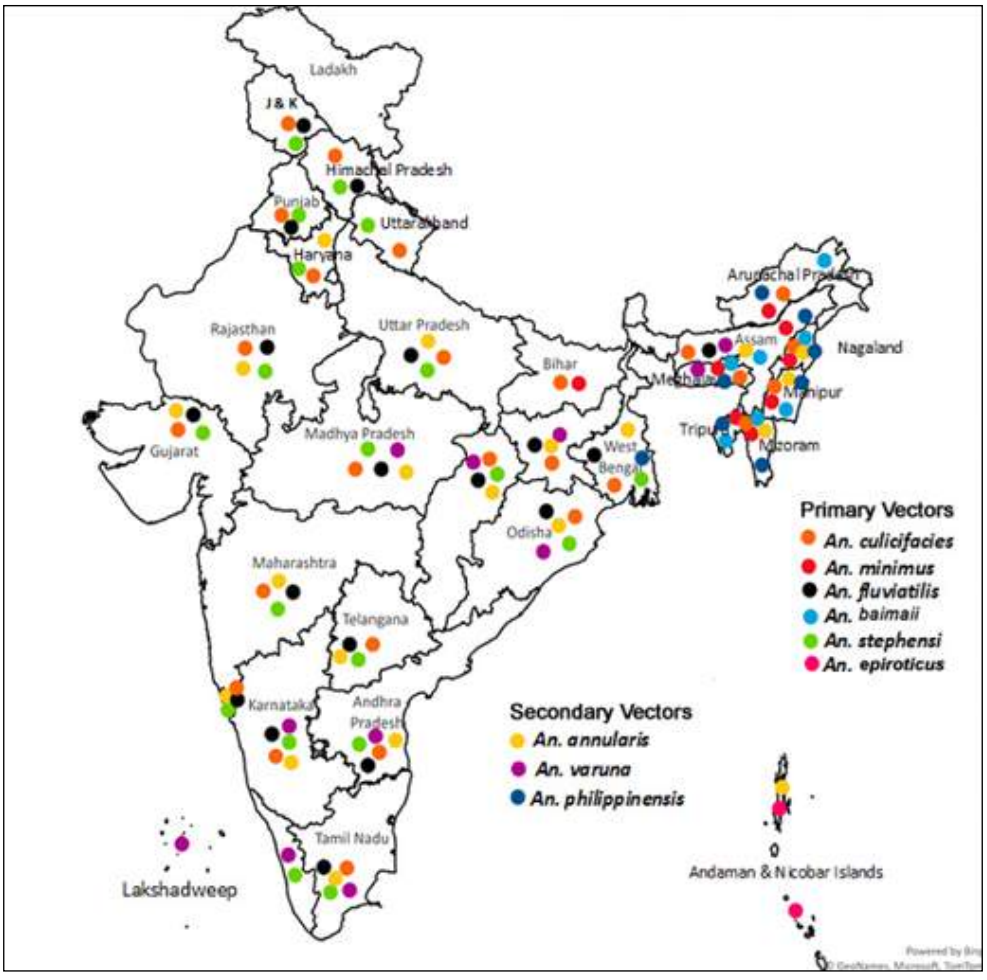

Figure 9.The distribution of malaria vector in india since 2000

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Conflict of Interest: None

Conflict of Interest: None

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