



## Diversity and abundance of *Anopheline* mosquitoes in tribal areas of India: A review

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### Abstract

Malaria is a serious public health problem in India. Most of the malaria cases are reported from the tribal areas. Districts with 30% or more tribal population comprising about eight percent country's population contributed to 46% of total malaria cases, 70% *Plasmodium falciparum* and 47% malarial deaths in the country. Six *Anopheles* species such as *Anopheles baimaii*, *An. sudaicus*, *An. minimus*, *An. fluviatilis*, *An. stephensi*, and *An. culicifacies* are primary malaria vectors in various eco-geographical regions in India. The secondary vectors i.e., *An. annularis*, *An. nivipes*, *An. philippinensis*, and *An. varuna* are also responsible to transmit malaria. According to published research articles approximately 42 of the totals 62 Anopheline species have been recorded in tribal areas of India. Use of long-lasting insecticide treated nets (LLINs) is the main malaria control strategy in all tribal areas, but lack of awareness and improper channelization of water bodies are also playing a key role to increase the larval breeding habitats. Outdoor biting of vector mosquitoes along with some other problems which are described in this article. "High burden to high impact" is a country-led approach that will be supported by WHO, the RBM Partnership to End Malaria and other partners.

**Keywords:** *Anopheline* mosquitoes, vectors, malaria, malaria vectors, *Anopheles*

### Introduction

Malaria is a serious public health problem in tropical and sub-tropical countries especially in the African countries. India is not an exception. Many efforts are being made to eliminate this disease by 2030. Since 1900, 127 countries have been declared malaria-free by the World Health Organization (Ghosh and Ghosh 2019). In 2020 WHO estimated 241 million malaria cases in 85 endemic countries with 627,000 related death (WHO 2021). India is the only country outside Africa has launched 'high burden to high impact' initiative in 2016 and contributes 83% estimated cases and 82% estimated deaths in Southeast Asia region of WHO reported in 2020 (WHO 2021). Significant progress has been made reducing the malaria burden. In 2021 over 160,000 malaria cases have been reported from India, but the main problem lies in the tribal-dominated areas. Districts with 30% or more tribal population comprising about 8% India's population contributed to 46% of total malaria cases, 70% *Plasmodium falciparum* and 47% malarial deaths. India has some of the most biodiverse ecozones such as tropical forests, temperate forests, deserts, high mountains, highlands, marshlands, areas around rivers, plains, grasslands, islands and archipelagos. These areas are also dominated by tribal communities, mosquito-borne diseases are highly transmitted in these communities such as Malaria, Chikungunya, Dengue, Japanese encephalitis, Filariasis and Zika, etc. Malaria disease is prominent in these areas, which is transmitted from one man to another by the bite of infected female *Anopheles* mosquito. Transmission dynamics of any vector borne disease by vectors depends on local environmental conditions, climate change, and a number of man-made factors such as improper use of water, population density, community sanitation, construction activities, and changes in human behaviour in the tribal belt

of India. The major mosquito vectors of India are *Anopheles* (*An.*), *Culex*, and *Aedes* etc. in which *Anopheles* is one of the prominent vectors in the tribal belt of India and it has accountable for malaria disease (Johari 2019) [23]. Malaria is a major communicable disease-causing illness and mortality, during a study in 2020 conduct by NVBDCP, in the same year reported 186532 malaria-positive cases and 93 deaths in its total population in India. There are 58 *Anopheles* species present in various region of India (Kumar *et al.* 2007) [25], out of which 6 species (*An. stephensi*, *An. culicifacies*, *An. fluviatilis*, *An. baimaii*, *An. sudaicus* and *An. minimus*) are transmitting malaria as a primary vectors and some species are transmitting malaria as a secondary vectors (*An. varuna*, *An. philippinensis*, *An. nivipes*, *An. annularis* and *An. annularis*), due to this disease the tribal tribes of India are more are affected, because the main work and business of these people is animal husbandry and agriculture, due to this there are more breeding habitats of *Anopheles* mosquito (Subbarao *et al.* 2019) [49]. Based on the World Malaria Report 2013, the disease is spread by a *Plasmodium* parasite (Protozoan), and five species of this genus and are capable transmitting of malaria diseases such as *Plasmodium falciparum*, *Plasmodium ovale*, *Plasmodium knowlesi*, *Plasmodium malariae* and *Plasmodium vivax* etc. among others the *Plasmodium falciparum* and *Plasmodium vivax* have proved to be the deadliest.

### State level *Anopheline* diversity with reference to vector species

Ecology and habitat are the major factors to determine the diversity of mosquitoes. Anopheline mosquito diversity varies according to the climatic factors. In different states anopheline composition differs and also their bionomics as described below (Figure: 1)

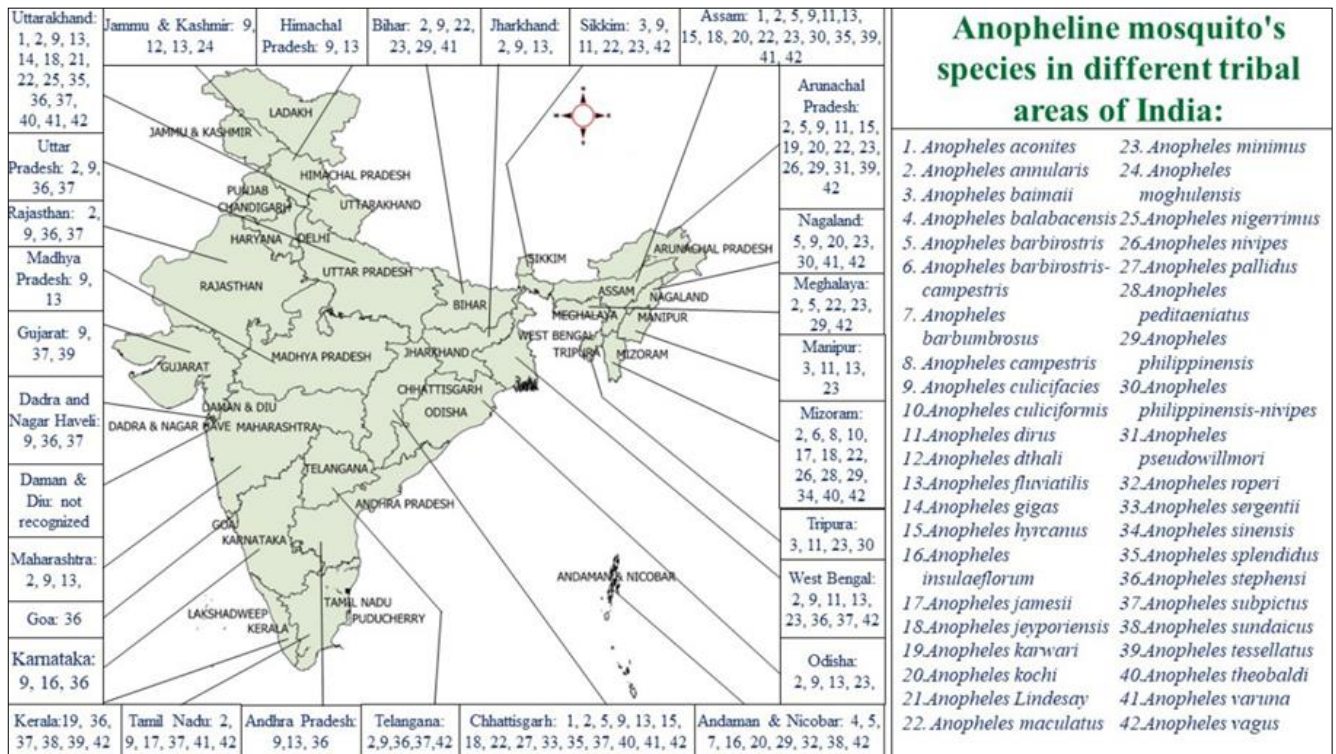


Fig 1: distribution of anopheline mosquito species in different tribal belts of India

**1. Andaman and Nicobar Island**

Andaman and Nicobar Islands of the Republic of India is a centrally administered area spanning from 92° to 94° East and from 6° to 14° North, and the region has experienced a lot of malaria transmission according to old data, covering 555 islands and in this area the Bay of Bengal is spread across 700 kilometres from north to south. Andaman and Nicobar Islands have two separate racial communities of primitive tribes inhabited by Negritos in Andaman (Great Jarawas, Andamanese, Sentinelese and Onges) and Mongoloid (Shompens and Nicobarese) in Nicobar, with an approximate population of 28,530 (total 7.5% of the population). Here peoples of tribal and rural areas travel from one place to another for employment, and these people come to malarious areas for daily and weekly works, due to which these peoples are contributing a lot to the spreading of malaria (Khan and Sunish 2019). A malaria survey was conducted among Jarawas in 2001 and 17% reported fever due to *Plasmodium falciparum* (Das et al. 2005) [10]. Malaria disease is endemic in the Andaman and Nicobar for more than a century and has been a highly cause of mortality and morbidity, so far there has been a lot of engineering work in this area which has increased the breeding habitat of the malaria vector, but the major malaria vector growing is *An. sundaicus* which thrives in saltwater bodies (Shanks and Bradley 2010) [42]. However, during the past few years, cases of the disease have seen a decline but *Plasmodium vivax* and *Plasmodium falciparum* are the main parasites that spread malaria, but *Plasmodium knowlesi* has also recently been reported as a parasite (Ittoop et al. 2015) [20]. *An. sundaicus* is an incriminated vector for the malaria parasite and these vectors breed in both brackish and freshwater, but both aquatic plants and filamentous floating algae appear to contribute significantly to its larval stage and larval development. This vector is predominantly of the zoophagic type which primarily bites animals, it shows the species bimodal biting, the first bites between 21:30 and

22:30 and the second bites by between 01:30 am and 02:30 am, *An. sundaicus* has more bite in the inside area than outside. According to Das et al. (2002) a total of 9 *Anopheles* species were collected from Little Andaman Island such as *An. insulaeflorum*, *An. barbumbrosus*, *An. roperi*, *An. kochi*, *An. balabacensis*, *An. barbirostris*, *An. philippinensis*, *An. sundaicus*, and *An. vagus* etc. but the most common species were found to be *An. philippinensis*. There have been reports of species-specific breeding preferences and associations in a variety of aquatic environments. This is the first time the Little Andaman Island mosquito fauna has been documented (Das et al. 2002).

**2. Andhra Pradesh**

Visakhapatnam district is topographically surrounded by the Gulf of Bengal in the east, north and west is surrounded by the hilly areas of the Eastern Ghats and in the south by the East Godavari. This district has 44 mandals, out of which 11 mandals are completely populated by tribal community, in which there are about 22 different tribal societies having a population of 5,66,893 (2,83,191 males and 2,83,702 females) spread in the hilly areas of the district where malaria was seen as a major continuing health problem among the tribals (Srinivasu 2014). A major malaria outbreak occurred in the Visakhapatnam district of Andhra Pradesh in 1999, recording 41,805 cases. From 2001 to 2016, in-depth research, and surveillance of this malaria epidemic were conducted. A total of 149,317 cases were reported, with 32% percent *Plasmodium vivax* cases and 68% of *Plasmodium falciparum* cases. During the monsoon, 70 percent of malaria cases were reported due to drastic changes in environmental conditions (Mopuri et al. 2020). *Anopheles* mosquitoes are commonly abundant in temperate climates. An survey conducted by Jaydev and Vardhani from July 2008 to June 2009 for the larval and adult phases of the *Anopheles* mosquitoes were collected at weekly and

monthly intervals at Vijayawada village in Krishna District, Andhra Pradesh in which adult *Anopheles* mosquitoes were collected at both fixed and random locations during the night hours (17:00 to 23:00), 15 minutes were spent in each house during the collection at 6 houses with the help of collection equipment of aspirators and flashlights. Adult mosquitoes were collected three times each month to cover 24 catching stations every day in the two areas. Among the 9 species of *Anopheles* mosquitoes reported in Andhra Pradesh, *An. stephensi*, *An. fluviatilis*, and *An. culicifacies* are dominant vectors. Malaria is mostly spread by *An. fluviatilis* in a hilly area, *An. stephensi* in urban and *An. culicifacies* in rural areas (Jayadev and Vardhani 2014)<sup>[22]</sup>. In the lab, the collected malaria vectors were identified using standard identifying keys. People living in slum areas face highly malaria positive cases of these people living standards, housing pattern, poor hygiene, socio-economic problems, and lack of proper health education helps in transmitting malaria disease to a higher level. (Jayadev and Vardhani 2014)<sup>[22]</sup>.

### 3. Arunachal Pradesh

Malaria is highly endemic in the north-eastern states of India (Arunachal Pradesh), and *Plasmodium falciparum* is particularly responsible as a malaria parasite (Campbell *et al.* 2006; Dev 2009; Dhiman *et al.* 2010)<sup>[7, 12, 14]</sup>. According to the World malaria report (2010) malaria was responsible for 46 % of deaths in the north-eastern states in 2007. During the research period, a total of 27,081 malaria cases were documented (2006 to 2012) A minimum of 838 instances of malaria cases were reported in 2012, which is one-tenth of the total number of cases reported in 2006. The largest number of malaria cases, 8451, was recorded in the year 2006, and the prevalence rate progressively dropped with each passing year (Upadhyayula *et al.* 2015)<sup>[53]</sup>. However, insufficient research has been conducted in India, especially in northern states like Arunachal Pradesh (Goswami *et al.* 2012)<sup>[17]</sup>. Various communities of tribal tribes are present in the areas of Changlang and Tirap district of this state such as Meeteis, Ao-Naga, Khasi, Tangsa, Nyishi, Galo, Wangcho (Wancho), Nocte, Singpho, Chakma, and Deori (Chakravorty *et al.* 2013)<sup>[8]</sup>. An entomological study conducted in Jairampur village of Changlang district of Arunachal Pradesh revealed that there are 35 species of total mosquitoes found here, malaria vector species *An. dirus* and *An. minimus* are found in abundance in these regions, and other 14 *Anopheline* species such as *An. hyrcanus* group, *An. annularis*, *An. philippinensis*, *An. pseudowillmori*, *An. maculatus*, *An. barbirostris*, *An. karwari*, *An. kochi*, *An. nivipes*, *An. tessellatus*, *An. vagus* and *An. culicifacies* group in the vectors are also capable of spreading Malaria disease. The *An. minimus* species was not previously seen in Jayarampur area as well as some other parts of Tirap district of Arunachal Pradesh but in the current study, it has been reported that *An. minimus* is seen in large numbers and it has been found that distribution of *An. minimus* in Tirap and Changlang district is well established, and this species is well established with *An. dirus*. Apart from these, Malaria is transmitting the disease, there is another incriminated vector present in the Tirap district.

### 4. Assam

Malaria is most of the major public health issues in the Indian state of Assam. Ignorance, low awareness and non-prioritization of health, delay detection of diseases and delay in treatment are some of the issues to be seen here. The focus remains on the attitudes and practices of the people. Studies have shown that the communities living here have direct contact with the malaria disease (Sharma *et al.* 2017). According to National Vector Borne Disease Control Programme there were 5281 cases of malaria in Assam in 2017, 3816 in 2018, 1459 in 2019 and 484 in 2020. The research was carried out between March 2004 and February 2005 in three forest fringe villages Bengenajuli, Nigam, Pathar, and Sapairaumari near the Assam-Arunachal Pradesh border in district Sonitpur. The ethnic tribes make up the bulk of the population in Bengenajuli (3,920), Sapairaumari Pathar (4,020), and Nigam (2,443). Nigam and Bengenajuli are in the Himalayan foothills zone, while Sapairaumari Pathar is in a forested zone. Since clearing thick woodland, farmers who had moved from elsewhere settled these areas. To make a living, the villagers engaged in rice cultivation and firewood collection. A survey of *Anopheline* mosquitoes was done in various rural and tribal areas of Assam, where 16 species of *Anopheles* mosquito were found. *An. culicifacies*, *An. aconitus*, *An. annularis*, *An. barbirostris* group, *An. jeyporiensis*, *An. dirus*, *An. fluviatilis*, *An. minimus*, *An. hyrcanus* group, *An. kochi*, *An. varuna*, *An. maculatus* group, *An. philippinensis-nivipes*, *An. splendidus*, *An. tessellatus* and *An. vagus* (Prakash *et al.* 2004). Study of malaria vector in 3 forest peripheral towns of Sonitpur district of Assam. *An. annularis* and *An. philippinensis/nivipes* species were recorded. The density of the malaria vectors was commonly higher during the monsoon period and lower in the winter months. *An. dirus* had the highest anthropogenic biting behaviour of all the species collected, whereas *An. fluviatilis*, and *An. varuna* was primarily related to zoophagic biting behaviour (Das *et al.* 2011)<sup>[11]</sup>.

### 5. Bihar

Malaria was reported in district Purnia of Bihar. Environmental variables (temperature, humidity, and rainfall, etc.), the condition of buildings, their location, sleeping habits outdoors, animal rearing, and drainage systems were all connected to the prevalence of malaria, according to the report, the prevalence of malaria is higher due to the district's proliferation of swampy fields, earthen hut walls, inadequate sanitation, and a poor drainage system, males were observed to have a higher prevalence of malaria than females, which may be attributed to their physical behaviours and sleeping habits outside the home, and according to the results of this report, families residing in houses with the worst construction and near mosquito breeding sites should be the main priority for the distribution of bed nets, furthermore, individuals with blood group O have a higher incidence of malaria (Pandey *et al.* 2013)<sup>[33]</sup>. Tribal tribes constitute 15% of the total population of Bihar. These tribes are Santhal, Munda, Oraon, Hos and Kharia who live in and around Chotanagpur region, some tribes like Santal, Munda and Oraon are large, whose population is in several thousand. The number of tribes like Birhor and Paharia is hundred or two. These tribes live in hilly areas, Birhor tribes live on the edge of forests of Bihar,

Birhors live in huts made of leaves with small entrances of two to three square feet. Epidemiological inspections were conducted in six tribal villages in the hilly region of Rajmahal range in South Bihar. This collection alone represented 72.8 percent of the total number of *Anopheles* mosquitoes gathered under these conditions among which the major malaria vectors *An. maculatus*, *An. minimus*, *An. philippinensis*, *An. varuna* and *An. annularis* were collected, *An. minimus*, *An. maculatus* and *An. philippinensis* is highly capable of transmitting malaria disease which gives a solid sign about their vectorial capacity in transmission of malaria. Due to poor socio-economic conditions, lack of sanitation, the presence of malaria carriers increases significantly. Malaria and other mosquito-borne diseases are commonly seen in these tribes. Bloodmeals were examined using counter current immune electrophoresis to establish the host specificity of *An. culicifacies* sibling species A and B obtained in Bihar. The results showed that species B and A are primarily zoophagic, with species A having a higher degree of anthropophagy. Furthermore, the proportion of human and cattle population in an area was found to be similar to the human blood index. This research is important because only species A was identified as the malaria mosquito in these zones.

## 6. Chhattisgarh

Malaria is a major public health issue in Chhattisgarh, and it is a leading cause of death and morbidity among tribal dominated districts. It was discovered that the density of *An. culicifacies*, the main malaria vector in the region, is decreasing while the density of *An. subpictus* is increasing. According to research from National Centre for Disease Control, Jagdalpur, the presence of sporozoites in *An. subpictus* was reported, and the anthropophilic index suggested the possibility of its vectorial potential in the Jagdalpur district, Bastar division. As a result, the current research concentrated on both mosquitos, the susceptibility tests and trials revealed that there is heterogeneity in the susceptibility/resistance status of both mosquitos to various types of insecticides (Viswan *et al.* 2019) [54]. About 25 tribal communities reside in different districts of Chhattisgarh, which are as follows: Gond, Munda Abujmaria, Bisonhorn Maria, Muria, Bhaiyana, Halba, Bhatra, Parja, Dhurvaa, Bhayna, Muriya, Kol, Dandamariya, Rajgond, Dorla, Bhunjia, Korwa, Kawar, Binjwar, Dhanwar, Parghi, Savra, Manji, Kamar etc. Epidemiological and entomological investigations were conducted in 21 malaria affected villages of district Korea in Chhattisgarh state. All the villages are situated near a perennial stream and the climate is favourable for mosquito breeding. Various Anopheline species were seen from the collection of mosquitoes done from these villages which are as follows *An. varuna*, *An. fluviatilis*, *An. culicifacies*, *An. maculatus*, *An. subpictus*, *An. annularis*, *An. vagus*, *An. splendidus*, and *An. theobaldi* (Mishra and Chand 2007) [30]. In order to determine the distribution patterns of various mosquito species and their seasonal fluctuations, research on the predominance of mosquito population in Block Chhura of the Raipur district of Chhattisgarh state was carried out between August 2002 and March 2004. Seven Anopheline species were identified such as *An. annularis*, *An. culicifacies*, *An. pallidus*, *An. hyrcanus* group, *An. subpictus*, *An. barbirostris* and *An. vagus* (Baghel *et al.*

2009) [9]. Mosquitoes were collected from Fingeshwar block of Raipur district, in which proportion malaria vectors was 14.09%; *An. culicifacies* (5.41%) and *An. annularis* (8.68%). *An. subpictus* had the highest dominance at 25.81% (Baghel *et al.* 2009) [9]. Entomological studies of Anopheline species were also gathered throughout the study period to document the prevalence of vector species of *An. fluviatilis* and *An. culicifacies* in a tribal wooded area of Bastar district, located in the southern portion of Chhattisgarh. Eight Anopheline species were recorded of the total 546 females collected, in which *An. fluviatilis* was the most dominant species, collected from human dwellings; *An. jeyporiensis* was the lowest density species. Apart from these, other species were also collected such as *An. aconites*, *An. sergentii*, *An. splendidus*, *An. subpictus* and *An. varuna* (Nanda *et al.* 2012) [32].

## 7. Dadra and Nagar Haveli

Epidemiological and entomological studies were scheduled in relation to malaria outbreaks in the Dadra Nagar Haveli. Since changes in human behavior and the environment play a significant role in the transmission dynamics of the vector-borne disease, making the disease endemic in Dadra Nagar Haveli - the union region located in the western part of India. The capital city of Silvassa is situated in the Western Ghats. It is a predominantly hilly and forested area spread over 487 sq. km, with about 72 villages mainly dominated by tribal tribes (population 0.342 million). In 2014, there was malaria in the Bonta sub-center of PHC Kilwani, due to which inspection was done here. During the inspection three species of *Anopheles* mosquitoes (*An. Stephensi*, *An. culicifacies* and *An. Subpictus*) were collected through sucking duct methods from human habitats such as animals' sheds and mixed residence. Primary vector *An. culicifacies* there was a highly abundant, due to which its density was also high. *Anopheles* was the highest collection from animal sheds followed by human habitation and mixed dwelling, and during study it was also found that hanging clothes were the favoured resting place of the mosquito in the human habitat. The transmission of malaria diseases is due to some factors such as climatic and non-climatic factors. Precipitation, temperature, and relative humidity are climate variables. Non-climatic factors, human host influences, parasites, population migration, vectors or movement, urbanization, deforestation, and control are interruptions and preventive trials.

## 8. Daman and Diu

The union territory of Daman and Diu is located on the India's west coast. Gujarat is the state that borders this UT of Daman City. Daman has a 7200 km<sup>2</sup> area and 91 percent humidity (Daman City Administration). The Daman Ganga River divides Daman into two halves, Nani-daman, and Moti-daman. Daman has a total population of 1,91,173 people (2011 census); that is 2700 individuals per square kilometre. Agriculture and small-scale enterprises provide most of the city's revenue. The city as a whole is an urban area (Jaiswal *et al.* 2018) [21]. But some tribal peoples also live in these areas. According to NVBDCP, 54 malaria cases reported in 2021 but malaria vector species is not recognised in these areas.

## 9. Goa

Research conducted after a malaria outbreak in Panaji (Goa) in 1986 found a significant difference in malaria incidence between migrant building labor and residents. The major breeding site for *An. stephensi* was water stagnation in and around the construction, and the rate of malaria transmission varied depending on the region under construction (Kumar & Sharma, 1991). Enough adult females could not be gathered and implicated as vectors in the past due to a lack of knowledge about their resting behavior. Mosquito collections were performed in three exotic urban and suburban areas of Goa for this study. 67 house of collection in well-built houses yielded not a single *An. stephensi* mosquito, though other species were observed, Collections in building sites and workers' huts for 151 buildings, on the other hand, yielded 38 *An. stephensi* females resting in 15 types of sites at a height ranging from 30 cm to 2.4 m, 31 of which were verified for the existence of *P. falciparum* circumsporozoite protein through an ELISA method and found to be *Plasmodium falciparum* circumsporozoite protein-positive (Sumodan *et al.* 2004). Please add article by Kumar in Malaria journal on *An. subpictus*.

## 10. Gujarat

The primary malaria vector in the Indian subcontinent's plains, like Gujarat in western India, is *An. culicifacies*. This species was first identified as a malaria vector in central Gujarat, and it is part of a group that includes sibling species A, B, and C. Outdoor resting, indoor resting, bovine bait trap, and immature collections were all used to gather anophelines from six villages in Gujarat's Kheda district. There were 113,487 specimens collected in all, representing 17 species. The most abundant species was *An. subpictus* (66.51%), followed by *An. culicifacies* (14.12%) and *An. tessellatus* (5.24 %). Bovine bait collections were found to be the extreme fruitful, generating the greatest species and anophelines per sample of collecting effort. Indoor resting collections produced the smallest diversity and the most specimens per sample of effort than outside resting collections. Outdoor collections showed the most diversity. The majority of the species had a unimodal prevalence. The seasonal occurrence, feeding, biting, resting, and breeding behaviour of this species has been studied in various parts of Kheda District with a high density of cattle (cattle: man, the ratio is 1: 1). In this state, various human settlements are situated along with the courses of seasonal rivers, many of which have a low cattle population, the abundance, feeding behaviour, and vectorial ability of *An. culicifacies*, a primarily zoophilic species, and its role in malaria transmission in human settlements where cattle populations are relatively scarce, have not been studied in this area. However, during 1991-1992 and again in 2000-01, a report on the role of *An. culicifacies* in malaria transmission was conducted in a village on the perennial River Mahi, which received 14 rounds of indoor residual spraying with malathion (Bhatt *et al.* 2008)<sup>[6]</sup>.

## 11. Himachal Pradesh

Malaria is one of the most communicable and severe mosquito-borne diseases in this state. The epidemiology of malaria and the spread of malaria vectors to Himachal Pradesh's mountainous regions are both severely impacted by climate change. *An. culicifacies* *An. fluviatilis*, known

efficient malaria vectors were detected in high density in the Kangra area of Himachal Pradesh (Kumar *et al.* 2022)<sup>[27]</sup>. The study was conducted in six towns in the Kangra district of Himachal Pradesh. A total of 4446 vectors were collected and processed into pools of ten for molecular characterization during the one-year study period (2018). Multiplex PCR and DNA extraction were performed at 900 *An. fluviatilis* for sub-species variation. ELISA was used to 3790 *An. fluviatilis* specimens and detected *P. vivax* and *P. falciparum* circumsporozoite proteins. Yet malaria transmission intensity was relatively low. In order to determine their function in malaria transmission, it was thought desirable to look at the sibling makeup of the *An. fluviatilis* group in the Kangra valley (Singh *et al.* 2021)<sup>[46]</sup>.

## 12. Jammu and Kashmir (J&K)

Some anopheline mosquito records from J&K have been published, but the first record of a malaria survey is a manuscript report from the Jammu Epidemiology Department in 1946. Local tribal people's settlements are located at elevations of 305- 335 meter above sea level. Approx 12 species of anopheline are present in J&K, but 4 species are mostly present in tribal areas. Two of them *An. dthali* and *An. moghulensis* being found in Kashmir for the first time. Malaria was found to be endemic and hyperendemic in a patchy distribution, and the months of July to September were when it was most conducive. It was determined from the data that the infection at this high altitude was autochthonous since *Plasmodium vivax* was the sole parasite found in a community at a height of around 1830 meter. *An. fluviatilis* was discovered in the homes at the time of the visit, which took place in a hot, humid environment. It is quite likely that this species is the vector. The previously implicated *An. culicifacies* was not discovered over 1220 meter (Jacob, 1950).

## 13. Jharkhand

Although malaria vectors are numerous in Ramgarh, their larval ecology and the climatic factors that affect malaria dynamics have never been examined. This is why the Ramgarh district of the state of Jharkhand is particularly malarious due to the availability of several malaria vector species. As a result, aim of these research were to determine variety of the possible breeding habitats and breeding priority of *Anopheline* vectors in Ramgarh district from August 2012 to July 2013, *Anopheles* immatures were collected at possible aquatic environments in Gola and Ramgarh sites using a regular dipper on a periodical basis, the immatures were raised until adulthood and then marked using normal keys, temperature data loggers were used to monitor surface and water body temperatures, and regular weather gauges were mounted at each location to monitor rainfall, a total of 6495 immature *Anopheline* species, including three malaria mosquitos, *An. fluviatilis*, *An. annularis* and *An. culicifacies*, were obtained from 11 different types of breeding environments, vector *Anophelines* favoured river pockets, lakes, streams, river margins, wells, wetlands, drainage channels and ditches for breeding habitats, throughout the year, the richness of mosquito larvae diverse according to rainfall and temperature patterns, at the Ramgarh site (Pandey *et al.* 2016)<sup>[34]</sup>.

#### 14. Karnataka

From 1997 to 2014, malaria epidemics and the function of the subspecies groups of the main rural malaria mosquito *An. culicifacies* were studied in villages in north Karnataka, data on the breeding, densities and resting site of malaria mosquitos found in the region was also gathered to develop an effective mosquito management strategy, three *An. culicifacies* subspecies, A, B, and C, were found to be sympatric, with combined percent compositions of 63.7, 28.2, and 8.1, respectively. The densities of *An. culicifacies*, *An. fluviatilis*, and *An. stephensi* per man-hour and per structure ranged from 0 to 27.5 and 0 to 56.0, 0 to 0.5 and 0 to 7.0, and 0 to 2.5 and 0 to 7.5, respectively, the percentage of semi-gravid and gravid females was higher than the proportion of fully fed and unfed females, indicating that the majority of the females slept indoors, Streams/rivers, wells, seepages, and drainage tanks are the primary breeding habitats for *An. culicifacies*, to control malaria in the field, integrated vector management methods such as indoor residual spraying of effective insecticides by national guidelines, as well as biocontrol technic such as the use of larvivores fish *Gambusia affinis* and *Poecilia reticulata*, are recommended (Tiwari *et al.* 2015) [52]. Please cite more articles published earlier. Here *An. stephensi mysorensis* was first identified.

#### 15. Kerala

This species was discovered in Kerala, India's southwestern state. While the new taxon seems to be related to *An. subpictus* and *An. sondaicus*, it differs from each in morphological (adult and immature) and molecular characteristics. Tyagi *et al.* (2019) characterized these species morphologically and molecularly in this study, using mtDNA sequences to separate it from *An. subpictus* and *An. subpictus*, the terminology used, as well as the abbreviations of generic and subgeneric terms, was drawn from different sources. According to Radhakrishnan (2019) [36], *An. stephensi* was found in urban and rural sites, breeding in a variation of habitats such as polythene sheets, water tanks and plastic containers, demonstrating its ability to spread in these habitats. The rise in *An. stephensi* distribution supports indigenous malaria transmission in the areas, where they can obtain parasite from migratory workers from malaria-endemic zones. The essential for malaria parasite surveillance of migratory workers is unavoidable if local transmission of the malaria disease is to be avoided, with a decrease in biodiversity, a quicker rate of emergence and re-emergence of communicable diseases will change the epidemiology of vector-borne disease transmission in the region. During January and August 2018, the biodiversity index was higher than usual. In the study areas, *An. karwari* and *An. tessellates* were present in advanced densities in hilly and forest fringe zones. *An. vagus* and *An. subpictus* were found in the Ernakulam district's coastal belt. During the survey, *An. karwari* was discovered breeding in rock pools near forest fringe zones (Radhakrishnan 2019) [36].

#### 16. Madhya Pradesh

Malaria is India's most serious public health issue, with Madhya Pradesh being one of the most malaria-endemic states. *An. culicifacies* is a group of five morphologically indistinguishable subspecies A, B, C, D, and E with varying biological characters that are the primary rural malaria vector in India. Mosquito reproduction takes place in a variety of environments and various forms of water. In this

research, the Physico-chemical characteristics of *An. culicifacies* larval environments were investigated. The samples were obtained from various malaria-endemic areas in Madhya Pradesh, India, between August and October, 11 sampling sites yielded immature stages of *An. culicifacies*. Using AS-PCR methods, the sub species were described, A was discovered in Khandwa; B in Jabalpur and Chindwada; C in Hoshangabad only; and D in Narsinghpur and Khandwa, species A and D were found breeding in the same location but in diverse habitats, the highest concentrations of larvae were detected in drainage tanks and riverside water sources. Dissolved oxygen, temperature, conductivity, pH, total dissolved solids, alkalinity, nitrogen, calcium, nitrate nitrogen, ammonia, chloride, magnesium and total phosphate were all tested in larval environments (Tyagi *et al.* 2013). The existence of numerous malaria parasites and mosquito types, as well as climatic variation that favours parasite and vector growth and proliferation, as well as a highly susceptible human community's, has resulted in high malaria disease transmission in central India's forested zones of Madhya Pradesh, Infection with *Plasmodium falciparum* accounted for 80% of all infected cases. *P. vivax* was found in 16.5 % of cases, *P. malariae* in 0.75 %, and combined infections of *P. falciparum*, *P. vivax* and *P. malariae* were found in the remaining cases. Infections were observed in more than 30% of infants under the age of six months. From 2010 to 2012, there was a growing trend in malaria positivity. Twenty-five *An. culicifacies* (sub species C, D, and E) tested positive for *Plasmodium falciparum* circumsporozoite protein (44%) and *Plasmodium vivax* circumsporozoite protein (56%). Two *An. fluviatilis* were also found to be positive for *Plasmodium falciparum* and one for *Plasmodium vivax* (sibling species S and T). In India, a sibling species 'T' of *An. fluviatilis* was discovered as a vector in forest villages for the first time (Singh *et al.* 2013) [44].

#### 17. Maharashtra

This study aimed to regulate the current state of malaria, its incidence, and the prevalence of its mosquitos in Maharashtra's Gadchiroli district. In the Gadchiroli district, entomological and epidemiological investigations were conducted in 46 villages of three higher malaria-endemic PHCs, the majority of the rurales are located in the district's dense forest and forest fringes, adult vectors were captured from outdoor and indoor resting zones and classified using standard keys to species level. The Maharashtra district of Gadchiroli is one of the most malaria-endemic, with 11372 malaria cases recorded in 2008 and 5484 cases reported in 2017, with *Plasmodium falciparum* accounting for 74.91 %. Around 2008 and 2017, the district's slide positivity score (SPR) fluctuated between 0.92 percent and 4.57 %, out of 47 PHCs, more than 67 percent of malaria cases came from 12 PHCs, including three rural hospitals (data provided by the state health department) in Gadchiroli, the major malaria vectors are *An. culicifacies* and *An. fluviatilis*, and their management is dependent on the use of insecticides. *An. fluviatilis* was found to breed in streams and stream pools in the forest region, with the highest numbers reported in cattle sheds. *An. annularis* mosquitoes were found breeding in paddy fields, rivers, ditches, drains, ground pools, and pits after being captured in human dwellings and cattle sheds. *An. culicifacies*, which was present in the houses of the surveyed villagers, was found to be the source of malaria transmission all year (Singh *et al.* 2019) [45].

### 18. Manipur

Malaria remains a major community health issue in India's north-eastern (Manipur) province, with 290 deaths and 174,000 cases reported in 2010 (NVBDCP 2010). The malaria vectors in this area are mosquitoes from the *An. dirus*, *An. minimus*, and *An. fluviatilis* complexes. *An. baimaii* (formerly *An. dirus* species D), a member of the *dirus* family, is the primary vector in forest-edge and forested zones in north-eastern India (Prakash *et al.* 2001; Prakash *et al.* 2010). This result was performed on mtDNA introgression from *An. baimaii* into *An. dirus*, as well as a selective mtDNA sweep. Both *An. baimaii* and *An. dirus* have a strong susceptibility to malaria diseases parasites, as well as highly anthropophily and highly survival rates, allowing them effective malaria mosquitos in Southeast Asia's (Manguin *et al.* 2008, Sallum *et al.* 2005, Sinka *et al.* 2011). As a result, biological characteristics reported for *An. baimaii* in one part of Southeast Asia do not extend to *An. baimaii* in another part of Southeast Asia. Some species in Myanmar, for example, have been shown to have different larval habitation preferences, breeding in rurales wells rather than forest ground water (Thin *et al.* 2002 & Minn *et al.* 1999). *An. baimaii* biological characteristics such as reproduction, biting and resting behaviors, insecticide reaction, and malaria transmission tend to be consistent across much of the country (Sarma *et al.* 2012)<sup>[40]</sup>.

### 19. Meghalaya

Malaria is the most common vector born disease in Meghalaya, and the second most common in India (NVBDCP 2012). Since 2001, the incidence of malaria in Meghalaya has been steadily increasing. In the previous decade, these regions have seen a string of epidemic seasonal malaria outbreaks. Annually, these outbreaks resulted in 29,710 therapeutic attacks (on average). *Plasmodium falciparum* is responsible for 93 percent of all malaria cases in Meghalaya. More than 75% of all cases reported in Meghalaya are found in the Garo Hills zone (East, West, and South Garo Hills district). Malaria has a yearly incidence of 106 per 100,000 people in India, but 920 per 100,000 people in Meghalaya, which is 8.6 times higher than the nationwide average. Malaria was formerly endemic in Meghalaya's foothills and valleys, but it is now steadily expanding to the state's highlands. Land usage and human settlement patterns are the primary causes of this increase in infection. There was a statistically important connection between land use and the land cover type and the presence of *Anopheles* larvae. Seasonally, the distribution of anopheline-positive ecosystems changed dramatically. *Anopheles* density was slightly higher in urban parts in both seasons, but only in rainy and post-rainy seasons in farmland and pastureland areas. *An. barbirostris* (5.1 %), and *An. minimus* (5.1 %), *An. philippinensis* (8.1 %), *An. annularis* (9.1 %), *An. vagus* (13.7 %), *An. maculatus* (19.2 %), were the six most common species collected (4.6 %). The majority of the land use and land cover improvements occurred in valleys and at the Phase III site of the National Highway Development Program. Overall, open woodland, farmland, and the process of a national highway improvement project increased by 2.9, 1.7, and 2.1 %, respectively (Srivastava *et al.* 2013)<sup>[48]</sup>.

### 20. Mizoram

In Thenzawl, Mizoram, a three-year systematic survey on *Anopheles* species occurrence, bionomics, and habitat preference was performed. For larval collection, a scoop-net method was used, and for adult collection, a locally made killing-jar was used. A total of ten species *An. peditaeniatus* (0.22%), *An. sinensis* (0.23%), *An. annularis* (0.26%), *An. philippinensis* (0.7%), *An. maculatus* (1.7%), *An. jeyporiensis* (11.4%), *An. jamesii* (15.1%), *An. vagus* (20.6%), *An. nivipes* (24.0%), and *An. campestris* (25.8%) were collected (Zomuanpuii *et al.* 2014)<sup>[55]</sup>. The larval-dip approach was used to perform a systematic survey of *Anopheles* species in four Mizoram County areas (Kolasib, Lengpui, Lunglei, and Thenzawl) from November 2008 to June 2009 (winter to pre-monsoon season). *Anopheles* has been found in seven different locations. *An. philippinensis*, *An. maculatus*, *An. vagus*, *An. theobald*, *An. culiciformis*, *An. barbirostris-campestris*, and *An. jamesai*. The distribution pattern and percent occurrence of the seven *Anopheles* species described differed depending on the geographic area. The larval ecosystems of *Anopheles* species were discovered to be diverse, including a stream and a rock-hole in Kolasib, a fish pond in Lengpui, a rock-hole in Lunglei, and a natural permanent pond in Thenzawl. The mean number of larvae per dip of the dominant species varied between 10 and 20 in various locations; more *An. vagus* and *An. barbirostris-campestris* larvae were caught in Kolasib and Lengpui (10-20 larvae/dip), but less in Thenzawl (*An. vagus* 0-2 larvae/dip; *An. barbirostris-campestris* 6-10 larvae/dip). The most common species in Kolasib, Thenzawl, Lengpui, and Lunglei is *An. theobaldi* (100 %), *An. barbirostris-campestris* (100 %), *An. vagus* (60 %), and *An. philippinensis* (60 %). In Thenzawl, all the seven *Anopheles* species were recorded (Zomuanpuii *et al.* 2009).

### 21. Nagaland

Entomological surveys were done in three riverine villages in Dimapur, Nagaland: Khekiho, Denial, and Dhansiri. These villages, which are situated in the foothills along the bank of the Dhansiri River in Assam's Karbi-Anglong district, are crossed by perennial and seasonal streams. Bamboo houses with thatched roofs are common near cattle sheds. Naga tribes, Nepalese migrants, and Muslim minority make up the population of these villages. Rice and maize are the primary crops, and agriculture is the main occupation. Mosquitoes preferred slow-moving waterways, paddy fields and undeveloped drains in agriculture field as breeding grounds. *Anopheles* mosquitos made up 40.5 percent of the available sample. Malaria vectors found included *An. minimus*, *An. philippinensis/An. nivipes*, *An. varuna* and *An. culicifacies* (50.1 percent of the total *Anopheles* species). *An. philippinensis/An. nivipes* was the most common species (12%), led by *An. barbirostris* (8.7%), *An. vagus* (5.9%), *An. minimus* (4.1%), *An. kochi* (2.9%), and *An. culicifacies* (2.5%), with the remaining three species accounting for 4.4% of the overall set (Baruah *et al.* 2004)<sup>[3]</sup>.

## 22. Odisha

Odisha is the most problematic state for malaria. The hilly and forested regions of Keonjhar district, mostly populated by tribal people, are strong malaria transmission areas. Malaria is also a concern in the district, owing to favorable ecological and geographical conditions for the proliferation of *An. minimus* and *An. fluviatilis*, which leads to the spread of malaria. Understanding transmission dynamics is critical for developing malaria management plans that provide site-specific and evidence-based vector control interventions. The vectorial potential of *An. minimus* and *An. fluviatilis* in the transmission of malaria during various seasons of the year was estimated in the Keonjhar district of Odisha State (Gunasekaran *et al.* 2014) [18]. The mosquito collection revealed a diverse *Anopheles* fauna, with two effective malaria vectors, *An. culicifacies*, the primary vector with a high peak value during monsoon, and *An. annularis*, the secondary vector, being collected in three research districts. The existence of all 5 sub species of *An. culicifacies*, namely A, B, C, D, and E, was identified through molecular identification, while only species A of *An. annularis* two sibling species A & B was observed. These entomological metrics, such as vector density, distribution, biology, and bionomics, as well as their vectorial attributes, are critical indicators for determining the pattern and severity of malaria transmission. At the peak transmission season, proper monitoring and assessment of these indices will help to slow the rise in malaria cases (Pradhan *et al.* 2020) [35]. An investigation into the bionomics and function of the *An. fluviatilis* and *An. culicifacies* sub species in malaria transmission in deforested and forested environments was conducted. *An. fluviatilis* sibling species S was found in forested villages. The former was anthropophagic to a fault (human blood index 0.88). Species B and C heterozygotes were included among the *An. culicifacies* sibling species and were extremely zoophagic. *An. fluviatilis* was virtually absent in deforested riverine settlements, but *An. culicifacies* sibling species A, B, and C heterozygotes were found. Annual parasite occurrence (269 cases/1,000) and slide positivity rate were substantially higher in forested villages than in deforested zones, with 39 cases/1,000, respectively (Nanda *et al.* 2000).

## 23. Rajasthan

Dungarpur, Banswara, Pratapgarh, and Chittorgarh districts are included in the scheduled tribal areas. Kherwara, Kotra, Gogunda, and Jhadole-falasia tehsils of Udaipur district make up the densely populated tribal region. According to tribal history, the four primary autochthonous tribes of Rajasthan, namely the Meena, Bhil, Saharia, and Damor, dominated the state. Certain tribes, such as the Saharia, Kathodi, and Patelia, continue to live in deplorable conditions. The Bhils and the Meenas are two of the region's most well-known scheduled tribes. The Bhils are predominantly found in the hilly districts of Udaipur, Dungarpur, and Banswara, whereas the Meenas are mostly found in the districts of Jaipur, Sawai-Madhopur, and Udaipur. The Bhils are not gypsies in the traditional sense. The whole Bhil community in Rajasthan's south-western corner is hilly, encompassing the wildest section of the

Aravalli hills (Kumar *et al.* 2017) [26]. Malaria is a main public health problem in western Rajasthan, but the vector fauna and transmission mechanisms are poorly understood. The current research presents a comprehensive profile of qualitative and quantitative aspects of anopheline species found in various desert ecosystem settings. During the rainy season, *An. subpictus* and *An. stephensi* were found in the village of setting I, while during the winter season, four species were collected: *An. subpictus*, *An. stephensi*, *An. culicifacies*, and *An. annularis*. During the summer season, no *Anopheles* mosquito was found in any of the villages in settings I, II, or III. The *Anopheles* species were only present during the rainy season in desert villages without any irrigation facilities via canals. Regardless of whether the region is canal irrigated or not, *An. stephensi* is the most common malaria vector in the desert. The absence of vector species in all villages during the summer season necessitates further research into the micro-ecology of the species under desert conditions. Malaria is seen as a worldwide health issue. More than 60% of malaria reports in India are found in tribal societies. In the tribal parts of Udaipur district, *An. culicifacies* and *An. stephensi* are regarded prominent and dominating malaria vectors. Malaria transmission is quickly growing in tribal, rural, and urban regions of Southern Rajasthan, necessitating an epidemiological and entomological research to better understand the dynamics of the malaria disease. The lack of understanding of vectors, such as the research of their seasonal abundance, vector incrimination rate, and behavioural involvement in transmission, is a crucial factor in the rise of malaria. Furthermore, insufficient information about local patterns of malaria disease infection rate, yearly and seasonal depend on *Plasmodium* parasite species occurrence, and the impact of anti-malarial measures is known in Southern Rajasthan. In the current situation, malaria control efforts are based on outdated prevention and treatment techniques. During the post-monsoon and monsoon seasons in Southern Rajasthan, tribal villages are flooded by water, resulting in a high malaria transmission rate. As a result, studying the transmission patterns of vectors is critical for eradicating malaria (Kumawat *et al.* 2021) [28].

## 24. Sikkim

Sikkim state lies at a latitude of 27°33'N and a longitude of 88°62'E covering an area of 7096 km<sup>2</sup>. Existing interventions and Indoor residual spraying (IRS) and long-lasting insecticidal nets / insecticide-treated nets are used for intervention of malaria in Sikkim district. In this area, *An. baimaii* and *An. minimus* are the two predominant vector species; both are highly susceptible to DDT. *P. falciparum* is the major infection. Sibling species B is the only affiliate species of *An. culicifacies* but has a minimal role in malaria transmission (Sharma and Dev 2015) [43]. The malaria mosquito *An. culicifacies* species (71%) was found to be the most abundant during the study conducted in the state of Sikkim, apart from other species such as *An. maculatus* (13%) and *An. vagus* (9%) and about 8 Anopheline species were collected. Apart from this, according to the old study, *An. dirus* was also found here (Gupta *et al.* 2016) [19].

## 25. Tamil Nadu

Tamil Nadu is a state in the Indian peninsula's southernmost region. Interstate movement of malaria carriers for employment and trade is influenced by regional inequalities in growth. Internal migration within the country affects around 326 million people, with rural male migrants accounting for 29 percent of the total (Bhagat 2017)<sup>[4]</sup>. The research was performed in villages (in Tamil Nadu's Villupuram district), which were adjacent to stone (granite) quarries that annually draw migrant laborers from other states, including malaria-endemic states. There had been previous records of malaria cases in the sample villages. Possible habitats were promoting the breeding of established primary and secondary malaria vectors, such as *An. culicifacies*, *An. varuna*, *An. annularis*, and *An. subpictus*, in and around the villages. Among the three research villages, the numbers of possible mosquito breeding habitats, including the established malaria mosquito species (primary/secondary) *An. annularis*, *An. culicifacies*, *An. varuna* and *An. subpictus*, were comparatively higher in Karasanur, followed by Kunnam. *Anopheles* made up seven of the 16 mosquito species collected from larval samples. *An. vagus*, *An. subpictus*, and *An. culicifacies* were the most common species in Karasanur village, alongside *An. varuna*. *An. subpictus* was the most common species in Kunnam village, followed by *An. annularis*; no *An. culicifacies* were found in immature samples. In Perumbakkam village, the recognized malaria vector species were found in lower numbers. *An. annularis*, *An. vagus*, *An. varuna*, and *An. culicifacies* were the most common species, followed by *An. vagus*, *An. annularis*, *An. varuna*, and *An. culicifacies*. Adult mosquitoes from various types of specimens in the three research villages belonged to 13 distinct insects, six of which were *Anopheles*. The *Anopheles* species composition in larval and adult samples was similar, except for *An. jamesii*, which was not seen in adult specimens. Perumbakkam village had the highest percentage of *An. subpictus* obtained (24.7%), led by Kunnam (13.5%). Kunnam had a higher proportion of *An. annularis* and *An. culicifacies* than the other two villages (Shah *et al.* 2018)<sup>[41]</sup>.

## 26. Telangana

From February 2012 to January 2014, researchers examined the variety of mosquitoes in both indoor and outdoor habitats in Warangal, Hanamkonda, and Kazipet, three parts of the Warangal Tri city of Telangana. *An. culicifacies*, *An. stephensi*, *An. annularis*, *Culex quinquefasciatus*, *Cu. tritaeniorhynchus*, *Aedes aegypti*, and *A. albopictus* were the seven species that were collected and identified, which are all members of three genera (Suhasini and Sammaiah 2014)<sup>[50]</sup>. At Telangana's Mahabubnagar district, mosquito frequency was examined in Mannanur, Janampeta, and B Veerapur. In the Mahabubnagar district, mosquito sampling was carried out in three chosen villages during the entire year from 2014 to 2016. For three years, 2014-2016, density, distribution, and habitat preferences are investigated. 1787 mosquitoes in all were gathered. Christophers (1933) and Barraud's (1934) identifying keys were used for identification. There were three genera identified: *Culex*, *Aedes*, and *Anopheles*. *Anopheles*, *Culex*, and *Aedes* each contribute 44%, 39%, and 17% respectively. *An. culicifacies* makes up 12 percent of the total, while *An. vagus* and *Culex tritaeniorhynchus* both make up 8 percent.

*Aedes aegypti* only contributed with 5%, whereas *An. subpictus* and *An. stephensi* both gave 7%. Breeding grounds make up 50% of human houses; cow sheds make up 25%; and rain water ditches make up a very small portion because they are only accessible during the monsoon. All of the habitats had *Cx. quinquefasciatus* and *Cx. gelidus*, but some of the habitats contained *An. subpictus*, *An. stephensi*, *An. culicifacies*, *Ae. aegypti*, and *Ae. Albopictus* (Mandla and Illendula 2022)<sup>[29]</sup>.

## 27. Tripura

In 16 villages in Tripura, north-eastern India, malaria epidemiological surveys were performed. Insecticide resistance in malaria vectors and chloroquine resistance in the parasite was also investigated, as well as the use of light traps to measure vector density. Malaria incidence was highest in June-July and lowest in November, according to epidemiological reports. *An. dirus*, *An. minimus*, and *An. philippinensis/nivipes* were the most common malaria vectors found in light trap collections (Dhiman *et al.* 2017)<sup>[15]</sup>. Malaria receptivity varied by region, as indicated by the number of confirmed cases, with districts in South Tripura and Dhalai registering the highest number of cases in contrast to districts in West Tripura and North Tripura, which corresponded to relative concentrations of tribal populations and forest cover. The disease was perennial and permanent, with a seasonal high leading to months of heavy rainfall, as indicated by the monthly spread of cases, but disease patterns were distinctly and slowly decreasing. Both *An. minimus* and *An. baimaii* were found to be widespread during the monsoon season (June-September), which corresponds to a strong transmission time. The prevalence of *An. minimus* in human dwellings indoors was poor compared to mosquito landing rate per person/night, indicating that the population occurrence of both mosquito species differed across ecotypes. *An. minimus* was implicated and shown to be effective mosquito vectors in the state, but the function of *An. baimaii* could not be established due to sporozoite infectivity. In addition, data on mosquito blood meal analysis for *An. baimaii* remained insufficient due to a lack of mosquitoes other than human bait capture to support host preferences (Dev *et al.* 2015)<sup>[13]</sup>.

## 28. Uttar Pradesh

Ghaziabad, a district of Uttar Pradesh, is part of the National Capital Region and has a rapidly expanding urban population, which has increased from about 0.15 million lakhs in 1951 to over 3.1 million in 2011 (Census 2011). 680 female *Anopheles* mosquitoes were analyzed by ELISA to see whether they were infected with *Plasmodium spp.* 74 specimens were *An. culicifacies*, 66 were *An. stephensi*, 399 were *An. subpictus*, and 141 were *An. annularis*, with an infection rate of 1.17 percent (8/680). Malaria incidence and prevalence were highest in urban PHCs compared to rural PHCs. Month-by-month data revealed that transmission occurred only during the monsoon season, from June to October. This may be because of the building boom, which has resulted in the presence of breeding sites for the urban malaria vector *An. stephensi*, which has increased in cases in Ghaziabad. Seasonal breeding sites, such as pools of water, existed in rural Ghaziabad, where *An. culicifacies* bred and induced seasonal malaria in the Ghaziabad district (Rani *et al.* 2017). *An. subpictus*, which has recently been identified

as a malaria mosquito, is prolifically reproducing and may be to blame for the occurrence of these diseases in Ghaziabad (Rani *et al.* 2018)<sup>[37]</sup>. ELISA was used to detect sporozoites, and PCR was used to validate positive results. In rural areas, *An. subpictus* was discovered for the first time with *Plasmodium* infection of 0.73 percent (5/680) and 0.74 percent (4/539) by ELISA and PCR, respectively (villages of Bhojpur and Muradnagar PHC). *An. subpictus*, *An. culicifacies*, and *An. stephensi* were found to be responsible for a combined sporozoite incidence of 1.63 % (11/680) by ELISA and 1.03 % (7/680) by PCR. *An. subpictus* (49.32 %) was the most common *Anopheles* species found in human dwellings (55.76 %). For the first time, *An. subpictus* was identified as a malaria vector in the Ghaziabad district (Rani *et al.* 2020)<sup>[39]</sup>.

### 29. Uttarakhand

Mosquito breeding in different environments has led to the conclusion that river beds, rainwater collection, lakes, flooded agricultural fields, canals, wetlands, and marshy areas are all potent mosquito breeding habitats. In the research belts of Raipur-Doiwala, Sahaspur-Selaqui, and Kalsi-Vikasnagar in district Dehradun, 15 species of *Anopheles* (*An. varuna*, *An. vagus*, *An. theobaldi*, *An. subpictus*, *An. stephensi*, *An. splendidus*, *An. nigerrimus*, *An. maculatus*, *An. jeyporiensis*, *An. gigas*, *An. lindesayi*, *An. annularis*, *An. fluviatilis*, *An. culicifacies*, and *An. aconitus*) The population of Anophelines was highest in the Raipur-Doiwala belt, followed by Kalsi-Vikasnagar and Sahaspur-Selaqui belts in that order. Twelve species of *Anopheles* were discovered as adults in the Kalsi-Vikasnagar and Raipur-Doiwala belts. The undeveloped density was higher in the Kalsi-Vikasnagar belt than in the Raipur-Doiwala belt (Bhatt 2020)<sup>[5]</sup>.

### 30. West Bengal

In Kolkata, India, mosquito-borne illnesses including malaria are widespread. Thirteen anopheline species, including the recognized malaria vectors *An. annularis*, *An. culicifacies* and *An. stephensi*, are among the species of mosquitoes that have been observed in Kolkata (Pramanik and Raut 2000). In the region of Jalpaiguri Duars, where malaria has been a persistent issue, research was carried out between August 1989 and April 1990. Three species of vector were identified within the anopheline fauna; *An. minimus* served as the main vector, supplemented by *An. dirus* in the wetter months and *An. fluviatilis* in the drier months. *An. minimus* was discovered to be largely a domestic vector, and all three vectors were discovered to be closely associated with human orbit. It has been made clear that *An. minimus* plays a key part in the spread of malaria in the area. Seasonal variations, biting preferences, biting durations, and vector infection rates were observed and noted (Nandi *et al.* 1996). *An. annularis*, *An. culicifacies*, *An. subpictus*, and *An. vagus* were reported in the rural areas. These mosquitoes vary in their seasonal abundance as well as their distribution between urban and rural locations. *An. subpictus* was shown to be the predominant species in terms of abundance in both rural and urban settings. In contrast to human residences, cattle sheds had a higher relative and absolute number of mosquitoes of all species (Pramanik *et al.* 2006).

### Discussion

Malaria in India is in a state of flux, with outbreaks driven mostly by *P. falciparum* infection. The country has an effective malaria control program. Improper surveillance and anti-vector efforts connected to spraying activities in rural regions, as well as anti-larval efforts in urban areas, have been identified as causes of such outbreaks. In India, the yearly incidence of malaria is 106 per 100,000 people, while in Meghalaya, it is 920 per 100,000 people, which is 8.6 times higher than the national norm (Srivastava *et al.* 2013)<sup>[48]</sup>. The standard way of identifying oocysts and sporozoites is to dissect the intestines and glands of vector mosquitoes. Because of recent research on species B of the *An. culicifacies* complex has revealed that *P. vivax* parasites in the mosquito stomach grow to the oocyst stage and do not develop into sporozoites, sporozoite detection would be an ideal approach for vector incrimination (Adak *et al.* 2006)<sup>[1]</sup>. The polytene chromosomal approach was used to distinguish between sibling species. PCR approaches have now been established to distinguish members of the *An. culicifacies* complex's sister species (Goswami *et al.* 2005; 2006)<sup>[16]</sup>. *An. stephensi*, *An. fluviatilis*, and *An. culicifacies* are dominant vectors in Andhra Pradesh, where they may be found in tropical and subtropical regions as well as temperate zones. Malaria is transmitted by *An. fluviatilis* in mountainous locations, *An. stephensi* in urban areas, and *An. culicifacies* in rural regions (Jayadev and Vardhani 2014)<sup>[22]</sup>. According to this paper, mosquitoes like *Anopheles* have found acceptable breeding sites in polluted breeding sites and sewers. According to health studies, Ghaziabad is in danger of illnesses. *An. subpictus*, a malaria vector newly found, reproduce rapidly and may be to blame for the emergence of these illnesses in Ghaziabad (Rani *et al.* 2018). In deforested riverine villages, *An. fluviatilis* was almost non-existent, but *An. culicifacies* sibling species A, B, and C heterozygotes were detected. In forested communities, the annual parasite incidence (269 cases/1,000) and slide positive rate (39 cases/1,000) were both significantly greater than in deforested regions (Nanda *et al.* 2000). Although *P. vivax* and *P. falciparum* are the two most common parasites that carry malaria parasites, *Plasmodium knowlesi* has just been identified as a parasite in Andaman Island (Sunish *et al.* 2015)<sup>[51]</sup>.

### Conclusion

This paper presented an overview of the Diversity and abundance of *Anopheles* vector and different breeding habitats and effective regions of malaria diseases in tribal belts of India. The dynamics of vectors are directly or indirectly linked to vector-borne illnesses. One of the most important aspects of any malaria eradication campaign is vector control. To assess the hazard of vector-borne illness, it is necessary to know the preferred breeding location in detail, as well as the circumstances of vector survival and resting behavior. These details might be useful in the execution of any malaria control methods. Feasible control actions must be based on a thorough understanding of the epidemiology of malaria in the targeted region, as well as the transmission dynamics and behavior of the vector species involved. This served as a starting point for developing and implementing evidence-based malaria control methods.

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