Chapter 2: REVIEW OF LITERATURE
The process of malaria transmission has been beautifully elucidated by Pampana (1969). He has compared malaria parasite with a seed, a mosquito with natural sower (rarely man as artificial sower with a infected syringe), and soil with another human being where the seed is sown i.e., a healthy person who received infection. In India, the epidemiology of malaria is very complex because of geo-ecological diversity, multi-ethnicity and wide distribution of nine anopheline vectors which transmit three Plasmodial species *P. falciparum*, *P. vivax* and *P. malariae*. The fourth human parasite species *P. ovale* is not known to be naturally transmitted in India. *Anopheles culicifacies* is widely distributed and is the principal vector of rural malaria. *An. stephensi* is the primary urban vector. *An. fluviatilis* is a vector in the hills foothills while *An. minimus*, *An. nivipes*, *An. philippinensis*, and *An. dirus* are vectors in the north east and *An. sundaicus* is restricted to Andaman and Car Nicobar islands. *An. annularis* and *An. varuna* act as secondary vectors with wide distribution in India (Kumar et al. 2007).

The biological challenges posed by Plasmodium-Anopheles system have, to a great extent, been compounded by the features of human behaviour and ecology. Thus malaria control efforts are not only hampered by biological phenomenon such as evolution of the drug resistance in the parasite and insecticide resistance in the vector but also by problems related to human ecology such as urban expansion, aggregation of labour, failure of radical treatment, the destruction of forest cover and so forth (Lai, 1998).

Malaria continues to be a major public health problem in India and the state of Goa is no exception. To understand the epidemiology of malaria one must have a thorough knowledge of the local determinants of malaria in an
endemic area. This knowledge is useful in the planning and evaluation of various control measures in the area (Pandhya, 1981).

A number of studies have been carried out to correlate environmental and behaviour risk factors with malaria incidence. In this chapter, the available literature has been reviewed from the past few decades to the more recent work on various aspects of malaria in relation to physiography, climatic conditions, demography particularly population migration, vector bionomics as well as control and epidemiology of malaria.

**Physiographic features related to malaria vectors and disease endemicity**

Gracias da Silva (1994) has written a historical review of Health and Hygiene spanning over 4 centuries from 1510 to 1961 in Portuguese Colonial rule in Goa. From the Portuguese literature she has found that malaria was rampant in Goa during Portuguese regime. Epidemics of diseases such as malaria and plague were common and responsible for shifting of the capital of Goa from Old Goa town to Panaji. The author has also mentioned that dense and humid forests coupled with poor hygiene were the major causes of malaria and the consequent decay of Golden Goa. Dense forest particularly in the many areas of Sanguem ‘taluka’, stagnant pools of water in and around houses, unused wells and marshy areas along with poor sanitation were responsible for mosquito breeding that led to malaria epidemics in Goa.

Garcia (1958) also carried out studies on the Health Services in the areas of Portuguese occupation in India i.e. the territories of Goa, Daman and Diu. According to him, formerly, malaria was a real scourge in the territories of Goa especially in Old Goa, an important and popular trading town situated along the Malabar Coast. Malaria was most intense and serious problem in the
'talukas' of Quepem, Sanguem and Canacona in the Southern Goa. These places were of economic importance because of the agriculture and mining of ores. The then established Health Services carried out extensive surveys on malaria in these 'talukas'. Research and investigations conducted by them showed that *An. fluviatilis* was the predominant malaria vector which was found breeding in the slow moving streams/rivers and rice fields and supported malaria transmission in these hilly regions.

According to Borcar et al. (1967), malaria was prevalent in Goa, especially in the eastern hilly regions since very early times. It had caused havoc in the Sanguem 'taluka' in the early part of the nineteenth century. Topographically Goa has 3 longitudinal regions viz., (1) hilly region in the east, (2) the middle intermediate region and (3) the coastal region on the west. The hilly region comprised of the concelhos of Sattari, Sanguem and parts of Canacona with steep valleys and thick forests which were full of springs, streams, shallow water ponds, swamps and small irrigation canals which were ideal breeding places for the vector species of malaria. The average altitude of this hilly belt was 1000-4000 ft above mean sea level. The terrain of the intermediate region comprised of hillocks, forests and valleys where rain fed paddy cultivation was done. The altitude of most of the areas varied from 500-1000 ft above mean sea level. The coastal region had vast paddy fields and the altitude of this region was up to 500 ft above mean sea level. They found distribution of different anopheline mosquitoes at various altitudes. However, *An. fluviatilis* which was considered as the vector in Goa was collected from areas having altitude more than 500 ft above mean sea level.
D'Sa (1919) carried out investigations into high malaria endemicity in Sanguem taluka in Goa. According to him, though this region had rich natural resources in terms of forests and mines yet it was backward with a large number of huts of labourers. He found that malaria endemicity was high in the areas where no major agricultural activity was carried out and did not have proper water management. The spleen rate in children in these areas varied from 30% to 100%.

In Burundi, Coosemans et al. (1984) found high rates of malaria in less irrigated areas of the Rosizi valley. On the contrary, however, Gaddal et al. (1985) carried out studies on malaria control in the Gezia Managil irrigated scheme of Sudan and found that irrigated areas had more out breaks of malaria infections compared to that of less irrigated areas in Sudan.

Nagpal and Sharma (1986) carried out studies on incrimination of *Anopheles culicifacies* as vector of malaria in Orissa state of India. They have mentioned that topographically, Orissa has three main geographical regions having (1) hilly districts (2) plain districts and (3) coastal districts. The state was endemic to malaria with high incidence of *P. falciparum*. They undertook an extensive mosquito fauna survey covering all the three geographical areas in the entire state of Orissa. Results of the survey revealed only *An. culicifacies* among other anopheline mosquitoes were positive for the gut and gland infection. Their studies showed the prevalence of *An. culicifacies* in the villages in the hills, plains, coastal areas and urban areas. They also established its role in the transmission of malaria in Orissa. Many other studies, however, suggest that *An. fluviatilis* and *An. culicifacies* transmit malaria in hills and foothills and
plain areas respectively while An. annularis is also a vector of malaria in the coastal Orissa (Panigrahi 1942, White 1943, and Rao 1949).

Matola et al. (1987) carried out qualitative studies on climate change and malaria in the highland areas in Tanzania. They suspected that forest clearing was one of the key factors that was responsible for high malaria rates in the Usambara Mountains of Tanzania.

Kumar and Thavaselvam (1992) conducted a longitudinal study on breeding habitats and their contribution to An. stephensi in Panaji, Goa. They found that although most of the human inhabitation was on and around a hillock, topographically the breeding of this important urban malaria vector occurred practically in all areas viz., plain, foothill and hilly part of the city in a variety of habitats throughout the year.

Dutta et al. (1992) carried out a comprehensive study on the Anopheline fauna in parts of Tirap District in Arunachal Pradesh which was afflicted with high incidence of malaria. Deforestation and other developmental activities in addition to some other factors influenced gross ecological changes in this region. They found that the area was covered with deep forests and traversed by rivulets and hill streams. They captured seven species of mosquitoes, An. philippinensis, An. dirus, An. minimus, An. culicifacies, An. maculatus, An. aconitus and An. annularis in the foothills ranges (1000-1400 feet above sea level) in this district, which are recognised malaria vectors in India.

Tandon et al. (1995) carried out studies on the Anopheline fauna in Ajodhya hills of District Purulia in the West Bengal, India. Purulia was one of the malaria endemic districts of W. Bengal. In Ajodhya hills of this district, the disease posed a serious health problem and malaria transmission was
perennial. During the study they found that this hilly region was an elongated area lying between two valleys. Most of the land area was covered with forests and interspersed with many streams. There were a number of small springs and fissures in rocks through which water oozed out throughout the year. A river 'Subarnarekha' and tributary of river 'Damodar' ran along the western and northern borders of this hill. Entomological investigations revealed that the perennial transmission of malaria was due to high prevalence of vectors in the foothill areas of this region.

Chatterjee and Hati (1997) also carried out studies on incrimination of Malaria Vector on Ayodhya–Bagmundi range of Hills situated in the extreme west of Purulia district, West Bengal, India. This region was highly endemic for Malaria. During their study, they found that the average altitude of this hill area was 2200 ft above mean sea level. Most of the area was covered with dense moderate forests and sparsely inhabited. While carrying out search for anopheline vectors responsible for the transmission of malaria, they found that the fresh water pools, streams and small rain water collections provided breeding grounds for the malaria vectors in the region.

Sharma (1995) reported that in Malnad foothill areas of the Western Ghats, the evergreen forest belt of Karnataka, An. fluviatilis was the only vector which bred in the slow moving streams and maintained holoendemic malaria. This area had indigenous people who were chronic carriers of malaria and also there was high mortality in the infants, pregnant woman and non immune migrants.

Patz et al. (1998) conducted studies on climate change and malaria transmission in highland areas in Kenya. They found that soil moisture
correlated with the human–biting rate of malaria vectors with a two-week time lag which was explained as the length of time it takes for mosquito larvae to develop into adults. They also found in the same study that soil moisture correlates with entomological inoculation rate, which are the product of the human-biting rate and the proportion of female mosquitoes carrying infective parasites (sporozoites) in their salivary glands ready to be delivered to the host with a six-week time lag. Six weeks was the time period necessary for the development of the infective parasites in the mosquitoes plus the length of time the mosquito survived.

Malakooti et al. (1998) also carried out studies on climate change and malaria in highlands in Kenya. They found that deforestation might have been a reason behind changes in malaria transmission in the highlands.

Sharma et al. (1998) carried studies on the impact of Spherix (a formulation of Bacillus sphaericus B101, Serotype H5a, 5b) on the control of mosquito breeding in rural areas of Farrukhabad District in Uttar Pradesh. In some villages of this district, abnormal rise in malaria incidence was reported during the post-monsoon period. During the survey, they observed that there was no river or irrigation canal in the selected villages. The terrain was plain Gangetic with sandy soil having high water absorption capacity and did not support mosquito breeding. However, extensive irrigation was done through the tube wells for the crops grown in the area. They found that crops such as potato and sunflower which required 5-6 times watering resulted in spillage of water and aggravated the mosquito problems in the area.

Singh et al. (1988) conducted studies on malaria outbreak in Kundam block, District Jabalpur in Madhya Pradesh. During the study, they found that
the topography of the area was mostly rocky with undulating terrain covered with thick forests. Most of the villages were located near the streams and remained cut off from other villages during rainy season. The rocky pools, rice fields, borrow pits, wells and seepage with rain water collections provided opportunities for the mosquito breeding. The investigations revealed that in spite of residual sprays carried out by the health authorities, the densities of malaria vectors in this region were high due to insecticide resistance and thus resulted in an outbreak in the area.

Mya et al. (2002) conducted studies of malaria in Yeasitkan village of lower Myanmar. During the survey carried out to identify the causes of malaria, they found that half of the total area in this village was covered by dense forest. They suggested that the prevalence of malaria vectors depends upon the distribution of forest. They also suggested the high incidence of malaria may be due to the presence of a big dam near the Yeasitkan village. This dam created conducive environment for mosquito breeding as well as the growth of vegetation which helped in increasing the mosquito densities.

Das et al. (1998) carried out studies on the mosquito fauna and breeding habitats of Anophelines in Car Nicobar Islands in India. This small flat island with an area of 127 sq. km. situated in the Bay of Bengal had posed a serious problem due to malaria. They found that the island was made up of corals. The island had 60 % of forest cover. There were seven live creeks; thick growth of mangroves, small streams emerged in northern and southern regions inside the jungle of the island influenced by tides, several water bodies and marshy areas. The results of their faunastic studies revealed that the above ideal environmental conditions along with suitable climatic conditions supported the
anopheline mosquito fauna especially the predominant vector, *An. sundaicus* and the malaria transmission in the area.

Pant et al. (1998) conducted studies on the prevalence of malaria and ABO Blood Groups in the sea port areas of Raigad district of Maharashtra. They confirmed the prevalence of malaria and distribution in various blood groups from the coastal region of Raigad district.

Das et al. (2002) in their studies carried out on mosquito fauna and breeding habitats of Anophelines in the Little Andaman and Nicobar Islands, India found that most of the areas of the Little Andaman were covered under thickly vegetated forest with tropical rain forest and natural vegetation. About 10% of the total area was covered by tidal flat areas, mangrove swamps and beaches and about 63% of the area was coastal plains. The central and southern portion of this island was undulating to moderately hilly area. The mangrove forests were wide spread along the coasts and in the estuaries of many creeks. The streams, forest nullahs, creeks, marshy area, mangroves and ponds were observed as the perennial sources of mosquito breeding. In their studies, they highlighted the breeding status of different Anopheles species in addition to *An. sundaicus* the malaria vector of this region.

Mohite et al. (2002) conducted studies on clinical analysis of malaria cases treated at MGM hospital, Navi Mumbai. The findings of the epidemiological study indicated that Navi Mumbai had higher mosquitogenic potential and incidence of malaria than other areas. There were about 136 quarries in the area. The land was marshy and low lying and resulted in the stagnation of water which was conducive for mosquito breeding along with other factors such as man made habitats created during construction activities,
small rain water collections, poor drainage facilities etc which helped in the transmission of malaria in the area.

Swarnakar and Dashora (2002) conducted longitudinal studies on prevalence of malaria vectors in Southern Rajasthan in India. This region experienced malaria epidemics. During the study, they found that the region was typically arid and semi arid consisting of dry sand desert areas interspersed with fertile plains and plateaus as well as forest clad hills. The Aravalis formed the main hill range of this region which was 1219 m above sea level. There were innumerable perennial and monsoon streams and lakes in the undulating landscape of hilly and plateau areas. On the basis of physiography and climate, Rajasthan was divided into four natural regions i.e., eastern plains, western desert plains, hilly regions and plateaus. With the introduction of Indira Gandhi Canal, the Western desert region was transformed into that of greenery. Similarly, Eastern plains and plateaus introduced with many irrigation schemes and industrial projects produced a very high potential of vector mosquitoes. However, their studies indicated that the prevalence of mosquito species was depended on the availability of natural breeding waters in an ecosystem. They found that along with other factors, the hilly and plateau areas which had many slow moving streams and stagnant water bodies provided facilities for the breeding of An. fluviatilis and An. culicifacies mosquitoes and supported the malaria transmission in the area.

Singh et al. (1989) carried out studies on bioenvironmental control measures of malaria in a tribal area of Mandla District in Madhya Pradesh, India. They found that had almost all villages were located either on low hillocks or in shallow valleys with a number of perennial streams and tributaries. There
were numerous natural depressions which resulted in stagnant water collections retained for long periods in the area. Primitive methods of rice cultivation were followed. Patches of swamps and seepage existed all along the streams and tributaries. Though rice was grown, there were no irrigation facilities. Their studies revealed that the Bizadandi block of District Mandla had high prevalence of malaria with high densities of *An. culcifacies* and *An. fluviatilis*. They found out the cause of potential mosquitogenic factors in the Bizadandi block were rocky hills which were subjected to continuous soil erosion thus providing breeding places to the vectors.

Dutta et al. (1989) carried out entomological studies to determine the prevalence of anopheline species *An. dirus* and their vectorial role in the transmission of malaria in the Northeast India. They studied a small foot hill area of Changlang district in Arunachal Pradesh. Close to this area were deep forests traversed by rivulets and hill streams. Small stagnant water pools and water collections in elephant’s foot prints in open jungles supported the breeding of anopheline vector, *An. dirus* in the area indicating the high risk of acquiring malaria in the forest areas.

Yadav et al. (1989) carried out studies on the Anopheline Fauna of Kheda District in Gujarat. They found that several factors like perennial irrigation and multiple cropping coupled with increased water logging due to seepage and poor drainage resulted in extensive mosquitogenic conditions in the area. Vast ecological changes had taken place in the area due to intense irrigation and developmental projects. Results of their study on mosquito ecology in various types of aquatic habitats reported maximum number of...
anopheline species recorded from the canal irrigated areas followed by the riverine areas and the non-canal irrigated areas.

Woube (1997) studied the geographical distribution and grammatic increase in incidence of Malaria and consequences of the resettlement scheme in the Gambela area in SW Ethiopia. He found that the Gambela area was crossed by many rivers and streams. This vast area remained wet throughout the year. The geomorphology and flat topography of the area made it favourable for mosquito breeding through out the year. There was diversity in the topography of the land; the Eastern region had landscape of hills and valleys and was less conducive for larval development and low malaria endemicity. The middle flat landscape which had rivers, streams, small ponds and swampy areas favoured mosquito breeding and supported malaria transmission through out the year, however the Western landscape which was marshy and swampy with lakes and flooded areas was the most permanent malarious area. According to him, the clay soils were characterized by the physical (hard pan) and chemical (iron-magnesium-Fe₂Mg) properties which made them capable of holding water for sufficient periods of time favoured the development of mosquitoes. He pointed out that the geographical characteristics such as altitude, topography, surface water along with other factors were responsible for the rapid breeding of mosquitoes and spread of infectious disease in the area.

Malhotra et al. (1992) carried out studies on enhancing the efficacy of Gambusia affinis to control mosquito breeding in Ponds in the Bhabar and Terai areas of district Nainital. Both these areas were well known for high transmission of P. vivax and P. falciparum malaria. During their study, they
found that the Bhabar area had scarce water resources as the soil was porous and had a high content of sand, pebbles and stones. This area was situated in the foothills with deposition of detritus material. According to them, the porous soil did not retain water long enough to support mosquito breeding. However, the transmission of the disease was supported by the malaria vector, *An. culicifacies* which was found breeding in innumerable small ponds/pokars in the area.

Dutta et al., (1997) carried out faunastic studies in Goalpara District of Assam which reported high incidence of Malaria. The malaria cases were reported mostly from the foothill areas bordering Meghalaya. The entomological studies conducted in the Agia PHC area of this district confirmed the role of *An. minimus* as a vector of malaria which was found in the foothill areas of this region.

Das et al. (1997) undertook epidemiological and entomological investigation of malaria outbreak at Tamulpur PHC, Assam. They found that the Tamulpur PHC, under Nalbari district lies on Northwest part of Assam and shared International border with Bhutan. The area was low lying. It was intersected by ‘katcha’ nallahs, streams having aquatic vegetations, ditches, ponds and paddy fields. During their surveys, they found profuse breeding of *An. culicifacies* and *An. minimus* in the slow flowing ‘katcha’ nallahs, streams and paddy fields and indicated their role as vectors causing malaria epidemic in the area.

In another study carried out by Shukla et al. (1998) on the bionomics of *An. fluviatilis* and its sibling species, it was found that in District Nainital in Uttar Pradesh, there were two long narrow belts of land with markedly different
physical features in the foothills of Himalayas. Immediately, touching the foothills, was the Bhabar area which had a waterless belt of porous and sandy soil with a width ranging from 10 -15 km and adjoining to it was a wet belt having wet, clay like soil about 13-16 km wide known as Terai. They observed that the breeding of *An. fluviatilis* was supported by water sources in the Terai region which had artesian (irrigation) drains, streams and water reservoirs.

Yadav et al. (1997) conducted a longitudinal study on the mosquito breeding and resting in tree holes in forest ecosystem in Orissa. They found that though the tree holes supported the breeding of several mosquito species, mainly *Ae. albopictus* however a small population of the malaria vectors, *An. culicifacies* and *An. fluviatilis* was also found breeding in the tree holes in the forest ecosystem.

**Meteorological factors and malaria**

Pampana (1969) in his review on Malaria Eradication has mentioned that the three main climatic factors, temperature, precipitation and relative humidity affect malaria. Temperature affects many parts of the malaria life cycle. The duration of the extrinsic phase depends on temperature and on the species of the parasite the mosquito is carrying. The extrinsic phase takes least amount of time when the temperature is 27°C. Rainfall affects the malaria transmission as it increases relative humidity and modifies temperature, and also affects where and how much mosquito breeding can take place. Though relative humidity does not affect Plasmodium parasites, it affects the activity and survival of Anopheline mosquitoes, thereby affecting the malaria transmission. According to Pampana, it is believed that if the average monthly relative humidity falls below 60%, the life of the mosquito would be so shortened that there would be
no malaria transmission. Instead of changing the amount and rate of transmission of the vectors and parasites that already exist in a certain location, changing the climate of an area can allow the introduction of different vectors and parasites that may be more efficient. Since *P. malariae* and *P. ovale* have longer extrinsic cycles some mosquitoes do not live long enough to transmit them. However, if environmental conditions change in ways that would increase the survival time of those mosquitoes then they would be able to transmit other species of malaria that were not present in that area before.

Covell, 1928 in his review, on the basis of studies on treatment of malaria cases at various institutions in Bombay has explained about the seasonal distribution of malaria in Bombay. The lean malarious month of the year was usually March whereas the incidence was slightly higher in April, and remained practically constant throughout from April to June. The malaria season began in the latter half of July and from then increased steadily to its highest peak in October. The months of September and October were the two most malarious months. In November, the number of cases decreased rapidly and continued till the minimum number was reached in the month of March. The results of adult collections when compared revealed that until the latter part of June, the adult Anophelines of all species were extremely rare. However, the numbers began to increase at the beginning of July along with collection of the first infected specimen in the second week of July which indicated a significant correlation between the malaria incidence and vector.

Fontaine et al., (1959) carried out studies on malaria epidemic in Ethiopia in the year 1958. They found that the increasing temperature and relative humidity were responsible for the epidemics in the area. However,
Khaemba et al. (1994) in their studies on 'Malaria in a Newly Developed Highland Urban Area' claimed that increasing drug resistance was one factor responsible for the malaria epidemic.

Russell et al. (1963) in their review on Practical Malariology mentioned that the life cycle of *P. falciparum* is limited if the temperature is below 20°C. However, malaria transmission can still occur in areas colder than 20°C because Anophelines often live in houses, which tend to be warmer than external temperatures. Larval development of the mosquito also depends on temperature. Though some contend that the amount of rainfall may be secondary in its effects on malaria related to the number of rainy days or the degree of wetness they found that malaria was dependent on the ground water level in that area. According to them, winds may play both negative and positive roles in the malaria cycles as very strong winds can decrease biting or oviposition by the mosquitoes, while at the same time extend the length of the flight of the mosquitoes. However, during the monsoons, winds have the potential to change the geographic distribution of mosquitoes and consequently transmission of malaria in newer areas.

Borcar et al. (1967) while carrying out malaria eradication campaign, found rainfall pattern varying in the three different regions of Goa. The annual rainfall in the hilly region usually varied from 184 to 212 inches, whereas the average rainfall in the middle intermediate region varied from 154 to 160 inches and in the coastal region it ranged from 128 to 142 inches. According to them, malaria transmission in Goa lasted from mid June to December with *An. fluviatilis* as the main malaria vector.
Loban & Polozok (1985) in their review on malaria stated that in countries with tropical climate malaria is transmitted all the year round, whereas in sub tropical and temperate zones transmission is limited to summer & autumn. The sporogony cycle in the female anopheline mosquito may be completed only at a temperature higher than 16°C and accelerates at higher temperature. In hot climatic conditions, digestion of blood by the female mosquitoes is faster and females feed more often on humans and produce more oocysts which accounts for higher intensity of infestation of the vector by sporozoites. This explains a high degree of malaria transmission in tropical and sub tropical countries wherein the ambient temperature creates optimal conditions for mosquitoes.

Matola et al. (1987) carried out studies on the changed pattern of malaria endemicity and transmission at Amano in the north eastern Tanzania. They suspected that climate change associated with forest clearing was related to the increased malaria rates in the Usambara Mountains of Tanzania.

Oaks et al. (1991) revealed that for a given Plasmodium species, if the temperature decreases, the number of days necessary to complete the extrinsic cycle increases. Since the *P. vivax* and *P. falciparum* have the shorter extrinsic incubation period they are more common than *P. ovale* and *P. malariae*. They opined that the Anopheline mosquitoes breed in water habitats requiring just the right amount of precipitation for mosquito breeding to occur.

Singh et al. (1995) in their studies on the longevity of a malaria vector *Anopheles culicifacies* Giles, 1901 in Doon Valley found that the mosquito survival was noted maximum at 10–13°C temperature and at 100% humidity and minimum at 20% humidity. The survival rate was found to increase from
minimum when the humidity increased from 40 to 80%. They inferred on basis of their laboratory evaluation that relative humidity, temperature and predation influenced the longevity of the vector, An. culicifacies.

Martens et al. (1995) carried out studies on the Potential Impact of Global climate change on malaria risk. They found that higher temperatures increase the number of blood meals that are taken as well as the number of times eggs are laid by the mosquitoes and thus help in population build up at faster rate. Therefore the rising temperatures may lead to acceleration of transmission of malaria in the regions where it was non existent due to lower temperatures.


Bouma et al. (1996) carried out studies on falciparum malaria and climate change in the North West Province of Pakistan. Based on their studies, they found that in the month of December, the climate parameters viz, rainfall along with humidity predicted malaria rates fairly well in the area.

Malakooti et al. (1997) carried out studies on Re-emergence of epidemic malaria in the highlands of western Kenya. They claimed that the climate was not the factor for malaria transmission in the area, as the average temperature and rainfall did not change during the time when the malaria rates changed. According to them, deforestation might have been the reason behind changes in malaria transmission intensity in that area.
Three studies on malaria epidemics were carried out in different parts of the highlands of Kenya. Kigotho (1997) carried out malaria studies in Kenyan highlands and found that increased rainfall was related to malaria epidemics. Woube (1997) carried out study on Geographical distribution and dramatic increases in the incidences of malaria and the consequences of the resettlement scheme in Gambela, SW Ethiopia. The epidemic of malaria was attributed to higher temperatures, rainfall and relative humidity as compared to the previous years in the area. However, Woube found that there was excess rainfall in 1993 but no malaria epidemic occurred, whereas in 1984-85 there was high malaria incidence but very little rainfall was reported in the same area. His study revealed that although the epidemic was associated with higher rainfall, it was not always true for that area.

Fonteneille et al. (1990) and Mouchet et al. (1997) carried out studies on malaria epidemics in Madagascar. They related the epidemics to the factors such as lack of anti-malaria medications, lack of control techniques and low levels of immunity in the population. However, a study carried out by de Zulueta, (1994) during a malaria epidemic in Madagascar showed that the epidemic was caused by anthropogenic climate changes although no statistics were presented in support of this assertion.

Marimbu et al. (1993) carried out studies on the contribution of environmental factors to malaria in Burundi. According to them, the increasing temperatures and malaria transmission were correlated in the Burundi area.

Freeman (1994) carried out studies on malaria outbreak in Manyuchi Dam, in Zimbabwe. He found that near the Manyuchi Dam, although many
other factors could also be contributing to the outbreak, higher winter temperature was one of the factors responsible for increase in malaria rates.

A large group of studies have related the El Nino Southern Oscillation (ENSO) to malaria epidemics. According to the studies carried out by Bouma et al. (1994); Kilian et al. (1999); Bouma and Van der Kaay (1995); Bouma et al. (1995) malaria epidemics in the former British Punjab, Pakistan, Sri Lanka, the highlands of Uganda, Columbia, Argentina, Ecuador, Peru and Bolivia, were proposed to be associated with ENSO cycles. Many areas which have experienced periodic malaria epidemics every five to eight years may have been related to the ENSO cycle.

Patz and Lindsay (1999) carried out studies on the impact of climate change on infectious diseases. According to them, the effects of temperature on both malaria vectors and parasites were easily seen in the latitudinal and altitudinal boundaries to malaria transmission. Many highland areas experienced malaria epidemics in the past few years as the boundaries were changing. From their studies, they hypothesized that the increasing temperatures along with many other compounding factors could be part of the reason for malaria transmission at high altitudes.

Githeko et al. (2000) assessed the evidence for the part and current impacts of inter annual and inter decadal climate variability of vector borne diseases on a continental basis with the aim of shedding light on the increased likelihood of climate change. As per their views, the average global temperature will rise by 1-3.5°C. This will increase the likelihood of many vector borne diseases in newer areas. Although investigations made on the climate change and the resurgence of malaria in the East African highlands by Hay et al. (2002)
has revealed that if climate was not changed at the study sites, then the other changes must have been responsible for the increase in malaria.

Kumar and Thavaselvam (1992) conducted a longitudinal study on the breeding of *An. stephensi* in different habitats in Panaji, Goa. In urban areas, this species was found breeding in a variety of domestic and peridomestic habitats and maintained malaria transmission at very low densities. Their studies on seasonal prevalence of *An. stephensi* immature breeding showed that breeding was detected throughout the year with a peak in June in different habitats. They also found that the breeding of *An. stephensi* was associated with the rainfall. With the onset of rains, the additional breeding habitats became available and intermittent rains and dry spells favourably supported vector breeding. However, when rainfall was continuous and heavy, the breeding potential was lowered due to the flushing effect.

Tandon et al. (1995) in Purulia, West Bengal found that the anopheline density was highest during the summer and lowest in the monsoons which they attributed to extremely inclement weather due to heavy rains and frequent Northwest winds. Their investigations revealed that out of the six vector species, *An. culicifacies* was predominant and was found in sufficiently high density during the summer and the monsoons, whereas the prevalence of *An. fluviaitilis* was relatively low in the corresponding seasons, though a considerable increase in the density of this species was noticed in the winter.

Singh et al. (1988) investigated malaria outbreak in Kundam block of Jabalpur District in Madhya Pradesh, India. They found that during the period of outbreak, there was heavy rainfall in the months of late August and September which resulted in creation of vast areas for mosquito breeding. Though
systematic meteorological records were not available, information gathered from sources revealed that the average rainfall in the area was about 1400 mm. The rainy season began from June and lasted till the end of September. Total rainy days varied from 60-70. The minimum and maximum temperatures during winter and summer were in the range of 5-25°C and 25-42°C respectively. The results of their study showed that with the onset of winter, downward trend of *An. culicifacies* and *An. fluviatilis*, densities was observed, whereas an increasing trend in the density of the secondary vector *An. annularis* was observed during that period of the year due to the favourable weather conditions.

Studies of Mohite et al. (2002) conducted on epidemiological and clinical analysis of confirmed malaria cases treated at MGM Hospital, Navi Mumbai showed high prevalence of malaria reported every month in this city. A good number of malaria cases were reported during the rainy season from July to November which was the peak transmission season. According to them, the high incidence of malaria in the region was due to the prevailing climatic conditions viz., the rainfall, and suitable temperature in winter (20°C to 30°C) which was favourable to the parasite growth and humidity more than 60% that favoured the longevity and activity of mosquitoes. Other factors such as man-made water habitats in construction sites, water accumulation in low lying areas, rain water collections, etc. made conditions conducive for vector breeding. As a result, high incidence of malaria was reported in the rainy as well as post rainy seasons i.e., from July to November.

Sharma et al. (1998) carried out studies to assess the impact of Spherix (*Bacillus sphaericus* B-101, Serotype H5a, 5b) spraying on the control of
malaria vector *An. culicifacies* breeding in Rural Areas of Farukkhabad District, Uttar Pradesh. During their survey, they found that the average annual rainfall in the area for two consecutive years 1993 and 1994 was 450 mm. The number of rainy days was 37 and 45 during these two years respectively with small precipitations in the beginning of the year. The temperature ranged from 6 to 45°C and the months of May and June were the hottest. Results revealed that during the first six months of the study i.e. from April to September 1993, the densities of total mosquitoes and of anophelines remained low in the experimental area as compared to the control area. Thereafter, the densities were comparable. The higher mosquito vector densities during July and August 1994 were attributed to high rainfall (522.4 mm) and more number of rainy days (30) as compared to the corresponding months of the previous year in which only 112.4 mm rainfall in the 18 rainy days was recorded. The anopheline mosquitoes including the malaria vector *An. culicifacies* attained high densities and peak during the monsoon season i.e. from July to October.

Das et al. (1998) reported that the in Car Nicobar Island, India tropical conditions existed as the climate was hot and humid with the temperature varying from 25 to 32°C and relative humidity from 70 to 90% which were conducive for *An. sundaicus* proliferation and malaria transmission. The annual rainfall in this island ranged from 2500 to 4000mm distributed mainly from May to December and was very less from January to April. In a mosquito fauna study carried out by Das et al. (2002) in Little Andaman Island, India they observed that climate of the Little Andamans was conducive for mosquito breeding and proliferation especially of the vector *An. sundaicus*. 
Bryan et al. (1996) studied malaria transmission in relation to climate changes in Australia. Although endemic malaria was eradicated from Australia by the year 1981, the transmission of imported cases occurred and natural vectors *An. hilli* and *An. farauti* sensu lato still existed in the country. They investigated the present and future distribution of *An. farauti* sensu stricto (s.s.) or number one of the three species belonging to *An. farauti* sensu lato an important vector with the CLIMEX (climate matching model) and the method of Hutchinson to infer meteorological data. The potential distribution of *An. farauti* s.s. was estimated under the recent climate change scenario for the year 2030, with an increase of 1.5°C in temperature and 10% rise in summer rainfall in northern Australia. They predicted that the potential distribution of *An. farauti* s.s. would extend further over 800 km towards south thus encompassing more non endemic areas under the risk of malaria transmission.

Dev et al. (2003) illustrated malaria transmission dynamics in the North Eastern region of India by plotting the malaria parasitic incidence data of a selected model PHC of Kamrup district of Assam in relation to meteorological indices for four years (1991-94). They found that malaria was prevalent during all months of the year and there were distinct peaks noticed between May to September marking high transmission periods. During the peak transmission period the relative humidity was 63% to 89% and the difference between maximum (33°C) and minimum (22°C) temperatures were uniform and less marked thus rendering the environment conducive for vector proliferation and longevity. In April there was a gradual increase in the number of malaria cases (largely *P. falciparum*) followed by a steep rise in June/July. Thereafter, there was a steady decline till September/October, which corresponded to the
cessation of monsoons. In the winter season, though there was a further
decline in number of cases, low levels of transmission continued. The infant
parasite rate for all the months of the year supported by entomological findings
affirmed the perennial transmission in the region.

Kamal and Das (2001) carried out the correlation of climatic factors and
the incidence of malaria in the tribal villages of Darrang district, Assam which
experienced persistent transmission of malaria. They found that the climate
was hot and humid for most part of the year except from November to February
which was the cold season. High rainfall during the transmission period was
responsible for increased breeding places of An. minimus, the malaria vector of
this region. Their findings revealed a positive correlation between rainy months
and high malaria incidence (coefficient equal to 0.649). This coupled with
favourable temperature and humidity led to heavy transmission of the disease
in the area.

Yan et al. (2005) in their climatic studies carried out in Kenya have found
that open, treeless habitats experience warmer mid day temperatures than
forested habitats and also affect indoor hut temperatures. As a result, the
gonotrophic cycle of female An. gambiae when compared with forest sites was
shortened by 2.6 days and 2.9 days during the dry and rainy seasons
respectively.

Patz and Olson (2006) carried out studies on malaria risk in relation to
temperatures in the East African highlands. They found that the minimum
temperature for development of parasites of P. falciparum and P. vivax was
approximately 18°C and 15°C respectively. However, the spread of malaria was
limited at higher altitudes owing to low temperatures as the altitude increased.
According to Bodker et al. (2003) there was a relationship between increasing altitude and decreasing mosquito abundance in Africa highlands. They found that changing landscapes could significantly affect local weather more acutely than long term climate change. However, Gibbs et al. (2005) found that land cover change could influence microclimatic conditions, including temperature, evaporation and surface run off. These were all keys to determine mosquito abundance and survivorship.

Similar findings have been documented in Uganda by Wilson et al. (2000). They found that the temperatures were higher in communities bordering cultivated fields compared with those adjacent to natural wetlands, and the number of *An. gambiae* s.l. per house increased along with minimum temperature after adjustment for potential confounding variables.

Munga et al. (2006) also observed that the higher maximum and mean temperatures of aquatic breeding sites found in farmlands had hastened larval development and adult mosquito population rates.

Pascual et al. (2006) in their studies on warming trends and malaria in the East African highlands observed the "biological amplification" of temperature effects. They found that a mere half degree centigrade increase in temperature trend could translate into a 30% to 100% increase in mosquito abundance.

**Malaria in relation to Developmental Activities**

Besides climatic factors, other factors such as urbanization, irrigation, agricultural practices, deforestation, etc. often confound the effect of meteorological variables on malaria, it is therefore important to understand them and their relationship with malaria.
Covell, 1928 in his review on malaria in Bombay mentions that *An. stephensi* which is the transmitter of urban malaria in India, held the same position as of *An. bifurcatus* in Palestine. It bred in unprotected cisterns not only in Bombay but in every town of India provided with a piped water supply which was followed by an increase in malaria incidence. According to him, the importance of this fact should be widely made known to all hydraulic engineers with regards to malaria control, which otherwise would pose grave danger just as in the case when irrigation projects are not accompanied by adequate schemes of drainage.

Pattanayak et al. (1985) in their studies on malaria paradigms in India and control strategies state that more and more dwellers in periurban areas are becoming exposed to a high risk of malaria.

Sharma et al. (1985) carried out studies on malaria in hutments of Delhi. They had found malaria was one of the most common causes of morbidity and the hutments constituted an important source of infection. The infection had also spread to other localities with improved sanitation and higher standards of living. According to them, the malaria incidence was due to rapid industrialization, large scale construction activities and employment opportunities which induced people to move to Delhi in large numbers. Many labour groups came from malaria endemic states, including regions with high *P. falciparum* incidence and also from regions having chloroquine resistance to *P. falciparum*. They stayed in temporary hutments in clusters and were scattered all over Delhi. These hutments had high malariogenic potential and poor sanitation facilities. They incriminated *An. stephensi* as the malaria vector that was found breeding in and around the construction sites and close to hutments.
in Delhi and the species indeed was responsible for malaria out breaks in the area.

Similar studies were carried out by Dhir (1969) and Choudhary (1984) reporting outbreak of malaria in Delhi caused by breeding of *An. stephensi* in construction sites. Pattanayak et al. (1977) in their study had also described the association of *An. stephensi* with local outbreaks of malaria in construction complexes in Delhi.

According to Kondrashin (1992) the urban population of the countries of Southeast Asia constituted about 23% of the total population, the highest being in India (25%) and the lowest in Bhutan (6.4%). However, it has been estimated that the urban population of Southeast Asia Region would reach 52% of the total population by 2025. The problem of urban malaria was confined mainly to the Indian sub continent. *An. stephensi* is the principal vector in urban areas of India. In the mid 1970's, urban malaria constituted not less than 10% of total malaria incidence in the country. Urban malaria constitutes about 50% of total malaria cases in Tamil Nadu state while 66% of total malaria cases of West Bengal state were contributed by Calcutta city itself.

Kondrachine and Trigg (1997) in their global review of malaria mention that urban dwellers of all age groups are under the risk of malaria in certain areas in South Asia (e.g. India, Pakistan) and Africa (e.g. Congo, Zaire). *Anopheles stephensi* is fully adapted to the urban environment, except for some cities of South Asia where malaria transmission does not occur even in well established densely populated areas. However, many tropical cities are surrounded by rapidly growing slums, such periurban areas leads to increased
malaria transmission. Urban and periurban areas contribute to 10 to 20% to the overall malaria incidence in certain countries.

A study conducted by Sharma S.N. (1993) in Faridabad showed that Faridabad town contributed 38.7% of total malaria and 38.2% Pf malaria in the entire Faridabad district. Malaria could also be an occupational hazard for the construction workers who live close to the construction complex in the hutment and are exposed to the vector bites that may be breeding in the stagnant water in these complexes. The work force itself serves as reservoir of infection. For example, in Delhi Adak et al. (1994) studied outbreak of malaria in a hotel construction site and found SPR of 60.1% SFR of 44.1 % and Pf% of 73.5.

According to Kumar (1997), towns contribute about 15% of total malaria in India. In 1982, malaria problem in labour hutment in Delhi was investigated and it was found that 39.6% fever cases had malaria of which 16.3% had P. falciparum infections. Age and sex wise distribution showed that malaria was prevalent in all age classes of both sexes (Sharma et al. 1985a). While overall infant parasite rate was 7.83%, it was as high as 94.1% in age group of 15-24 years.

Martens and Hall (2001) in their studies on malaria related with population move and transmission mention that the world's urban population is growing at four times the rate of the rural population. Urban pull is prevalent throughout the developing world, with rural-to-urban migration taking place faster than ever before. Sub-Saharan Africa is the most rapidly urbanizing region in the world, and the urban population in India has doubled in the last 2 decades. Although water pollution in urban areas usually leads to decreases in
vector populations, however some vectors, such as An. arabiensis in the forest belt of West Africa, may adapt to breeding in polluted waters. In Asia, An. stephensi is proving adaptable to urban conditions, and in India it is a well-established vector of urban malaria. In urban areas of India, water is not supplied regularly and is stored in houses, providing extensive breeding places for An. stephensi in overhead tanks and cisterns. In the peri-urban areas, where 25% to 40% of the urban population lives in poor housing without proper water supply and drainage, another vector, An. culicifacies, also transmits malaria. When accompanied by adequate housing and sanitation, urbanization leads to a decrease in malaria through reductions in human-vector contact and vector breeding sites. However, in developing countries, rapid, unregulated urbanization often leads to an increase in or resumption of malaria transmission because of poor housing and sanitation, lack of proper drainage of surface water, and use of unprotected water reservoirs that increases human-vector contact and vector breeding.

Sharma (1996a) carried out studies on Re-emergence of malaria in India. According to him, in India with industrialization, urbanization has followed. In the eradication era, urban areas had not experienced much malaria in the past and so limited efforts were made for controlling malaria in those areas. In the 1990s, however due to an increase in industrial growth, many forest areas where malaria was endemic were cleared and those areas were developed. Since, these areas were easily accessible, migration of non-immune people in those areas created an environment for malaria epidemics.

Sharma (1996b) also highlighted the impact of ecological changes on vector borne diseases and mentioned that the expansion of urban areas was
unplanned and poor people lived in unsanitary conditions. This created the right
environment for malaria epidemics, caused by increase in *An. culicifacies*
breeding in clean rain waters on the ground surface and *An. stephensi* breeding
in wells as well as in intradomestic containers. The author opined that the
expansion of *An. stephensi*, distribution in urban areas was related to the
spread of piped water systems throughout the country over the past four
decades in more and more towns and peri-urban areas.

Sethi et al. (1990) carried out studies on the role of migratory population
in maintaining endemicity of malaria in metropolitan cities of India. According to
them, peri-urban malaria was a new malaria paradigm as migrants often had
chronic malaria and with poor environmental conditions in their temporary
settlements, they fostered the mosquito breeding and malaria transmission in
the urban areas.

Kumar (1997) wrote a review on Urban Malaria and its control in India.
According to the author, malaria has emerged as a major public health problem
in many small, medium and metropolitan cities in India. It had assumed serious
proportions in the states of West Bengal, Andhra Pradesh, Gujarat, Rajasthan,
Tamil Nadu, Maharashtra and Goa. Many major towns viz; Ahmedabad,
Baroda, Chandigarh (UT), Delhi and Chennai have also reported increased
incidence of malaria due to urbanization. In most of these places, the two
vectors involved in the transmission of malaria were the type form of *An.
stephensi* in the core area of the cities supplemented by *An. culicifacies* in the
peri-urban areas. These two potent vectors complimented each other’s role in
maintaining malaria transmission in and around cities. The author summarises
that urban malaria is essentially a man-made problem which is the outcome of
rapid and haphazard expansion of the cities, inadequate piped water supply, and storage of water in cisterns, disuse or scarce use of wells, developmental activities and aggregation of migrant labour and over all population movement.

Kumar et al. (1991) carried out a study on Malaria related to construction activities in Panaji, the capital city of Goa which had experienced a severe outbreak of malaria in 1986 and the following years. The focus of malaria which was initially confined to a labour camp near a major construction site in the Campal area had gradually spread to the entire city in 1987. The survey in these labour camps revealed that most of the construction workers had migrated from states outside Goa and were residing in hutments close to the construction sites where *An. stephensi* breeding occurred in masonary tanks and curing as well as rain water collections occurred. The study showed that the tropical aggregation of labourers and the buildings under construction were the main problem areas which enhanced vulnerability and receptivity of area and created malaria foci. Inference was that the wards of the city which had accelerated construction activity had many fold malaria (x14) than others which had lesser amount of construction activity.

Sharma (1996b) carried out relative studies on ecological changes and vector borne diseases. He found that *An. culicifacies* took over *An. fluviatilis* when irrigation was implemented in an area in Uttar Pradesh and created more problems as *An. culicifacies* was resistant to DDT and HCH. Similarly the Sardar Sarovar irrigation Project on the River Narmada, which was intended to irrigate 1.8 million hectares in drought prone areas of Gujarat and Rajasthan, also caused the invasion of *An. culicifacies* and *An. fluviatilis*, thereby extending
the malaria season and changed the area into an endemic malaria region with a ten to fifteen fold increase in malaria.

Tyagi and Chaudhary (1997) carried out studies on malaria in the Thar Desert. Many different canal projects carried out in the area stimulated agricultural production through increased irrigation. They found that due to seepages from the canals, 860 hectares of land was permanently inundated, 1000 hectares was converted to marshy land, and there was a rise in water table along with growth of hydroponic weeds, which increased the preferred breeding grounds of An. culicifacies. Earlier, the same area which was dominated by An. stephensi, a desert species, was now found with An. culicifacies breeding in and around the canal areas. According to them, the increase in malaria was due to the mismanagement of the widespread developmental activities of canal based irrigation in the area.

Sharma and Hamzakoya (2001) carried out larval studies in Lakshadweep Island, in India which was endemic for malaria. During the survey they found that the topographical features of the Lakshadweep Islands were devoid of any natural breeding sites like streams, swamps and marshes thus restricting the diversity of mosquito fauna. However, only those mosquito species could become endemic which could afford to breed in man–made habitats. According to them, An. stephensi (type form) the vector of urban malaria had posed an immediate threat not only to the Lakshadweep islands but also to the adjoining Maldives Islands. It showed a southward geographical spread on the Indian mainland due to rapid urbanization and water storage practices.
Population Migration and Malaria

Kondrashin (1992) while reviewing the malaria situation in the WHO South East Asia Region opined that the exact extent of population movement was not known, however it was estimated that the degree of internal migration within India was much greater and amounted to not less than 15 to 20% of the total population every year. Migration of population was viewed as a serious public health problem because it usually increased the spread of disease. The uncontrolled population movement caused operational constraints thus resulting in obstructing malaria control measures, development and spread of resistant malaria, establishment of urban malaria and changing epidemiological pattern of the disease. Unemployment was one of the major factors in the malarious country contributing to the phenomenon of population movement and was closely related to malaria problem. The enormous increase in population had resulted in increasing the number of landless farmer and promoting migration to urban areas or to those areas with previously uncultivated lands. It was observed that the risk of acquiring malaria was considerably higher among mobile workers and among those exposed to mosquito bites in the open air on account of their occupation. Malaria epidemics occurred mainly among non-immunes when they moved into highly malarious areas as was seen in Myanmar and Thailand. Malaria epidemics were also reported particularly in areas in Nepal where population movement and developmental activities took place and were instrumental in the re-establishment of malaria endemicity in areas previously freed from malaria.

Kumar et al. (1991) while carrying out studies on malaria related to construction activities in Panaji, Goa had found that the construction activity in
Panaji had increased enormously during 1980s. Survey in the labour camps revealed that the labourers had migrated from 13 states of India of which 72.5% were only from Karnataka state belonging to Bijapur, Hubli, Dharwad and Belgaum districts and resided in hutments close to the construction sites. A large number of malaria cases were found amongst the labourers who had come from many malaria endemic areas and were engaged in the construction of multi-storeyed complexes and construction of two bridges in the capital city. Some of these labourers revisited their homes once in six months or once every year or once in two years, etc and also frequently moved within Goa. The mosquito surveys in different construction sites revealed extensive An. stephensi breeding in the different habitats at the construction sites. The study showed that the migrant labourers were a major vulnerable risk group for contracting malaria in their place of work.

Migration and tropical aggregation of labour are common in developmental projects i.e. Railways, Dams, irrigation canals, etc., wars, famines floods, strifes, gem mining and in International border areas especially in the South East Asia.

**Geographical Reconnaissance of breeding habitats of Mosquito immature**

Larval Sampling of Mosquito immature breeding habitats: According to Oaks et al. (1991) a little is known about the biology of the aquatic phase of Anopheline mosquito breeding. However, there are innumerable studies on breeding ecology of mosquitoes in larval habitats. Nagpal and Sharma (1995) have described that different Anopheline mosquitoes prefer different types of water bodies in which they breed.
Gupta et al. (1992) carried out longitudinal studies on the intradomestic mosquito breeding sources and their management in Nadiad taluka of Kheda district, Gujarat. Their search of intradomestic breeding sources revealed the breeding of seven mosquito species, viz., *An. culicifacies, An. stephensi, An. annularis, An. subpictus, An. barbirostis, Cx. quinquefasciatus* and *Ae. aegypti*. Both *An. culicifacies* and *An. stephensi* were observed breeding in intradomestic containers regularly in spite of the free access to peripheral breeding sources. *An. stephensi* was found pre-dominantly breeding in almost all types of containers, which indicated the potential and preference of *An. stephensi* to breed in intradomestic water collections particularly in urban or semi urban areas and its role in the transmission of the disease.

Mariappan et al. (1992) carried out extensive surveys to find the magnitude of vector breeding in the city of Cochin in Kerala. They checked various habitats such as cement tanks, wells, ponds, canals, cess pools, water meter chambers and miscellaneous peridomestic habitats such as tree holes, tree stumps, containers, tyres, mud pots, flower pots, grinding stones, etc. Among these, cement tanks, overhead tanks and wells were found to support the breeding of *An. stephensi*. Out of the 2581 wells and 2128 cement tanks examined, 59 wells and 39 cement tanks respectively were found to support heavy breeding of *An. stephensi*. According to them, owing to the availability of piped water supply, the number of disused wells was increasing in the town and these were more prone to breeding of *An. stephensi* more than other habitats.

Mukhopadhyay et al. (1997) carried out longitudinal studies on the epidemiological status of Malaria in Calcutta Municipal Corporation in West Bengal. Since 1990, this city showed remarkable increasing trend of *P.*
cases and deaths due to malaria. They carried out monthly larval breeding surveys in fixed hundred houses in the area. Results revealed that the vector An. stephensi was found breeding throughout the year in water reservoirs. However, maximum breeding was encountered in the rainy season in a wide range of water collections. The larvae on emergence into adult mosquitoes were identified with the help of standard keys to determine the Breteau and Container index of An. stephensi. The larval indices on comparing with the month wise malaria data collected from the study area indicated that the malaria incidence and breeding index coincided and had direct correlation.

Sharma and Hamzakoya (2001) while carrying out studies on the geographical spread of An. stephensi and Ae. aegypti in Lakshadweep Islands of India, carried out larval surveys in the two islands of Agatti and Kavaraththi to ascertain the status of malaria and to collect the information on the prevalence of vectors. Their findings revealed the presence of 5 mosquito species, viz., An. stephensi (type form), An. varuna, Cx. quinquefasciatus, Ae. aegypti and Ae. albopictus. An. stephensi was found breeding in small cement tanks containing clean/turbid water attached to mosques/community lavatories, whereas An. varuna occupied draw wells as their breeding sites. This study revealed the permanent foothold of the An. stephensi which was found breeding in a large number of community and rain harvesting cement storage tanks.

Dev et al. (2003) in their review of malaria transmission in the North-eastern region of India concluded that in this terrain mosquito breeding was recorded in a wide variety of habitats including pools, wells, and roadside puddles, cut bamboos, paddy fields and streams. However the breeding of the vector An. minimus was recorded throughout the year in slow moving
streams/streamlets with grassy banks along with *An. fluviatilis* and *An. culicifacies*. The monsoon species *An. dirus* breeding was reported in pools/rain water collections in the deep jungles.

Prasad et al. (1992) carried out vector surveillance while investigating malaria epidemic on Baniyani district of Uttar Pradesh. They found 12 small ponds, 33 wells and one minor drain around the village. There was no river or canal and the area was not water logged. None of the ponds, wells checked for mosquito breeding were positive for mosquito larvae. However, anopheline mosquito breeding was encountered in the water collections in the rice fields and tube well tanks. Three anopheline species, *An. culicifacies*, *An. annularis* and *An. subpictus* were found. On larval sampling carried out, larval densities of 78 and 241/5 dips were found in rice fields and tube well tanks respectively.

Uprety et al. (1983) carried out mosquito breeding survey in 14 localities of Delhi which was struck by a fever epidemic. They found that the main areas affected were urban central parts which were thickly populated, as well as the peripheral parts of Delhi. The breeding of Anopheles larvae along with Aedes larvae was confined to the overhead tanks (OHT). Most of the tanks were poorly maintained, not cleaned for a long-time, the lids were broken or left open, some were not in use and had rain water in them. Some of the tanks were not accessible being placed very high on roof tops with no ladders for inspection. Results of the survey revealed that the mosquito breeding occurred in the OHTs throughout urban Delhi. Out of 1,644 cement and steel overhead tanks checked, 339 tanks were found breeding with Aedine larvae and 23 were found with mix breeding of *An. stephensi* and *Ae. aegypti* larvae. No other mosquito species was found breeding in the overhead tanks. Their studies
revealed that overhead tanks were a permanent source of mosquito breeding. The intensity of breeding per tank varied considerably from 10-20 larvae to a few thousands.

Biswas et al. (1992) carried out a year long surveillance of *An. stephensi* larvae in and around a fixed number of human dwellings (100 nos.) in an area of persistent malaria transmission in South Calcutta. They found that the area was characterized by 1-3 storey brick built houses with 2-3 masonry tanks within roofed structures on the ground floor of almost all houses and also some tanks outside the houses. All types of water containers in and around the selected houses were searched for *An. stephensi* larvae once a month. The larval sampling was carried out by dipping and pipetting. They found that masonry tanks (42.8%) were the major breeding source of the vector species. The other important categories of *An. stephensi* breeding containers were earthen pitchers (14.3%), tin drums (6.7%), tin cans (6.7%), plastic flower vases (6.1%), earthen barrels (3.8%), earthen flower pots (3.8%), plastic buckets (3.5%), and overhead tanks (3.5%) which showed that the vector species had a greater preference for outdoor man made water bodies than indoor ones. The average number of breeding containers per positive house was lowest (1.1) in December and highest (4.1) in August. The house index, container index and Breteau index of *An. stephensi* calculated during sampling of immature stages showed that both house index and container index remained uniform throughout the year however, the breteau index i.e., number of breeding container per 100 houses, showed a wide variation. The index was lowest (13) in January, started increasing (25) with the onset of summer (March) and reached its highest peak (58) in August which was the month of
highest transmission in Calcutta. Their studies indicated that though, breteau index is recognized as the most suitable as indicator of the larval population of *Ae. aegypti*, this index could also be used for the assessment of *An. stephensi* larval populations.

Singh and Nagpal (1985) carried out studies on mosquito fauna of Mandla district in Jabalpur. Malaria was one of the major health problems among the tribals which constituted 60% of the population in the area. Larval surveys revealed heavy breeding of anophelines in rivers, pits and intradomestic containers. These breeding sites were commonly encountered in all the villages surveyed. The surveys revealed that the density of immatures was very high in the river/stream. Most of the mosquito larvae were of *An. culicifacies* which indicated its role as a vector in malaria transmission in the area.

Singh et al. (1985) carried out larval surveys in the Mandla district of Madhya Pradesh having high incidence of malaria. Immatures were collected from ponds, rivers, streams, pools, pits and wells etc. from the area. The identification of the mosquito fauna revealed 12 species of genus Anopheles, 2 species of *Aedes*, 1 species of *Armigeres* and 2 species each of genus *Culex* and *Manson*ia. It was noted that most prevalent species among the anophelines collections was *An. culicifacies* (79%) followed by *An. annularis* (14.9%) and *An. subpictus* (3.7%) respectively. *An. culicifacies* was considered as the most likely vector of malaria in this district.

Kumar and Thavasivelam (1992) conducted a longitudinal study of breeding habitats and their contribution to *An. stephensi* in Panaji, Goa. Their results showed that 1.1% (747) of the 67,360 breeding sites searched contained
An. stephensi immatures and the overall positivity varied from 0.4% to 3.5% with a peak in June. The habitat wise proportion of An. stephensi breeding in wells was 0.1 to 4.1%, curing water in construction sites 0.6 to 9.0%, groundwater tanks 0 to 1.4%, tyres 0 to 8.9%, barrels and tins 0 to 5.4% and intradomestic container 0 to 1.9% in different months. A variety of habitats supported An. stephensi breeding alone or with other species (interspecific association) such as An. subpictus, An. vagus, An. barbirostris, Cx. quinquefasciatus, Cx. vishnui, Ae. aegypti, Ae. albopictus and Ae. vittatus. Their studies revealed that in most of the habitats, An. stephensi breeding was detected throughout the year in variable proportions, though the positivity increased in the month of April, peaked in June followed by a decline in July and August due to continuous heavy rains followed by low grade breeding till the month of March.

**Adult Catches and Biting Rhythm of Mosquitoes**

Rao (1984) in his book 'The Anophelines of India' mentions that anopheline mosquitoes, except for a few species occurring in the deep shade of the forest, take their blood meals at night time. They feed on man, cattle and other domestic animals, the animals of the forest including monkeys and perhaps birds. According to him, females of anophelines in India bite mainly at night but occasional observations have been made during day light hours also. These species differ considerably in their biting rhythms. Some species bite early and others bite late though there are innate differences between different species yet the behaviour of the same species could also be influenced by seasonal factors. Though biting may occur throughout the night on a small scale, there are distinct peak biting times.

Ghosh et al. (1985) undertook a study to investigate the probable role of An. annularis as a principal of vector of malaria in rural W. Bengal. They carried all night landing mosquito collection on human baits, placed indoors and outdoors from 18.00 to 06.00 hours twice in a month for one year in a village endemic for malaria. Results showed An. vagus (0.70%), An. annularis (0.44%), An. subpictus (0.43%) and An. hyrcanus (0.10%) came in contact with human bait at night. Out of the total number of 5428 An. annularis caught both from cattle sheds and human habitation only one mosquito dissected, was found with sporozoites. They found natural infections in An. annularis only whereas no infection was detected in An. vagus and An. subpictus. Their studies were in conformity to earlier authors, Covell (1927), Timber (1935) who had incriminated An. annularis as the malaria vector and thus confirmed its role in malaria transmission in rural areas of W. Bengal.

Kumar et al. (1995) carried out longitudinal studies on biting behaviour of vectors on human baits from 18.00 to 06.00 hrs in Goa. During the 75 all night
mosquito collections six disease vectors species viz, *An. stephensi, Culex quinquefasciatus, Culex vishnui, Culex pseudovishnui, Culex tritaeniorhynchus* and *Aedes aegypti* were collected. *Anopheles stephensi* was the only malaria vector collected from the urban localities of Panaji and Bambolim. It was found active throughout the night feeding in small proportions (7.2 to 8%) at dusk, with peak biting observed (68.8%) between 22 to 24 hrs which further remarkably declined till 05.00 hrs with nil % in early morning except for a very few females caught biting between 5 to 6 hrs in the early morning. Analysis of season wise data showed that crepuscular biting of *An. stephensi* was more pronounced (29.4%) during the pre-monsoon period (February-May) and comparatively less (17.2%) during the monsoon period (June–Sept.) and least (7.4%) in the post monsoon period. The biting rhythms of *An. stephensi* was found to be trimodal with its first peak in the month of April with an average of 3.0 mosquitoes/bait with the second and highest peak in the month of June with 4.4 mosquitoes/bait and the third peak during October with 2.66 mosquitoes/bait.

Sumodan et al. (2004) conducted studies on the resting behaviour and malaria vector incrimination of *An. stephensi* in Goa. The study was carried in three malaria endemic coastal towns of Goa urban and sub urban viz; Panaji, Porvorim and Calangute. The results showed that in well built houses, 67 hours of collections indoors did not yield a single *An. stephensi* mosquito, although other species were encountered. However, collections in the construction sites and from worker’s huts for 151 hours yielded 38 *An. stephensi* females resting in 5 types of surfaces such as unplastered surfaces, plastered surfaces, bamboo or wood surfaces, metal surfaces and others at a height varying from
30cm to 2.4 meters from the ground or water. Most of the mosquitoes were collected from galvanized iron sheets and from unplastered brick walls. Out of the 37 mosquitoes tested for the presence of Circumsporozoite protein (CSP) by ELISA technique, one was found to be *P. falciparum* CSP positive. It was concluded from the study that *An. stephensi* showed considerable diversity of resting places in Goa but did not rest indoors in the well built permanent houses. Similar observations were made earlier by Hati et al. (1987) in Calcutta, India.

Dev et al. (2003) carried out studies on malaria transmission in the Northeastern region of India. They identified a total of 23 different anopheline species during the year round collection from various ecotypes. Of the total species collected, *An. minimus* and *An. hyrcanus* group of species constituted a fair proportion of the fauna. Except the *An. fluviatilis*, all other species were found in the cattle sheds. They reviewed the feeding habits of the anopheline mosquitoes and their role as vectors. Majority of the species were collected during evening collections from cattle sheds while *An. minimus*, the major incriminated vector species was most abundant in the indoor day resting catches from human dwellings and night biting catches over human bait. All these species were widely prevalent from June to October except *An. fluviatilis* which was found during the post monsoon season only. The host blood meal analysis of the anophelines revealed that most species were zoophilic and cattle biting except *An. minimus* which was attracted to human host and had an anthropophilic index as high as 93%. During the whole night bait catches, *An. minimus* fed throughout the night and the feeding was more pronounced between 01.00 to 04.00 hrs and its biting rate was 13.72 mosquitoes per
person per night. Other species including *An. philippinensis* and *An. dirus* were also collected over human bait but in less numbers.

Vishwanathan et al. (1943, 1944) in their observations, found the *An. fluviatilis* biting mostly during the first quarter of the night in North Kanara District. However, Brooke Worth (1953), Bhombore et al. (1956) found biting of *An. fluviatilis* occurring much later in the night in Old Mysore state which was about 200 kms south in the same Western Ghats.

Vishwanathan et al. (1955) carried out critical studies over a period of about 100 nights near Pune and exemplified the typical behaviour of *An. culicifacies* species. They constructed special huts in which careful observations were made. A calf was tethered in the huts at night. They found that over 67 percent of the females entered and took blood meals before midnight. They observed that *An. culicifacies* bites mostly in the earlier part of the night i.e. prior to midnight though some degree of biting continues throughout the night.

Reisen and Aslamkhan (1978) in their studies near Lahore observed that there were innate differences in the biting rhythms among mosquitoes, though seasons also brought about marked variations. In their collections, they found that the *An. culicifacies* biting took place mostly in the first segment of the night during the cooler months i.e. from November to March, it then shifted to the 2"nd and 3"nd segments during the hot months i.e. during April/May and September/October and during mid summer i.e. June to August, biting was entirely arrhythmic and occurred through out the night, Whereas the biting rhythm of *An. annularis* was found throughout the year during the 1"st and 2"nd segment of the night but a slight shift occurred covering a little earlier period
during cold weather. In case of An. stephensi, it was found feeding took place mostly before midnight and was markedly crepuscular in periods of low ambient temperature. They postulated the possibility of genetic factors which influenced the behaviour and the changes in the degree of anthropophilism and endophagy among different populations of anophelines and adenine species of mosquitoes.

Nursing et al. (1934) in Old Mysore found a bimodal rhythm of An. stephensi biting rhythm with one peak between 21.00 and 24.00 hours and another between 04.00 to 06.00 hours. Deburca and Jacob (1947) however observed that the species could also bite during day time even at 09.00 hours and also in the evenings in the open.

According to Rao (1961a) the biting of An. sundaicus took place in the first half of the night rather than in the second half. When the species occurred in large numbers, it was found biting throughout the night and some even fed in early daylight hours. However, Sundaraman et al. (1957) observed in Indonesia that most of the feeding of An. sundaicus occurred during the second and third quarters of the night.

Sharma et al. (1993) carried out studies on role of An. culicifacies and An. stephensi in malaria transmission in urban Delhi. Their findings revealed that both An. culicifacies and An. stephensi prevailed throughout the year in peri urban areas with higher densities during the post monsoon months.

Bhatt et al. (1994) carried out studies on biology of malaria vectors in Kheda district in Central Gujarat in order to understand the vector behaviour in the wake of ecological changes and their role in malaria transmission in the area. In 70 all night bovine bait trap collections; they collected 41,552
anophelines with *An. culicifacies*, *An. fluviatilis* and *An. stephensi* accounting for 5.57%, 0.32% and 0.42% respectively. Most biting of *An. culicifacies* occurred in winter during the first quarter of the night which shifted to the second and third quarters during hot and rainy seasons, whereas biting took place in varying magnitudes from dusk to dawn throughout the year. *An. fluviatilis* exhibited no definitely rhythm in its feeding activity, however during rainy season, 71% of the specimens were collected in the first half of the night with a peak between 20.00 and 21.00 hours. Similar observations were made in Madhya Pradesh (1987). The third vector, *An. stephensi* was observed biting mostly before midnight. During hot and cold seasons, the maximum biting activity took place in the first quarter of the night and continued till third and fourth quarters, though at a very low rate. Similar findings were also reported by Reisen and Aslamkhan (1978).

Chatterjee and Hati (1995) in their studies carried out in different areas indicated that seasonal prevalence of *An. stephensi* varied widely. In Calcutta, in W. Bengal, of the 927 *An. stephensi* captured from six collection stations on human baits, the maximum number (725, 78.2%) was obtained in the rainy season and only 140 (14.4%) and 62 (6.68) were captured in the winter and summers seasons respectively. These findings also tallied with the findings of man landing collections conducted by Mukhopadhay and Hati (1978) and Mukhopadhay (1980) when 20, 5 and 2 mosquitoes were collected in the rainy, winter and summer seasons respectively. However, two earlier observations of Rao (1946) and Bhatia et al. (1958) revealed that in Madras, the maximum abundance of *An. stephensi* was observed in the winter season (976) followed by in the rainy (678) and summer seasons, whereas in Delhi, maximum
prevalence was in the summer (1577) followed by in the rainy and winter seasons. In Mandora, Haryana, the highest collection was reported in the month of February (Subbarao et al. 1984). In Pakistan, through a release and recapture experiment, maximum prevalence was noted in the month of November & December (Reisen and Aslamkhan 1979). In Bandar Abbas this species was active throughout the year with bimodal peaks one in April-May and the other in August–September which were not observed elsewhere (Manouchahri et al. 1976).

Devi and Jauhari (2006) carried out studies to evaluate the relationship between An. fluviatilis & An. stephensi catches & the prevalence of malaria in Dehradun district (Uttaranchal). Results indicated that the correlation between vector density and monthly parasite incidence was higher in monsoons and post monsoon months than the other months suggesting that with the rise in density of An. stephensi, the number of cases increased. The density of An. stephensi showed significantly high correlation \( r = 0.819; P<0.001 \) whereas An. fluviatilis showed a slight variation in this type of relationship. Both temperature and rainfall were found to be positively correlated with malaria incidence. Their findings showed that both An. fluviatilis & An. stephensi played a significant role in malaria transmission in Kalsi area of Dehradun.

Malaria Epidemiology studies

Kondrashin (1992) reviewed the malaria situation in the WHO South East Asia Region. According to him, the coastal areas support different vectors of malaria such as An. sundaicus in Bangladesh, An. annularis in Orissa and An. culicifacies in eastern coastal areas of India, etc. The diversity of landscape along with variation in the climate and economic activities of the population
determine the zonal and intra-zonal distribution of malaria in this region. The coasts which are greatly influenced by the large biomass determine the natural drainage system; the latter in turn facilitate the mosquitogenic potential. The plains have open terrain systems, in turn attract the largest concentration of human population both in urban and rural areas, and are thus exposed to extreme climatic variations, produce unstable malaria systems which are prone to malaria epidemics at periodic intervals. Whereas, the foothill regions support malaria systems with *P. falciparum* predominance and the hilly regions which are 3000 ft above m.s.l. with rich flora and fauna and criss-crossed by perennial hill streams support long lived vector populations and thus give rise to hyperendemic types of malaria.

Mukhopadhyay et al. (1997) carried out malaria epidemiological studies in Calcutta Municipal Corporation to assess the actual situation of malaria in the city. A ward with population of 20,000 reporting large number of malaria cases, especially *P. falciparum* was selected for the study. The malaria cases including of *P. falciparum* were detected throughout the year. Results showed that from January 1995 to July 1996 out of 8432 blood slides collected, 4045 (48%) slides were found positive for malaria. The highest SPR (69.4%) was recorded in the month of February 1995 and a decline (27.5%) was noted in the corresponding month of 1996. They attributed the decline in SPR to the constant surveillance and treatment of malaria cases and mass awareness created amongst the locals. The peak period of malaria when maximum number of cases were recorded was from July to November, 1995.

Kamal and Das (2001) studied epidemiological situation due to persistent transmission of malaria in a tribal village of Darrang district, Assam.
The study conducted from April 1994 to March 1995 revealed that out of a total of 1122 blood smears collected from fever cases, 193 were positive for malaria parasites with a slide positive rate (SPR) of 17.2%, slide falciparum rate (SfR) of 15.77%, slide vivax rate (SvR) of 1.25% and mixed infections (Pf and Pv) of 1.05%. It was evident from the study that the malaria incidence due to *P. falciparum* was considerably higher than *P. vivax*. Malaria cases were recorded in all the months of the year indicating perennial transmission. The monthly parasite incidence indicated that May to October was the peak transmission period, while rest of the months was the low transmission period. A positive correlation between rainy months and high malaria incidence was observed (correlation co-efficient, $r = 0.64989$). *An. minimus* was incriminated as a major malaria vector in this region with high densities recorded from human dwellings in the study villages. According to them high morbidity and persistent transmission of malaria was due to poor surveillance, difficult terrain and favourable climatic conditions conducive for mosquito breeding and survival coupled with low socio-economic conditions in this region.

Sharma et al. (1985) carried out parasitological surveys in the itinerant labour camps of Delhi. Results of one year study of daily surveillance in the 12 hutments showed that the fever rate in the community was very high and showed great variation between the months. *P. vivax* cases were reported from early spring and reached high numbers in August-September, and gradually declined with simultaneous increase in falciparum cases which peaked in September and October, and declined with the onset of extreme winter. Out of 7191 blood smears collected and examined, 2851 (SPR:36.6%) were found positive for malaria, of which 2386 (83.7%) were *P. vivax* positive, 454 (15.9%)
were *P. falciparum* positive and 11 (0.4%) with mix infection of both malarial parasites.

Kumar et al. (2007) carried out a retrospective analysis of burden of malaria in India. According to them as per NVBDCP records, the distribution of malaria in most states of India showed API less than 2, and regions with API from 2-5 were scattered, where as the states of Rajasthan, Gujarat, Karnataka, Goa, Southern Madhya Pradesh, Chhattisgarh, Jharkhand, Orissa and in North Eastern states the API was more than 5. The Annual blood examination rate which indicates the quality of surveillance system was an average 9% in India for the year 2004 as against 10% prescribed by the national programme. The study revealed that of all the states, Orissa state contributed 25% of the total of 1.5-2 million reported annual malaria cases and 39.5% of the total *P. falciparum* malaria cases and 30% of the deaths attributed to malaria in the country.

**Malaria incidence in different ages and sexes**

Srivastava et al. (1995) in their report on malaria in Buhari PHC of Surat have distributed malaria according to <1, 1-4, 5-9, 10-14, 15-29 and >30 years age groups in both sexes. They showed that while in male children of 1-4 year age, SPR was 80%, it was 21.92 % in >30 years adults. Almost similar trend was noticed in females in different age classes. On the other hand Shukla et al. (2002) investigated outbreak of malaria in Moradabad, U.P. and distributed malaria cases age-wise together for both sexes. The age groups were <1, 1-5, 5-15, 15-25, 25-50 and 51 & above and found SPR of 80% in infants which declined gradually over other age classes to 57.1% in the age group of > 51 years.
Dhiman et al. (2001) chose yet another classification of age groups to group malaria cases in Bahraich district of Uttar Pradesh and their age classes were <5 years (SPR 19.2%), 6-14 (28.84%), 15-25 years (12.5%) and > 25 years (39.4%) which means malaria showed increasing trend with age which was contrary to the earlier studies referred above. Yadav et al. (1993) in a study carried out in Shankargarh in Allahabad district, it was found that malaria was high in all the age groups of both sexes e.g. 47% amongst infants and 50% in children of 1-4 year age followed by 57% in 4-8 years, 57% in 8-14 years and 52% above 14 years. They also found that Pf gametocytaemia ranged from 15.7 to 24.8% amongst these patients and only 56% were symptomatic cases.

Prakash et al. (1997a), in a village based study in Sonitpur in Assam, have reported high prevalence of malaria with SPR ranging from 39.7 to 50% and spleen rate in children <10 years 51.3%. The P. falciparum proportion varied from 95 to 100%. In Kamrup district of Assam, Dev and Sharma (1995) reported perennial transmission of malaria with SPR ranging from 22.9% to 36.5% with proportion of Pf 74%. High incidence of malaria was reported in all the months amongst all age groups including infants.

In Morigaon district of Assam, malaria outbreak was investigated by Dev et al. (2001). They found that 68% of the blood smears were positive for malaria (Pf 87%). Age and sex wise distribution of malaria cases detected in mass survey revealed that 44% children below 4 years age had malaria while 45% in the age group 5-14 and 38% from 15 and above age group suffered from malaria.
In a study carried out in ethnic communities in Assam and Arunachal Pradesh, Dutta et al. (1999) found that incidence was quite high amongst tribals with proportion of *P. falciparum* 80%. The slide positivity for malaria in apparently healthy school going children was 7.25 to 17.46%. Problem of malaria was high in infants and children (44.11%) in Rabha, Bodokachari area and decreased with the age (14.7%). Whereas, it was high in children <10 years of age (21.09%) and then reduced in 10-20 years age group (11.4%) followed by another rise in >20 years adults (24.4%) in Karbi ethnic communities. In Arunachalis, on the other hand, it was 25.27% in children <10 years (25.3%) followed by 42.62% in 10-20 year of age and then declined once again to 20.3% in > 20 years of age. Dutta et al., (1991) conducted a study on epidemiological situation of malaria in Tengakhat PHC in Dibrugarh district in Assam. In this area, they found that malaria was seasonal (1987-89: SPR ranged from 12.9 to 28.5% and SFR from 10.78 to 25.01%) and all age groups suffered from malaria. The attack rate (Cases per 1000 pop.) was the least (9.07) in infants but highest in children (53.98%) and in the higher age groups it ranged from 11.97 to 35.19%. They found that An. dirus was the principal vector of malaria in this area.

Dutta and Bhattacharya [(1990) conducted a malaria survey in some parts of Namsang circle of Tirap district, Arunachal Pradesh and found that SPR was 26.84% in a sample of 190 blood smears examined and SFR was 21.05%. They analyzed malaria according to age groups <1, 1-10, 11-20, 21-30, 31-50 and >51 years in both sexes and found that while SPR was nil in
infants and low in persons >50 years of age, it gradually increased up to 30 years of age.

A study conducted by Das et al. (2000) on epidemiology of malaria in tribal Rajmahal Range, Bihar showed that the slide positivity rate was 25.1% and Pf% was 64.2. Age wise distribution showed that SPR in children was 25% and it increased to 34.4% in 6-10 years age group and 37.7% in 11-15 years age group. In Lakhimpur district, Assam, Das et al., [35] found that in forest fringed villages the SPR was 46.5%, SFR 28.1% while Pf% was 60.4%. Malaria greatly affected children below 5 years (SPR:47.6%), and in the higher age groups SPR ranged from 30.9% to 64.3% showing thereby alarming situation created by the outbreak of malaria. Prakash et al. (1997b) studied malaria problem in forest fringed areas in Dibrugarh district Assam and found that SPR% was 47, SFR was 39.0% while Pf% was 83.1. Age and sex wise distribution showed that infants suffered the maximum in this area (SPR: 69.2%) while malaria problem was also acute in other age groups (SPR range 36.1 to 60.7%).

Mohapatra et al. (1998) have highlighted the importance of younger age groups during epidemic in Tamalpur, Assam and found out that the children between 3 and 12 years of age who were treated and recovered continued to harbour gametocytes and transmit malaria as gametocyte reservoirs. Kamal and Das (2001) found in Darang district of Assam that peak transmission of malaria was between May and October and SPR ranged from 2.3-45.67% in different months with predominance of *P. falciparum* (91.7%) as found in other
studies. The worst affected age groups were 0-1 and 21-30 years although all the age groups suffered from malaria (SPR 11.65% to 19.09%).

Kondrashin (1992) reviewed malaria situation in the WHO South East Asia Region. According to him, in India there was wide variation with respect to malaria among different age groups of both sexes from one state to another. Only 0.5% of total malaria cases were accounted by infants who constituted 2.5% of the country’s total population. In the age group of 1-4 and 5-15 years, there was a marginal difference observed between the population in those age groups and percentages of malaria cases detected in them. This showed that malaria at present was confined to the older age groups probably because of the higher mobility of the adults. Statistical analysis of malaria data of Sri Lanka, Thailand, and Myanmar indicated that malaria incidence was greater among higher age groups than in lower age groups. There was a marked preponderance of malaria among males as compared to females.

Kamal and Das (2001) carried out analysis of age and sex wise data on malaria of tribal village of Darrang district, Assam which experienced persistent transmission of malaria. They found that malaria positive cases were recorded in all age groups including infants in all the months. However maximum number of positive cases were reported in the age groups from 0-1 years (SPR = 32.83%) and 21-30 years (SPR = 2.187%). However the least number of cases were recorded in the age group of 51 years and above. Analysis of the sex wise data revealed very little difference in malaria incidence between the males and females who suffered almost equally with SPR of 18.08 and 16.19 respectively.
Sharma et al. (1985) found that there was low malaria incidence amongst the infants in hutments of Delhi. This was attributed to maternal immunity and also the fact that infants were generally kept well covered. Whereas, maximum incidence was observed in 9-24 years age group. This group was most active and children above 10 years generally accompanied their parents to work.

According to Kumar et al. (2007) who reviewed malaria situation in the entire India found that malaria incidence when distributed according to age and sex specifically showed that the burden is generally higher in men than women in all the age groups. Also children in the states of Assam, Arunachal Pradesh and Rajasthan had a higher incidence of malaria than adults, whereas in the Indo-gangetic plains and in the peninsular India, the situation was reverse i.e. incidence was much higher in the middle and older ages than younger ages.

Kumar et al. (2007) have also shown that in general, malaria mortality across all ages was comparatively higher in males than in females. This mortality gap in both sexes widens after the age of 25 years. Overall, the proportion of deaths in males:females were 1:0.56. Unlike in Africa, where most of the malaria attributed deaths are reported in infants and children, in India, malarial deaths increased up to the age of 44 years in both the sexes and declined thereafter. Although the deaths in infants and children <14 years of age accounted for 20.6%, in older ages (15-54 years), they accounted for 56.1%, and the rest 23.3%, were in those > 55 years of age. Hence, most of the burden of malarial mortality was borne by the economically productive ages. The total computed DALYs lost in India for 1997 because of malaria were 1.86 million years. Among females, DALYs lost were 0.786 million versus
1.074 million in males. The maximum DALYs lost (53.25%) were in the middle productive ages from 15 to 44 years of age, followed by children < 14 years of age (27.68%), and 19% in those > 45 years of age.

**Demographic distribution of malaria**

Kumar et al. (1991) in their study carried out on malaria related to constructions in Panaji, the capital city of Goa which had experienced a severe outbreak of malaria in 1986 showed that the fever rate in labour camps was comparatively much higher, ranging from 8.3% in December to 33.7% in June as compared to 0.6% noticed in March and April to 4.5% in July observed among the locals. Slide positivity rates (SPR) in the two demographic groups were also compared up to April 1990. In the labour camp, there was a sharp increase from 16.8% in April to 50.5% in May, whereas in the local population SPR increased from 17.2% in April to 25.7% in May i.e. an increase of 8.5% as against 33.7% witnessed in labour camps. The increase in SPR coincided with an abrupt increase in the malaria vector, *An. stephensi* per cent positivity in the construction sites. In the subsequent months, except in the month of November, the SPR remained higher in labour camps as compared to local population. Similarly, slide falciparum rate (SfR) was higher in labour camps ranging from 2.3 to 9.5% as compared to 1.2 to 7.8% in local population. Annual parasite incidence (API) was 528.1 in the labour camps and 37.97 in the local residents in the same year showing a marked difference in the incidence among these demographic groups. According to them, labour camps were very important epidemiological niches of malaria where highly vulnerable population resided.
Stratification based on Malaria endemcity

The stratification of the SEAR was carried out by the WHO based on the distribution of Pf resistance to antimalarials in 1993. The endemic countries were stratified based according to drug to chloroquine (CQ), chloroquinine plus sulphadoxine methamine (SP) and CQ+SP+ Mefloquine. A new strategy was endorsed based on the recognition that malaria varied from country to country, area to area and even within population groups.

Sharma et al. (1996) in their review on Epidemiology of Malaria in India, mention that during early part of this century, the malarious areas of the world were classified on the basis of 'malaria prevalence' in the area. The degree of malaria prevalence was correlated with climatic conditions. Celli and later on Gill (1938) described Equatorial, Tropical, Sub-Tropical and Temperate Zones of malaria. Subsequently as wide variations in malaria prevalence were observed within each zone, Christopher, Pampana, and later on WHO (Kampala Conference, 1950) recommended the classification or stratification of malarious areas during eradication era based on disease prevalence in the population surveyed for spleen enlargement in children in the age group of 2 to 9 years as hypo, meso, hyper and holo-endemic areas. Later on, another dimension was introduced in this classification by adding infant and child parasite rates prevalent in community. Only much later, attempts were made to classify or stratify malarious areas based on 'epidemiological profile' of malaria in the area, as 'stable' and 'unstable' malarious areas. Models of Macdonald and Mostikovsky independently explained malaria 'transmission dynamics' and disease epidemiology, but the control strategies based on these and those adopted in areas like Garki project did not record much success. The atlas of
Kenya and Tanganyika helped in understanding the malaria epidemiology in relation to land relief of the locality but did not lead to successful multi-disciplinary control strategy. The operational stratification was done in El Salvador, China, Vietnam, Turkey and Iran and recently in many countries of South East Asia. Except for China, the stratification based control programmes have not shown very good results; even in China the programme which had shown good progress till 1990 has recently recorded some setbacks. Therefore, the adoption of malaria stratification technique for planning a successful, cost-effective and sustainable malaria control programme needed further research and refinement.

Sharma et al. (1996) in their review mention that the zoning of malarious areas of India was carried out in 1986 by the Govt. of India which constituted a malariogenic stratification committee which as a preliminary exercise, took 14 different variables into consideration for stratification and divided the country into seven strata: 1) Non-Refractory Areas with low to moderate epidemic potential of Southern India; 2) Moderately Refractory Areas with high epidemic potential of Central-Western India; 3) Non-Refractory Areas with moderate to high epidemic potential of North-Western India; 4) Non-Refractory Areas with high epidemic potential in North-Western India; 5) Non-Refractory Areas with limited epidemic potential in Northern and Eastern India; 6) Refractory Areas with high receptivity (malariogenic potential) in Central-Eastern and Eastern India; and 7) Refractory Areas with high receptivity in North-Eastern India. The stratification strategy suggested by this committee was based on 'Refractory' and 'Non-Refractory' nature of malaria. It must be emphasized that malariogenic stratification as suggested by different experts was not an
academic exercise alone but it had an ultimate goal of defining control programme objectives in different maliogenic strata.

The WHO has classified malaria epidemiological types related to human activity viz., (1) Agriculture related malaria including irrigated malaria such as rice field malaria, irrigation canal malaria, tube-well malaria, reservoir/pond related malaria, sugarcane cultivation malaria and non irrigated malaria such as cotton/tapioca/tea garden/coffee plantation malaria, tree plantation malaria including rubber/coconut tree plantation malaria and fruit orchard malaria, animal grazing malaria (2) Forest economy related malaria including gem/gold/ore mining malaria, hunting/food gathering malaria, forest fringed malaria such as settled/shifting cultivation malaria, re-settlement malaria, animal grazing malaria, logging/firewood collection malaria (3) Urban Malaria including urban malaria, peri-urban malaria, slum malaria, industrial malaria and (4) Industry related malaria which included coal/ore mining malaria and developmental project malaria. The above classifications only broadly identified a situation where human population could be exposed to risk of malaria. But to organize a control programme for each situation, detailed investigations on transmission dynamics were required.

The identification of malaria paradigms was carried out by the Directorate of National Malaria Eradication Programme (NMEP) in 1994 as there was a sudden upsurge of malaria in India (Sharma et al. 1996). Epidemics were recorded in the States of Rajasthan, Manipur and Nagaland. The State of Rajasthan recorded about four fold increase in number of deaths due to malaria. To look into the causes of these epidemics and deteriorating malaria situation, the GOI appointed an Expert Committee who reviewed the malaria
NMEP and other agencies and laid down the criteria for identification of 'high risk' areas. Under the Rural areas (1) Recorded deaths due to malaria (on clinical diagnosis or microscopic confirmation of *P. falciparum*) locally acquired infection in an endemic area, during any of the last three years (2) The Slide Positivity Rate (SPR) index is to be used for the identification of the areas as follows: (a) Doubling of SPR during the last three years provided the SPR in second or third year reaches 4% or more (b) Where SPR does not show the doubling trend as above but the average SPR of the last three years is 5% or more. (3) *P. falciparum* proportion is 30% or more provided the SPR is 3% or more during any of the last three years (4) An area having a focus of Chloroquine resistant *P. falciparum* (A Chloroquine resistant PHC will be characterized by detection of more than 25% of R II and R III level cases in a minimum sample of 30 cases), as per WHO recommendations (5) Tropical aggregation of labour in project areas (6) New settlements in endemic/receptive and vulnerable areas. For the urban areas (1) 15 cities/towns were identified as high risk areas (2) among the remaining cities/towns presently covered under Urban Malaria Scheme, the SPR is 10% and more during the last three years (3) any other urban area with a population of 50,000 or more and SPR more than 5% or the ratio of clinical malaria cases to fever cases more than one third as per hospital/dispensary statistics during the last calendar year. The Committee further broadly classified malaria paradigms into epidemic prone areas, tribal areas and urban areas. They sub-classified these paradigms into: Plain irrigated areas (tube-well irrigation), Plain areas with sandy soil without water logging, Plain desert areas, Plain coastal areas, Undulating hills and foothills areas and malaria in organized sector, etc. The
Committee further divided the epidemic prone areas into different sub-paradigms of malaria, on the basis of the endemic potential of the area, correlating the endemicity levels with the presence of malaria vector. They took into consideration the effect of the vectorial capacity of local vector and other factors related to the transmission dynamics in the area. According to the Committee malaria is an exclusively local phenomenon, the disease prevalence and epidemiological factors vary from area to area and that approach to malaria control in any area should have the following two main activities; firstly disease management, through early diagnosis and prompt treatment (EDPT) and secondly selective suitable intervention measures.

Ceccato et al. (2007) carried out studies on the malaria stratification, climate and epidemic early warning system in Eritrea, a malaria epidemic prone country in the horn of Africa. Eritrea had successful malaria control program but was susceptible to devastating malaria epidemics. Remotely sensed climate and malaria data was averaged over the same 'subzoba' (=districts), geographic administrative units. Relationships between monthly incidence of clinical malaria by 'subzoba' and monthly climate data were investigated. Although correlation was good between malaria anomalies and actual rainfall from ground stations (lagged by 2 months), the stations did not have sufficiently even coverage to be widely useful. Satellite derived rainfall was correlated with malaria incidence anomalies with a lead time of 2–3 months. Their findings revealed that the seasonal forecasting skill from Global circulation Models for the June to August season was low except for the Eastern border and for the coastal October to December season, forecasting was good only during 1997 and 1998 (El Nino period). Thus the monthly malaria data derived from 242
health facilities in 58 ‘subzobas’ of Eritrea from 1996 to 2003 was used in a novel stratification process using principal component analysis and non-hierarchical clustering to define five areas with distinct malaria intensity and seasonality patterns to guide future interventions and development of an epidemic early warning system.

Kumar et al. (2007) in a study on burden of malaria in India presented stratification of different states of India based on the annual blood examination rate (ABER), annual parasite incidence (API), and the proportion of \textit{P. vivax} and \textit{P. falciparum} in 2004. It was revealed that against the 10% norm of ABER, the overall ABER in the country was 9%. In 14 out of the total 29 states, it ranged from 1% to 8%, and in the remaining 15 states and union territories, ABER was 10% to 40%. As per the NVBDCP reported incidence data, in most of India, the API was <2, whereas 2-5 API was in scattered regions, and regions with >5 API were scattered in the states of Rajasthan, Gujarat, Karnataka, Goa, Southern Madhya Pradesh, Chhattisgarh, Jharkhand, and Orissa and in northeastern states.

This stratification also showed that the proportion of \textit{P. vivax} and \textit{P. falciparum} varied widely in different parts of India. Although mostly indo-gangatic plains and northern hilly states, northwestern India and southern Tamil Nadu state have <10% \textit{P. falciparum} and remaining \textit{P. vivax} infections; in the forested areas inhabited by ethnic tribes, the situation was reversed, and the \textit{P. falciparum} proportion was 30-90%, and in the remaining areas, it was between 10% and 30%. The stratification also highlighted that in India, malaria is being contributed the most by the Orissa state. Although Orissa has a population of 36.7 million (3.5%), it contributed 25% of a total of 1.5-2 million reported annual
malaria cases, 39.5% of \textit{P. falciparum} malaria, and 30% of the deaths caused by malaria in India (Source NVBDCP, India). Similarly, in the other states inhabited by ethnic tribes mainly in the forest ecosystems, meso to hyperendemic conditions of malaria existed with the preponderance of \textit{P. falciparum} to the extent of 90% or even more.

The stratification of India based on chloroquine resistance in \textit{P. falciparum} based on the results of 28-day in vivo studies until 2001 and therapeutic studies from 2002 onward conducted by the NVBDCP and research institutes including the National Institute of Malaria Research was helpful in revising the National drug policy. The drug policy has been revised in 2007 in 241 primary health centers (PHCs) in 71 districts in 20 states of India.

\textbf{Malaria Risk Factors and outbreaks}

According to World Health Organisation (WHO), malaria in countries of South East Asian Region (SEAR) ie., Thailand, Bangladesh, Nepal, Indonesia, India, Myanmar, Sri Lanka and Bhutan had re-emerged in the mid seventies and reached a peak of 7.2 million cases in 1976. In 1995, however, though 3.4 million cases, the actual number was estimated to be six times higher with increase in the proportion of \textit{P. falciparum} cases. The contributing factors for the increased malaria incidence was the development of drug resistance in the \textit{P. falciparum}, development of new foci of multi drug resistance, insecticide resistance in the mosquitoes, human factors e.g. the expansion of areas under human habitation thus diminishing their immunity and bringing them in close proximity to vector mosquitoes, migrant populations engaged in forest related and other occupation who are important conveyors of drug resistant malaria, effect of climatic changes giving malaria vectors an opportunity to breed in new
geographical areas and cause widespread epidemics, poor political commitment in many countries in respect of adequate allocation of resources leading to institutional deficiencies and weak programme management. Besides these, other factors include radical changes in ecology and land use patterns, highly efficient vectors, multiple vector transmission, and prolonged transmission season due to climatic changes usually resulting in epidemics & lack of commitment for sustainable intersectoral partnership & community involvement in malaria control.

According to the National Vector borne Disease Control Programme, Govt. of India, no state in India was free from malaria and has clusters of villages from where cases were being reported regularly. The problem in these states persisted due to ecological and geographical conditions favourable for spread of malaria in addition to water management deficiencies. About 10% of the total cases of malaria were reported from the urban areas on account of planned and unplanned human activities like proliferation of developmental projects and associated construction activities, population migration, inappropriate water storage and disposal of junk/reused containers, tyres, vessels etc.

Kondrashin (1992) while reviewing the malaria situation in the WHO South East Asia Region analyzed various factors such as levels of malaria endemicity, seasonality of transmission, vector density and bionomics, transmission dynamics. It was observed that forests, developmental projects sites and border areas should be accorded highest priority in all malaria endemic countries of the region. In some countries of South East Asia, the plains, irrigated and urban areas were also identified as malaria priority areas.
Infants, young children and pregnant women were identified as malaria high risk groups followed by mobile population groups particularly those engaged in forest related economy, fishing, industrial and construction work, etc. in all counties of this region. According to him, analysis of the malaria situation state wise in India revealed that there was a correlation between the magnitude of malaria in a state and the proportion of people below the poverty line. The mobility of poor from rural to urban areas also resulted in alteration of malaria pattern, including urban malaria, occupation related malaria and drug resistant malaria.

Sharma (1996) in his studies on Re-emergence of malaria in India opined that the fact that the National Malaria Eradication Program concentrated only on rural areas, ignoring the problem of urban malaria, was one of the factors leading to a resurgence of malaria in the 1970s. Several types of population movement contributed to malaria transmission in India. First, circulation from stable rural malaria areas to unstable urban areas had firmly established malaria transmission in urban areas. Then, after the National Malaria Eradication Program, rural areas became free of endemic malaria but were receptive, so circulation from urban areas back to rural areas reintroduced malaria transmission. Changes in vector behaviour (exophilic and exophagic behavior limiting the effectiveness of spraying), vector resistance to insecticides, and increasing drug resistance, especially in *P. falciparum*, also played a role. Population movement also contributed to drug resistance, with people of different immune status moving from endemic to non endemic disease areas, accelerating transmission of resistant strains.
Prasad et al. (1992) carried out studies to investigate the probable cause of malaria epidemic in Baniyani village of District Farukhabad. Their investigations revealed high incidence of malaria with only *P. falciparum* cases and the occurrence of deaths during the transmission season i.e. July to November along with increase in fever cases, high rate of splenomegaly spelling in children coupled with high infant parasite rate confirmed the ongoing active transmission of the disease in the village. According to them, the cause of the epidemic was breakdown in surveillance, faulty diagnosis of cases, non-spraying of insecticides for the previous ten years and immigration of the people from the village to malarious areas of Madhya Pradesh to bring 'bidi' leaves for making 'bidis' as one of their occupation along with illiteracy and poor socio-economic conditions of the village.

Dev et al. (2003) reviewed the epidemiological situation of seven states of Northeastern India namely Assam, Arunachal Pradesh, Meghalaya, Manipur, Mizoram, Tripura and Nagaland which are malaria endemic and reported deaths associated with focal outbreaks of the disease. The study revealed that this region as a whole constituted only 3.96% of the country's population but accounted for nearly 10% of *P. falciparum* malaria cases and 20% of the total deaths recorded in India. They attributed factors such as drug resistant Pf malaria, delayed diagnosis due to non-availability of health facilities in interior villages/hilly areas and tribal belts, delayed referral from periphery due to difficult communication, late treatment of cases due to non-availability of drugs in interior places and the environment conducive to mosquito proliferation, survival and longevity as reasons for the significantly higher mortality and morbidity in these states. According to the WHO (SEARO), there being poor
health infrastructure at the periphery, many cases go undetected or unreported due to lack of blood examination reports and also because of the fact that 8% to 33% of the ethnic communities were asymptomatic carriers of the parasite.

Martens and Hall (2000) carried out studies on population movement and malaria transmission. According to them, population movement for a number of reasons such as environmental deterioration, economic necessity, conflicts and natural disasters has contributed to the spread of malaria disease. Failure to consider this factor contributed to failure of malaria eradication campaigns in the 1950s and 1960s. The movement of infected people from areas where malaria was still endemic to areas where the disease had been eradicated led to resurgence of the disease. As people move, they increase their risk for acquiring the disease through the ways in which they change the environment and through the technology they introduce, for example, through deforestation and irrigation systems. Such activities create more favorable habitats for Anopheles mosquitoes; at the same time, workers may have increased exposure to the vector. Furthermore, people inadvertently transport infectious mosquitoes to malaria-free areas, reintroducing the disease. Population movement was also increasingly implicated in the spread of drug resistance in malaria. Their findings indicated that identifying and understanding the influence of these population movements would improve prevention measures and malaria control programme.

Poveda et al. (2001) carried out studies on coupling between annual and El Nino/Southern Oscillation (ENSO) time scales in the malaria-climate association in Colombia. Their results presented evidence that El Nino phenomenon intensified the annual cycle of malaria cases for P. vivax and P.
falciparum in endemic areas of Colombia, as a consequence of concomitant anomalies in the normal annual cycle of temperature and precipitation. During El Nino events (Interannual Time Scale) the timing of malaria out breaks did not change with the annual cycle but the number of cases intensified. Such anomalies associated with a consistent pattern of hydrological and climatic anomalies i.e. increase in mean temperature, decrease in precipitation, and increase in dew point and decrease in river discharge favoured malaria transmission. Seasonal statistical correlation according to them was helpful in forecasting outbreaks & for developing health early warning systems of meteorological conditions conducive to malaria outbreak.

Devi & Jauhari (2006) carried out study on climate variables and malaria incidence in Dehradun in Uttaranchal. The study aimed to find out the effect of climatic factors on malaria incidence with particular emphasis to capture the essential events as a result of climatic variability. Their results revealed higher positive correlation of association was found between monthly parasite incidence and climate variables i.e. temperature, rainfall and humidity. However highest significant correlation was found between rainfall and malaria incidence ($r=0.718, p <0.0001$) when the data was staggered to allow a lag of one month. In case of maximum temperature, highest correlation was found with two month lag period and for relative humidity was found during zero period lag. This indicated that rainfall seemed to play a more important role in the transmission of the disease then temperature did. Several workers from different places have found similar results (Penget et al. 2003; Greenwood et al. 1993 and Ramasamy et al. 1992). On the basis of correlation analysis, they concluded
that the climatic variables that predicted the presence or absence of malaria were likely to be best suited for forecasting the distribution of malaria disease.

**Sensitivity to commonly used antimalarials**

Sehgal et al. (1973) reported for the first time chloroquine resistance in *P. falciparum* from Manjha in the Karbi Anglong District in 1973 and from Nowgaon in 1974 in the northeastern state of Assam. More cases were detected in the next 3-4 years in Assam, Arunachal Pradesh, Mizoram, and Nagaland. Although foci of resistance to chloroquine are present in the entire country, the problem is more pronounced in areas with intense *P. falciparum* transmission like the northeastern states and Orissa and in areas where there is intermixing of the population, such as project areas, including construction sites, in big metropolitan areas, and along international borders.

Although the available data on sulfadoxine-pyrimethamine (SP) resistance is limited, it seems that efficacy for this drug is within acceptable limits, except in limited areas such as the Indo-Myanmar border in Arunachal Pradesh and some parts of Assam and West Bengal NVBDCP (2002) and Mohapatra et al. (2003).

Only limited reports of chloroquine resistance in *P. vivax* are available from India. Recently, 16% RI and 6.7%, RII resistance in *P. vivax* was reported in 75 patients in Bihar in a study conducted by Singh R.K. (2000). In addition, multi-drug resistance has also been reported by Kshirsagar et al. (2000). Contrary to this, Nandy et al. (2003) observed in a study in West Bengal and Orissa during 1998-2001, 100% cure rates by Day 7 in 480 *P. vivax* malaria patients. Incidentally, these areas, where *P. vivax* is still sensitive to chloroquine, have high drug pressure and chloroquine resistance in *P. falciparum*. Similar findings
were confirmed in a therapeutic efficacy study with chloroquine in vivax malaria in Gautam Budh Nagar (Uttar Pradesh) in the north, Navi Mumbai (Maharashtra) in the west, and Chennai (Tamil Nadu) in south India in 287 patients in 2002. The curative efficacy of chloroquine was 100% in these patients with vivax malaria. Rapid parasite and fever clearance was observed in all cases, and the drug was well tolerated Valecha et al. (2006). From the data available thus far, it is evident that the problem of drug resistance in \textit{P. vivax} is not of major concern; however, one needs to be vigilant because \textit{P. vivax} produces a relapsing type of infection and is a predominant species in India.

**Malaria Control Strategies**

According to the report of WHO study group (1995) the four basic elements of the global malaria control strategy for all endemic countries are (a) to provide early diagnosis and prompt treatment (b) to plan and implement selective and sustainable preventive measures including vector control (c) to detect early, contain or prevent epidemics, (d) and to strengthen local capacities in basic and applied research to permit and prompt the regular assessment of a country's malaria situation in particular the ecological, social and economic determinants of disease.

Earlier in 1992 WHO had outlined malaria control strategy for all endemic countries of the South East Asia Region (SEAR). The objective of this malaria control strategy was to prevent deaths, reduce morbidity and reduction in social & economic loss. It had essentially all the elements of the global strategy of malaria control outlined above.

According to the National Vector Borne Diseases Programme (NVBDCP), Government of India, strategies for malaria control in rural areas of
India are (a) early detection and prompt treatment (EDPT) through village-based community volunteers such as Drug Distribution Centres (DDCs), Fever Treatment Depots (FTDs) or Malaria Link Volunteers (MLVs) (b) Integrated vector management by IRS in selected project populations at high risk of malaria, promotion of insecticide treated bed nets (ITBNs) through free or subsidized supply to Blow Poverty Line (BPL) population living in remote, inaccessible areas with high risk of malaria, as well as insecticide treatment of community owned bed nets, use of larvivorous fish, environment and minor engineering methods (c) capacity building of the medical and non-medical personnel as well as involvement of inter-sectoral partner organizations, community volunteers for imparting knowledge & strengthening skills in respect of prevention and control initiatives including innovative technologies (d) IEC to enhance awareness among members of the target communities & health care service providers about cause, prevention and treatment of malaria, availability of facilities, (e) Epidemic preparedness and response by having rapid response teams in the event of an outbreak of malaria, (f) Monitoring and evaluation of programme activities including effective utilization of computerized management information system (CMIS).

The current strategy for malaria control in Goa includes early detection and complete treatment (EDCT) of malaria cases, selective mass suppressive treatment (MST) in outbreak areas, intensified anti larval measures with larvicides, Abate (Temephos), Baytex (Fenthion)/MLO (Mosquito larvicidal oil) and introduction of larvivorous fish in mosquito breeding habitats, etc., selective anti-adult measures i.e. thermal fogging with pyrethrum and Ultra Low Volume (ULV) fogging of synthetic pyrethroids in the affected areas aimed at knocking
down infected adult females and finally health education aimed at behavioural change and community participation (Source: NVBDCP, Goa).

Covell, (1928) investigated into malaria problem in Bombay and recommended various preventive measures to tackle the problem. He recommended that (1) all the permanent breeding places of *An. stephensi* such as wells should be hermetically covered, (2) all cisterns must be of iron or reinforced concrete, (3) corrugated iron sheets should not be permitted as covers for any cisterns, (4) water gauges necessitating an aperture in the roof or side of a cisterns must be prohibited, (5) man hole lids to be well fitting the pattern approved by the Municipality, (6) no inlet pipe to enter a cistern through the man hole, large cisterns to be covered with a double flange secured by bolts through the cover, (7) all unserviceable cisterns to be removed, (8) malaria sub inspectors inspect every cisterns in their area on a specified day of every month, (9) in case of non mosquito proof cisterns, one weeks notice to be given to repair the defect, if no action has been taken within a week, the Municipal Commissioner should permit the work to be carried out immediately and recover the cost from the owner, (10) all garden tanks to be demolished or filled in and converted into flower beds if so desired, (11) no fountains to be permitted, except those which were constructed such that no water remains, when fountain has ceased playing, (12) in case of reinforced concrete buildings, all builders and contractors engaged be required to add a sufficient quantity of saponified cresol (larvicide) to all water used to keep cement concrete wet till the water turned distinctly milky, (13) A register of the number and location of all buildings under construction should be maintained in the office of the Special Malaria Officer of the Municipality so that he can at any
time make a personal inspection of them, (14) all water receptacles including those used for soaking bricks must be inspected daily after use and turned upside down, (15) during the monsoon, the temporary breeding places such as yards containing machinery and scrap iron should be levelled and adequately drained and the machinery, etc., stacked so that it provides no hollow in which rain water collects, (16) unfinished and abandoned buildings should have each floor levelled so that water may no longer collect and any depression beneath the building to be filled in, (17) roof gutters and terraces in case of new buildings to have proper grading so that no water collects and in old buildings to be compulsory swept once a week, (18) the presence of discarded tins, earthenware vessels, etc. on roof or in yards of compounds found to contain mosquito larvae should constitute an offence punished by law, (19) all the open drains to be covered and properly graded, the provision of adequate legal powers to enforce the necessary measures and which will apply to private individuals as well as the Government bodies, (20) the use of larvicidal fish and (21) lastly free distribution of drugs to be administered systematically & under strict supervision.

Sharma et al. (1985) carried out field trials for the control of mosquito breeding in their natural habitats using EPS beads (Expanded Poly Styrene Beads) in the villages of Nadiad taluka of Gujarat. They found that the application of EPS beads in biogas plants, unused wells and septic tanks eliminated culicine mosquito breeding on a semi-permanent to permanent basis.

Rao (1984) and Sharma (1985) have reported that in Delhi, rural areas support profuse breeding of *Cx. quinquefasciatus* along with *An. culcifacies* and
An. stephensi in wells. On the other hand, Seetharaman et al. (1975) and Batra & Reuben (1979) have reported that in Salem and Hyderabad, An. stephensi breeds mainly in wells and maintains malaria transmission throughout the year. Since, EPS beads were safe and one application lasted for a very long time, its application in wells could greatly reduce the anopheles mosquitoes breeding in wells and also would reduce or eliminate the disease transmission.

Chakravorthy and Kalyanasundaram (1992) carried out studies to find the speed of selection for resistance to permethrin in the adults of An. stephensi and also evaluated the extent of cross resistance to other pyrethroids and DDT and multiple resistances to malathion. They recommended change of insecticides in vector control programmes with different modes of action in situations where the vector mosquitoes developed resistance against pyrethroids or organochlorine insecticides as a high level of resistance to permethrin and cross resistance to other pyrethroids and DDT was observed.

Biswa et al. (1992) carried out a longitudinal study on breeding survey of An. stephensi in an area of Calcutta and observed that the water storage practices among the city dwellers were mainly responsible for An. stephensi breeding in intra and peridomestic containers which further supported malaria transmission in the city. According to them, an effective solution for the reduction of the breeding sources of the vector species was through the implementation of bye-laws and by generating massive public awareness.

Ansari et al. (1992) carried out studies on Esbiothrin impregnated ropes as mosquito repellent in two villages in Ghaziabad district which had high density of An. culicifacies. Their findings revealed that the smouldering Esbiothrin impregnated ropes @ dose of 500ppm prevented entry of more than
95% of the *An. culicifacies* and nearly 96% of total mosquitoes in the open rooms of the houses and in the cattle sheds respectively. The impact of the ropes was more pronounced on the biting rate of mosquitoes. According to the authors, indoor and outdoor human baits made to seat at a distance of about 3 metres from smouldering esbiothrin ropes did not experience many bites from *An. culicifacies*. They recommended that Esobiothrin impregnated ropes could prove to be an effective and cost effective method of personal protection measures in the rural areas under the influence *An. minimus*, *An. fluviatilis* and *An. culicifacies* as well in labour population in urban slums as compared to the high cost of repellents viz: oils, creams, coils/mats which do not provide adequate protection against mosquitoes. Similar studies were also carried by earlier workers using ropes impregnated with deltamethrin by Sharma et al. (1989) and Ansari et al. (1990).

Singh et al. (1993) undertook studies to observe the mosquito collections by (CDC) light traps in 4 tribal villages of Madhya Pradesh, to assess the feasibility of using impregnated bed nets for controlling malaria in the area. The hamlets were located on hill slopes or at the foot of hills and were scattered with natural barriers of thick forest and rocky streams. The analysis of the all night mosquito collection data in human dwellings (indoors) in each village showed that peak activity for *An. culicifacies*, the predominant vector species were between 19.00 and 21.00 hrs. However, their findings highlighted the fact that as the feeding of *An. culicifacies* started soon after dusk, the use of impregnated bed nets for control of malaria was not feasible in that area against that particular species.
Prasad et al. (1993) carried out studies on the control of mosquito breeding through *Gambusia affinis* in the nursery and paddy fields. They identified six anopheline species, viz; *An. culicifacies, An. annularis, An. subpictus, An. nigerrimus, An. barbirostris* and *An. aconitus* along with Culex and Aedes species breeding in the rice fields. Results of their study revealed that, *G. affinis* survived well in submerged rice fields and provided mosquito larval control to the extent of 87.8%. However, moderate larval control was achieved in those rice fields, which exhibited intermittent drying up leading to formation of pools, puddles, etc. They suggested that though this method had limitations, mosquito larval control in the rice fields could be achieved to a good extent through larvivorous fish.

Lopes et al. (1994) undertook a massive campaign for the promotion of bioenvironmental control of malaria in Goa through the Junior Red Cross Counsellors volunteers (a NGO), supported by school authorities, the education department, religious and business institutions. The programme first of its kind was introduced in the school curriculum in Goa to reach the community through the students and teachers so as to involve people in the vector and disease control process. This target oriented health education campaign resulted in creating awareness and motivation in the community to prevent the disease and take various remedial measures

Kumar et al. (1994) carried out studies on community participation and Intersectoral Cooperation in Malaria control in Panaji, Goa. Various government and non governmental agencies actively participated in malaria control activities viz., weekly survey of breeding sites, mosquito proofing of lids of water cisterns, introduction of larvivorous fish in the wells, masonry tanks,
fountains, pit wells, drains, etc., application of biolavicides in masonry tanks, curing and rain water collections in the construction sites, source reduction measures and health education campaigns through exhibitions, health camps, door to door visits to residential and construction sites, distribution of pamphlets, training programmes to disseminate information in the community about various malaria prevention and control measures. The results showed a marked decline in the overall positivity of intra-domestic breeding sites for all mosquitoes in general including An. stephensi in 1991 as compared to 1990.

Earlier, in the area of vector borne diseases, the community based programmes have not only been framed but also applied successfully in India at various locations such as Nadiad in Gujarat (Sharma and Sharma 1989), Hardwar (Dua et al. 1988), Mandla (Singh et al. 1989), Shahjahanpur, Madras and Rishikesh (Sharma 1991 b).

In another study, Kumar et al. (1994) had also demonstrated control of malaria utilizing Bacillus sphaericus (spherix formulation) against An. stephensi in the urbanised area of Panaji. The spherix spraying in the vector habitats showed sharp reduction in habitat positivity and immature densities of An. stephensi in the treated areas. The impact was very much pronounced during the monsoon months from May to July which was also the peak Plasmodium transmission period in Panaji. The study proved that B. sphaericus strain proved to be a useful bio-control agent for the control of vector mosquito, An. stephensi and also on the overall incidence of malaria.

Sharma et al. (1996) carried out studies on impact of Deltamethrin spraying on malaria transmission in Rameshwaram Island in Tamil Nadu. This Island was endemic for malaria since several decades. An. culicifacies was the
main vector in the area. The impact of spraying deltamethrin 2.5% w.d.p @ 20mg/m² and malathion 25% w.d.p. @ 2gm/m² was carried out. The monitoring of entomological and parasitological indices revealed that due to deltamethrin spray, malaria transmission was effectively interrupted and a significant reduction in malaria cases was achieved. *P. falciparum* also showed a significant reduction, whereas in the malathion areas for comparison, reduction in malaria cases or in Pf cases was not recorded. Similar observations were recorded by Ansari et al. (1986) and Sharma (1988). The study thus indicated that the conventional residual spray having failed, the change of insecticides like deltamethrin should be considered for control of malaria in the area like Rameshwaram where malaria has been a major public health problem.

Kumar et al. (1997) in their study on dynamics and control of *An. stephensi* transmitted *P. vivax* and *P. falciparum* malaria in the coastal belt of Goa, since mid eighties revealed that the vector breeds in wells, sumps, overhead tanks, masonry tanks, waterlogged basements, curing waters, rain water pools, ornamental fountains and a variety of intradomestic water containers. Further, *An. stephensi* build-up starts in April with the rise in temperature and peak populations are observed in June or July depending upon the onset of south-west monsoons. A natural decline in vector populations occurs from mid August as the rains subside. Following the spurt in the vector populations, a very active transmission is witnessed and peak malaria incidence is observed from May to October each year. The incidence however, declines from November to February with the lowering of temperature and humidity. Based on malaria transmission dynamics, a time frame intervention model for *An. stephensi*
control was prepared and tested in the Candolim PHC of Goa in 1995. The intervention measures included selective spraying of *Bacillus thuringiensis* var. *israelensis* and introduction of indigenous larvivorous fishes, *Aplocheilus blocki*. As a result, malaria incidence declined to the extent of 81.6% in the PHC areas with the reporting of 263 cases in 1995 as compared to 1431 in 1994. *P. falciparum* cases were not encountered after March 1995. This intervention model for the control of *An. stephensi* transmitted malaria was recommended not only for Goa but for similar situations in India.

Sharma and Srivastava (1997) carried out studies on role of remote sensing (RS) and geographic information system (GIS) in malaria control. One study explained the application of RS on the mosquito production in the Sānjay Lake and surrounding areas in Delhi and its usefulness in assessing relative mosquito abundance in large water bodies. The second study was carried out in the Kheda Village in Nadiad Taluka of Gujarat, provided the application of RS and GIS in analyzing receptivity and vulnerability to malaria. Their results showed that malaria annual parasite incidence (API) indicated a relationship with water table (37%; p=0.05),) followed by soil type (26%; p=0.04) irrigation (24%; p=0.02)) and water quality (21%) contributed significantly to malaria receptivity. Based on GIS analysis, they suggested location specific malaria control strategy to achieve cost effective control of malaria on a sustainable basis.

Kumar et al. (1998) carried out field trials of biolarvicide *Bacillus thuringiensis* var. *israelensis* strain 164 and the larvivorous fish, *Aplocheilus blocki* against the vector *An. stephensi* for malaria control in Goa. The study was conducted in highly malaria endemic Candolim Primary Health Centre.
Their results demonstrated that the biolarvicide *Bacillus thuringiensis israelensis* 164 (Bacticide formulation) in combination with the indigenous larvivorous fish *A. blocki* proved highly effective. This one year intervention field trial led to the containment of the vector *An. stephensi* and reversed the upward trend of malaria in the malaria affected PHC to the extent of 80.5% when the incidence of 1995 was compared with 1994 as well as the near elimination of *P. falciparum* malaria in 1995, which suggested that the intervention measures had successfully curtailed transmission of malaria in this endemic PHC.

Sumodan and Kumar (1998) carried out studies on the distribution and feeding efficacy of indigenous larvivorous fishes of Goa. Fifteen species of larvivorous fishes from different parts of the state were collected and tested. They studied their natural distribution and density. In laboratory experiments, they found that the daily average consumption of mosquito larvae varied between 62.5 & 736 per fish. On the basis of their larvivoracity and extensive distribution, *Aplocheilus blocki* and *Rasbora daniconius* were recommended for use in malaria control in Goa.

Yapabandara et al. (2001) carried out studies on control of malaria vectors with the insect growth regulator pyriproxyfen in a gem mining area in Sri Lanka. There were many shallow pits dug by gem miners breeding malaria vectors *An. culicifacies* and *An. subpictus*. With the help of local volunteers and on the basis of a year’s pre-intervention data, the villages were stratified into four with high levels of malaria transmission and the other four with lower transmission. Within each stratum, two villages selected randomly and all the gem pits and river bed pools were treated with pyriproxyfen @ 0.01 mg a.i./litre. The intervention caused significant reductions in the adult populations of *An.*
culicifacies and An. subpictus. Similarly, incidence of malaria was reduced in the intervention villages to about 24% (95% C.I.; 20-29%) of that in the controls. Prevalence of parasitaemia also declined significantly. Their study indicated that with active community participation, the vector control by a highly active and persistent insect growth regulator was a very effective means of malaria control.

Yeya (2001) in his report entitled ‘Malaria vector control in Africa: Strategies and Challenges’ states that indoor spraying of insecticides in high mortality endemic and drug resistant areas was implemented and yielded good results in Africa. Other vector control strategies adopted were personal protection methods based on Insecticide Treated Nets (ITNs) and curtains which provided 30 to 60% reduction in malaria morbidity. However, according to him, environmental control if used in urban and periurban areas with community participation and intersectoral collaboration were useful in vector control.

Mishra (2003) took up a hospital based study of malaria in Ratnagiri district of Maharashtra. The results revealed the prevalence of both P. vivax and P. falciparum infections. Adults were found more vulnerable to the disease in the area and the working group (20-40 years) was more affected, due to malaria. Detailed epidemiological studies indicated Pf transmission was high in new talukas of this district. To improve the malaria situation in the district it was recommended that early detection and prompt treatment along with community awareness. Also mosquito control operations were needed especially before the onset of rainy season as malaria prevalence was high during the rainy season in this area.
Dev et al. (2003) have recommended prevention and control measures based on local transmission pattern in the North eastern region of India facing persistent malaria transmission due to the prevalence of malaria vectors, *An. minimus*, *An. fluviatilis* and *An. dirus*. *P. falciparum* is the major malarial infection in most of the North eastern states. Based on local transmission pattern, they proposed integrated approach for vector control through insecticide impregnated mosquito nets backed by health education, inter-sectoral co-operation and biological control coupled with early case detection and complete treatment. These according to them could provide a long lasting solution for malaria control. Similar strategies were also recommended by Jana-Kara et al. (1985) and Kondrashin (1997).

Curtis et al. (2003) in a study on insecticide treated nets carried out trials in Assam and Tanzania and found that if a whole community was provided with treated nets, so many mosquitoes of anthropophilic species were killed by contact with the nets that the density and sporozoite rate of the vector population was reduced. Their data showed that there was less malaria morbidity in both the areas provided with impregnated mosquito bed nets than those without the nets. This was attributed to the mass effects of the nets.

Ansari et al. (2004) carried out laboratory and field trials of pirimiphos-methyl (50% EC) an organophosphorus insecticide against the immatures of Anopheles and Culex species in different breeding habitats in District Ghaziabad (U.P.) and Goa. Presently in India, temephos and fenthion are used as larvicides in fresh and polluted waters respectively. Since use of the same larvicide’s precipitated resistance, an alternative chemical primiphos-methyl was evaluated. The results showed that larvicidal formulation of pirimiphos-
methyl was found to be relatively more effective against immatures of Anopheles i.e. *An. stephensi* and *An. culicifacies* than Culex species. However, the study also suggested that doses higher than 0.25 ppm were not safe to non target species, i.e. the larvivorous fish which is a limitation of this compound.

Matta et al. 2004 carried out a hospital based study for assessment of knowledge about malaria among patients reported with fever at Safdarjung Hospital, New Delhi. Data on socio demographic profile, history of fever & health seeking behaviour of 200 fever cases were recorded. The findings revealed that about 83% of fever cases did not approach the doctor even after three days of onset of fever symptoms, 25.5% tried self medication and 20.5% approached chemists for treatment. Their results indicated that knowledge about cases and symptoms of malaria was poor even in persons residing in urban localities and proper health education was required for successful control of malaria. Information, Education and Communication (IEC) activities were suggested to create awareness among the community.

Panda and Mohapatra (2004) have highlighted malaria situation in the context of malaria eradication in India. The manmade natural destructions such as concretizations, water storage for future consumption, irrigation etc., sometimes resulted in the emerging of malaria in non endemic areas. The findings revealed the fact that besides other factors it is essential to bring about the changes in the health seeking behaviour among the rural inhabitants and especially among the migrant labourers, who are frequently travelling from one direction to another carrying the malaria parasite with them. According to them, the control strategy will be fruitful only when people understand the problem of disease transmission and its management and also realize the seriousness of
the disease. The health workers have to be oriented to malaria properly along with the community for better malaria control.

Sreehari et al. (2007) evaluated the bioefficacy of PermaNet® in both the laboratory and field against *Anopheles culicifacies* and *An. stephensi*, major malaria vectors in India. Contact bioassays were carried out after repeated washings and ring net bioassays to determine the median knockdown time of mosquitoes. Three villages were selected for the field trial: in the 1st village PermaNets® were distributed, in the 2nd village untreated nets were distributed, and the 3rd village was kept as a control. Entomological data was collected using standard procedures. The PermaNet® contact bioassays showed high mortality (>80%) even after 20 washes against both the vector species. The median knockdown time of *An. culicifacies* and *An. stephensi* was 392 and 480 sec when exposed to fresh PermaNets® and 472 and 986 sec when exposed to PermaNets® that had been washed 20 times, respectively. Their studies indicated that PermaNets® showed high efficacy in reducing the person-vector contact as evidenced by reduced person-hour density in the PermaNet® village.