

Malaria en route to elimination in two endemic coastal environments of southern India: an eco-epidemiological analysis from 2004 to 2019

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Abstract

Background

Coastal environment and climatic condition are more suitable in propagation of mosquito vectors, and malaria parasite transmission throughout the year. In the present investigation, malaria prevalence in two endemic coastal localities of India viz., Besant Nagar (Chennai district) and Pamban (Rameshwaram district) were analysed from 2004 to 2019.

Methods

Malaria surveillance data and entomological data from malaria clinic were used to investigate epidemiological parameters. The annual malaria cases were correlated with highest maximum temperature.

Results

The analysis showed that the malaria case (P.v. and P.f.) report were directly proportional to the temperature increase. Malaria cases were remarkably increased from 2004 to 2011 and subsequently, both P.v. and P.f. cases were drastically reduced till 2019. *P. vivax* was higher than *P. falciparum* and male population was found to be more affected. Mixed infection of P.v. & P.f. was observed only in Besant Nagar site (0.3%). The most affected age group was adult age group (15 years and above) in both Besant Nagar (76.1%) and Pamban (69.5%).

Conclusions

Improved surveillance, complete treatment and integrated vector control activities showed declining trend of malaria cases in both the coastal sites towards malaria elimination.

1. Introduction

Malaria is of challenging global concern in public health [1] and gives harsh negative impact on the economic development of the nation. It is transmitted by infected female *Anopheles* mosquitoes. The financial burden of malaria falls most heavily on the poor [2]. The incidence of malaria in the world has been estimated approximately 300 million clinical cases each year [3]. According to an estimate, 239 million cases in 2010 and 219 million cases in 2017 occurred worldwide [4]. As per the World Malaria Report [5], the Southeast Asia region is the second most affected region in the world; India had the highest malaria burden followed by Indonesia and Myanmar. Among Southeast Asia region, 75% – 77% of malaria cases are contributed by India with 95% population at risk [6]. In India, malaria transmission and control are very complex because of the different environmental conditions and involvement of many ecotypes of *Anopheles* vectors in transmission of *Plasmodium* species viz., *P. falciparum*, *P. vivax*, *P. malariae*, and *P. ovale* [7, 8]. As per the World Health Organization, country office for India, the highest malaria cases of 75 million cases and 0.8 million deaths were reported in 1947^{7,9,10}. Several ups and downs in malaria case incidences in several parts of India were reported from 1950s to 1990s [9–11] and analysis showed there is a significant reduction in malaria case after 1996 throughout India except few pockets, where outbreak reported [4, 7, 10, 12]. The recent WHO report documented that there was reduction of 2.6 million malaria cases in 2018 compared to 2017 in India [13].

As far as anti-malarial drug is concerned, quinine (QN) was the only drug used for the treatment of malaria in India from 1900 onwards. Afterwards, the first National Malaria Control Programme was initiated in 1953 [14]. Following the report of resistant strain of *Plasmodium falciparum* (P.f) and *Plasmodium vivax* (P.v) to chloroquine in 1973 [15], the formation of first antimalarial drug policy with Chloroquine and Primaquine (CQ + PQ) drugs was launched in 1982, and thereafter the antimalarial drug strategy was periodically revised. According to the recent national drug policy on malaria 2010, all *P. falciparum* cases confirmed by both microscopically and RDT were treated with artemisinin combination therapy (ACT) using Artesunate (AS), and Sulphadoxine-Pyremethamine (SP) [AS-4mg/kg daily for 3 days + SP-adult dose 1500/75mg single dose + PQ-0.75 mg/kg single dose]. The

pregnant women with P.f malaria also treated with same ACT (AS + SP) during 2nd and 3rd trimester otherwise treated with QN (20mg/kg) during 1st trimester. In the 2013 drug policy, the treatment for P.f confirmed cases were same except north eastern states of India where artemether + lumefantrine (80 + 480 mg adult dose) was introduced.

Malaria surveillance is well equipped in India to determine the incidence by blood smear examination at Primary Health Centre (PHCs) and Community Health Centre (CHCs) as a passive surveillance. Here, patients who are reported with fever accompanied by chills, fatigue, shivering, perspiration, headaches, vomiting, anorexia, and malaise etc., from the surrounding areas were screened for malaria as per standard operating procedures [16–18]. Further, active surveillance also being done regularly by health workers at Health Sub Centre (HSCs) level and active slides are brought to the laboratory within 24 hours for staining, and examination [16–18]. In southern India, Chennai and Ramanathapuram are the two endemic districts which contribute significant number of malaria cases every year to overall malaria burden of India. The localities selected for the present analysis were Besant Nagar in Chennai district (urban) and Pamban in Ramanathapuram district (rural) are the two malaria hotspots, where malaria clinic is situated. In this study, we correlated the annual malaria cases and epidemiological data collected by passive, and active surveillance from 2004–2019. Further, Annual Blood Examination Rate (ABER), Slide positivity rate (SPR), Annual Parasite Index (API), Slide *falciparum* rate (SFR), Annual *falciparum* Index (AFI), parasite species prevalence, sex and age wise malaria distribution, vectors involved in transmission, and climatological factors of the two selected localities were also analysed.

2. Methods

2.1. Study sites

We conducted a long-term study on prevalence of malaria in urban and rural coastal regions of Southern India. The urban coastal malaria survey was carried out at malaria clinic attached with Regional Office of Health and Family Welfare (ROHFW) located in Chennai (Locality: Besant Nagar). The rural coastal malaria survey was carried out at malaria clinic attached with primary health centre (PHC), located in Ramanathapuram (Locality: Pamban). Both the study sites are located in the Tamil Nadu state of southern India (Fig. 1) and the roadway distance between Besant Nagar to Pamban is 594km. These two places are coastal regions, which includes political, economic, environmental and public health variables. The urban coastal study site (Besant Nagar) lies at 12°59'N and 80°16'E, on the coast of Bay of Bengal to the east. The rural coastal study site (Pamban) lies at 9°17'N and 79°12'E, on the east and south by Bay of Bengal. The total area and population covered by Besant Nagar clinic is 136km² and 37000 and Pamban clinic is 96km², and 33855, respectively. These two coastal study sites are hotspot for malaria in Tamil Nadu state and reporting vast number malaria cases throughout the year.

2.2. Malaria surveillance methods

Passive smears were collected from all fever cases who are reporting to the clinic and tested microscopically for malaria. Similarly, active smear collection was carried out from fever cases during field survey and in areas where fever outbreak occurred. The slides were brought to the laboratory within 24 hours, stained and tested microscopically for malaria. The above said surveillance was carried out throughout the year and data were registered.

2.3. Malaria diagnostic methods

Blood smears were collected as thick and thin film in a glass slide and stained with Jaswant Singh-Bhattacharji (JSB) stain I & II for parasite identification under oil-immersion microscopy as per established method with the exception of parasite density [17, 18]. Early diagnosis and complete treatment (EDCT) concept were followed.

2.4. Environmental data

Pamban is an Island which is separated from mainland India by a canal called Pamban channel located at the south-eastern tip of the Indian peninsula. The seaway distance between Pamban Island and Mannar Island, Sri Lanka is about 40 km. The total area of Pamban island is 61.8 km² with an average elevation of 10 m and more than 70 % of the area is covered with sandy soil with many sandy pits. Chennai is an urban city located at the southeast coast of India with an average elevation of 10 m. The climate of Pamban and Chennai is tropical, dry, hot and humid. The average annual temperature is 28.6 °C and average annual

rainfall is 1197mm in Pamban. The average annual temperature is 28.8 °C and average annual rainfall is 835mm in Besant Nagar. The year wise mean highest temperature of these two study sites were obtained from the Indian meteorological department, Chennai.

2.5. Data analysis

The annual total malaria case was correlated with highest temperature and figures were generated in the excel spreadsheet. The API, SPR, SFR, AFI, and ABER were estimated using the following formula as per standard guidelines [18].

$SPR = \frac{\text{Total number of positive slides (P.v + P.f + mixed)}}{\text{Total number of blood slides examined}} \times 100$

$SFR = \frac{\text{Total number of P.f positive slides}}{\text{Total number of blood slides examined}} \times 100$

$ABER = \frac{\text{Total number of blood smears examined in a year}}{\text{Total population under surveillance}} \times 100$

$API = \frac{\text{Total number of malaria positive}}{\text{Total population under surveillance}} \times 1000$

$AFI = \frac{\text{Total number of P.f positive}}{\text{Total number of blood slides examined}} \times 100$

3. Results

3.1. Annual slide positivity rate (SPR)

Table 1 show the malaria positive cases (both passive and active) from 2004 to 2019 recorded in urban malaria clinic (Besant Nagar). The average blood smear collected by active and passive surveillance was 4165 per year. In 2004, the calculated SPR was 44.6% (n = 2340) and it was 46.1% (n = 3423) in 2005. The SPR showed decreasing trend from 2005 to 2009. In 2010 SPR was again increased to 29.2% (n = 1387) and it reached the maximum to 49.0% (n = 2330) during 2011. Again, it showed decreasing trend from 2012 to 2019 (Table 1). Table 2 show the malaria positive cases from 2004 to 2019 recorded in rural malaria clinic (Pamban). The average blood smear collected by active and passive surveillance at an annum was 14521. The SPR of Pamban coastal region showed fluctuations. In 2004, the SPR was 5.2% (n = 784). In 2006, it was increased to 7.6% (n = 542) and again decreased. It reached the peak during 2010 (SPR = 10.3%). Subsequently, SPR decreased up to 2019 (Table 2).

3.2. Malaria parasite prevalence and slide falciparum rate (SFR)

The malaria parasites *P. falciparum* and *P. vivax* are prevalent in the selected urban and rural coastal study areas. Among them, *P. vivax* is the dominant species in both coastal areas (77.5% in Besant Nagar; 88.3% in Pamban). Further, mixed infection (both P.v. & P.f.) were found to occur only in urban coastal area (0.3% in Besant Nagar). The calculated SFR in urban coastal site was 10.3% (n = 573 + 5mixed) during 2004 and it was 8.8% (n = 635 + 19mixed) in the following year 2005. The SFR showed decreasing trend from 2005 to 2009 in urban coastal site (Table 1). In 2010, the SFR was increased to 1.8% (n = 87 + 2mixed) and it reached to 2.8% (n = 129 + 7mixed) during 2011 in urban coastal site. Subsequently SFR showed decreasing trend from 2012 to 2019 in urban coastal site (Table 1). Whereas, SFR was 0.5% (n = 81) in rural coastal site during 2004 and it showed slightly increasing trend up to 2007. In 2008 and 2009, the SFR was decreased in this rural coastal site (Table 2). It was then increased to 0.9% in the year 2010 (n = 86) and it reached the maximum of 1.2% in the year 2011 (n = 196) in rural coastal site. Then from 2012 to 2019 SFR was drastically decreased to 0% (Table 2) in rural coastal site. Even though there was ups and down, the API was gradually decreased from 2004 (63.2%) to 2019 (0.51%) in urban coastal area and 23.16–0.177% in rural coastal area (Tables 1 and 2). Similarly, AFI was also decreased from 2004 (14.5%) to 2019 (0.03%) in urban coastal area and 2.39–0% in rural coastal area (Tables 1 and 2).

3.3. ABER, age and sex wise malaria prevalence

As per the national guideline the annual blood smear examination rate should be 10 & above. The calculated ABER in both the study sites were found to be above 10% in all the years (Tables 1 and 2). The age wise distribution of malaria was analysed based on the five different age groups viz., 0–1, 2–4, 5–8, 9–14, 15 and above. The present analysis showed that the malaria prevalence (both P.v. and P.f.) was very high in adult age group of 15 years and above in Besant Nagar (76.1%) as well as in Pamban (69.5%)

(Fig. 2). The sex wise malaria prevalence analysis showed that the male population observed to be more affected with 69.44% and 72.43% by P.v and P.f, respectively in urban coastal site. Similarly, the male population found to be more affected with 74.57% and 76.65% by P.v and P.f, respectively in rural coastal site. There was no mortality due to malaria in both the coastal study sites during the study period.

3.4. Temperature and malaria prevalence

Climatic variability is considered as the key determinant to the transmission of malaria. In particular, rise in temperature is directly related to increase in malaria transmission. In the present study, malaria cases (P.v. and P.f.) were high during summer season. The average annual malaria cases during summer season were found to be 37.73% and 42.81% in urban (Besant Nagar) and rural (Pamban) coastal sites, respectively. The selected endemic coastal study sites of present investigation have almost same summer climate. The summer season begins in the month of March and continues till May but the same temperature extends till June. Our study coincides the result of Baghbanzadeh *et al* [19], who had reported that the malaria epidemics and positive case increased during summer season in India.

Figure 3 and 4 shows the correlated results of annual total malaria case with highest maximum temperature. In urban coastal site, highest malaria case was recorded in 2005, when the highest maximum temperature was 41.3°C. Malaria case was started to decline in 2006 and less case was recorded in 2007, but the temperature was increased to 43°C. Again in 2011, the malaria case was increased significantly when the temperature was 41.7°C. There was a sudden reduction in malaria cases in 2012 and recorded declining malaria trend in the subsequent years. The temperature was also showed variations after 2014 and notably decreased below 40°C during 2015 (Fig. 3). In Pamban the occurrence of malaria case was drastically increased during 2010 when the temperature increased. However, during 2011 and 2012 the recorded case was high even when the temperature was decreased (Fig. 4). In Besant Nagar, the recorded *P. falciparum* case was very high during 2005 and then decreasing trends were observed except the year 2011. In Pamban, decreasing trends were observed in *P. falciparum* malaria except the year 2007 and 2011.

3.5. Coastal malaria and mosquito vectors

Anopheles stephensi (Liston) is the urban vector in India responsible for the malaria transmission in Chennai areas (urban coastal). *An. stephensi* breeds profusely in overhead tanks (OHT), wells and cement cisterns etc. *Anopheles culicifacies* (Giles) is the rural vector in India, which transmit malaria in Rameshwaram islands (rural coastal). It breeds mostly in pits around the coconut plantations [20, 21]. Our survey also recorded the presence of *An. stephensi* in Pamban coastal areas (unpublished data). The larval and adult density of the malaria vector is continuously monitored and mosquito control measures are being regularly carried out.

3.6. Coastal malaria and drug resistance

Earlier, some investigators reported the chloroquine resistance *P. falciparum* from Chennai [22–24]. Similarly, chloroquine resistance *P. falciparum* has been reported from Rameswaram Island during 2007 [25]. Recently, *P. falciparum* resistance has been reported to artemisinin-based combination treatment in coastal states of India like West Bengal, Andhra Pradesh and Orissa [26–28]. However, there is no resistance recorded on *P. falciparum* against artemisinin-based antimalarials in these coastal study sites.

3.7. Urban and Rural perspectives

The total *p. falciparum* cases in urban (Besant Nagar) and rural (Pamban) sites are shown year wise in Figs. 3 and 4. From 2004 to 2008, similar malaria trend was observed. The revision of drug policy during 2008 recommended the use of AS + SP in districts where more than 90% of *P. falciparum* is reported. This led to the reduction of *P. falciparum* case in the year 2009 and only 31 and 58 *P. falciparum* positive case reported from urban, and rural site, respectively. Again, increase of *P. falciparum* case was observed during 2010 and it reached a peak in 2011 in both study localities (Tables 1 and 2). However, the reported number of *P. falciparum* case in 2011 was high in rural (n = 196) than urban site (n = 129). Subsequently, drastic reduction of *P. falciparum* case was observed in both the sites from 2012 onwards. The occurrence of *P. vivax* was comparatively very high than *P. falciparum* in both

urban and rural areas and the *P. vivax* positive case reached a peak during 2011 and 2012 in urban, and rural site, respectively. Subsequently, *P. vivax* positive case showed declining trend in both localities (Figs. 3 and 4).

4. Discussion

Careful monitoring and surveillance of malarial cases is one way to reduce the menace, nonetheless the socio-economic status of rural and urban coastal areas play a vital role in malarial parasite transmission [29]. Socio economic status is connected with demographic changes in urban areas accelerated by migration, rapid industrialisation, hectic construction activity, density of population, scarcity of drinking water and tropical climate etc [30]. documented that malaria is highly prevalent among individuals with low socio-economic factors. Malaria is highly risky to people of Rameshwaram district, which is directly linked to low levels of education, low levels of income, outdoor sleeping, fishing in nearby coastal areas, night stay in temporary sheds during fishing and population movement. The environmental factors like uninterrupted wind leading to formation of pits on the seashore and pits made by coconut tree growers for drying coconut leaves are the main reasons for *An. culicifacies* population increase and perpetuate malaria in Pamban coastal pocket. Similarly, it is a tough task to tackle malaria in metropolitan city like Chennai, where moving population alone more than a lakh per day and the city is thickly populated. Here, urban slum contributes considerable number of malaria positive cases connected to people's low socio-economic status. Further, the suitable humid climatic condition, breeding places like OHT's (overhead tanks), wells, and cemented tanks are conducive for the vector mosquito *An. stephensi* propagation and malaria transmission in Besant Nagar coastal pocket.

In spite of continued surveillance, EDCT, health awareness campaign, reaching out public and school children by the health workers, and other research activities as described in 'National Framework for Malaria Elimination in India 2016–2030' [31] brought many victories in successful control of malaria in these coastal areas. Essentially, the imparted training to all lab technicians has improved malaria diagnosis. Moreover, the successful implementation of new "National Drug Policy on Malaria" with artemisinin-based combination therapy functioned well and reduced malaria parasite load in the community. Further, sustained larval control activities with *Bacillus thuringiensis israelensis* (Bti) in water holding pits and *Poecilia reticulata* (Guppy fish) in wells, and minor environmental modifications like closing the unused pits certainly helped much in reducing vector mosquito population. On the other hand, two rounds of "Indoor Residual Spray" (IRS) in every year with chemical insecticide in Pamban areas has yielded fruitful result in adult vector control. In recent decades, malaria positive cases have significantly reduced in these two coastal pockets [32, 33]. Such drastic reduction of malaria morbidity trends reflects the achievement and catalyse further declines to zero cases towards malaria elimination, and malaria free-future.

5. Conclusion

In summary, the average annual malaria cases (P.v. and P.f.) increased in summer season (37.73% in Besant Nagar and 42.81% in Pamban) and *P. vivax* was higher than *P. falciparum* in both urban and rural coastal areas. This study observed mixed infection of P.v. & P.f. only in urban coastal area (0.3%). This study report that the malaria prevalence was very high in adult age group (15 years and above) in both Besant Nagar (76.1%) and Pamban (69.5%) and male population was more affected. It is also observed that the revision of drug policy in standard interval prevented the formation of resistance. The upcoming challenges like drug resistance in malaria parasite, insecticide resistance in vector mosquitoes, change in vector bionomics, vectorial capacity of each sibling species of *An. culicifacies*, and role of *An. stephensi* in transmission, seasonal parasite load in mosquito vectors, asymptomatic malaria, climate change, environmental disturbance due to any natural calamities, and other unfamiliar changes pose major threat in coastal malaria elimination.

Declarations

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Contributions

A.D.R., N.J and R.A designed the study. A.D.R., C.S.K., S.B. and P.N.U. collected data. A.D.R., C.S.K., P.T. and A.N. analysed data. A.D.R., J.A.J. and C.S.K. interpreted the data. A.D.R. and C.S.K. prepared the manuscript. All authors contributed to writing of the final manuscript, reviewed, and approved the manuscript as submitted.

Ethics declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Tables

Table 1 Year wise malaria surveillance and prevalence in urban coastal site (Besant Nagar).

| Year | Examined | Positive cases | | | Total Positive | SPR (%) | SFR (%) | ABER (%) | API (%) | AFI (%) | Male | | Female | |
|------|----------|----------------|-----|--------------------|----------------|---------|---------|----------|---------|---------|------|-----|--------|-----|
| | | P.v | P.f | Mixed* (P.v & P.f) | | | | | | | P.v | P.f | P.v | P.f |
| 2004 | 5248 | 1798 | 537 | 5 | 2340 | 44.6 | 10.3 | 16.2 | 63.2 | 14.5 | 1349 | 433 | 449 | 109 |
| 2005 | 7429 | 2769 | 635 | 19 | 3423 | 46.1 | 8.8 | 16.8 | 92.5 | 17.2 | 1938 | 491 | 831 | 163 |
| 2006 | 6797 | 1912 | 300 | 4 | 2216 | 32.6 | 4.4 | 15.6 | 59.9 | 8.11 | 1330 | 211 | 582 | 93 |
| 2007 | 4403 | 1166 | 102 | 1 | 1269 | 28.8 | 2.3 | 14.8 | 34.3 | 2.76 | 799 | 67 | 367 | 36 |
| 2008 | 5504 | 1426 | 139 | 4 | 1569 | 28.3 | 2.5 | 14.6 | 42.4 | 3.76 | 963 | 90 | 463 | 53 |
| 2009 | 5292 | 1165 | 31 | 1 | 1197 | 22.6 | 0.6 | 14.5 | 32.4 | 0.84 | 793 | 24 | 372 | 8 |
| 2010 | 4747 | 1298 | 87 | 2 | 1387 | 29.2 | 1.8 | 14.1 | 37.5 | 2.35 | 896 | 60 | 402 | 29 |
| 2011 | 4756 | 2194 | 129 | 7 | 2330 | 49.0 | 2.8 | 12.1 | 63 | 3.49 | 1471 | 89 | 723 | 47 |
| 2012 | 5038 | 1812 | 73 | 8 | 1893 | 37.5 | 1.6 | 12.8 | 51.2 | 1.97 | 1229 | 58 | 583 | 23 |
| 2013 | 5352 | 830 | 61 | 2 | 893 | 16.6 | 1.1 | 12.6 | 24.1 | 1.65 | 587 | 42 | 243 | 21 |
| 2014 | 3842 | 488 | 45 | 3 | 536 | 14.0 | 1.2 | 12.8 | 14.5 | 1.22 | 344 | 30 | 144 | 18 |
| 2015 | 2879 | 301 | 28 | 3 | 332 | 10.4 | 1.0 | 11.8 | 8.97 | 0.76 | 208 | 18 | 93 | 13 |
| 2016 | 1718 | 120 | 7 | 0 | 127 | 7.3 | 0.4 | 11.6 | 3.43 | 0.19 | 84 | 4 | 36 | 3 |
| 2017 | 2046 | 106 | 4 | 0 | 110 | 5.1 | 0.2 | 10.8 | 2.97 | 0.11 | 81 | 2 | 25 | 2 |
| 2018 | 1336 | 43 | 3 | 0 | 46 | 3.2 | 0.2 | 10.2 | 1.24 | 0.08 | 33 | 3 | 10 | 0 |
| 2019 | 1158 | 17 | 1 | 1 | 19 | 1.6 | 0.1 | 10.1 | 0.51 | 0.03 | 9 | 2 | 8 | 0 |

* All mixed cases are considered as P.f. case during sex wise distribution analysis.

Table 2 Year wise malaria surveillance and prevalence in rural coastal site (Pamban).

| Year | Examined | Positive cases | | | Total Positive | SPR (%) | SFR (%) | ABER (%) | API (%) | AFI (%) | Male | | Female | |
|------|----------|----------------|-----|--------------------|----------------|---------|---------|----------|---------|---------|------|-----|--------|----|
| | | Pv | Pf | Mixed* (P.v & P.f) | | | | | | | P.v | Pf | P.v | Pf |
| 2004 | 15138 | 703 | 81 | 0 | 784 | 5.2 | 0.5 | 16.6 | 23.16 | 2.39 | 492 | 61 | 211 | 20 |
| 2005 | 14379 | 638 | 94 | 0 | 732 | 5.1 | 0.7 | 18.2 | 21.62 | 2.78 | 479 | 75 | 159 | 19 |
| 2006 | 7176 | 481 | 61 | 0 | 542 | 7.6 | 0.9 | 17.4 | 16.01 | 1.8 | 360 | 42 | 121 | 19 |
| 2007 | 18882 | 779 | 174 | 0 | 953 | 5.0 | 0.9 | 16.8 | 28.15 | 5.14 | 585 | 131 | 194 | 43 |
| 2008 | 12603 | 759 | 95 | 0 | 854 | 6.8 | 0.8 | 15.7 | 25.23 | 2.81 | 600 | 70 | 159 | 25 |
| 2009 | 8367 | 527 | 58 | 0 | 585 | 7.0 | 0.7 | 18.6 | 17.28 | 1.71 | 448 | 42 | 79 | 16 |
| 2010 | 9739 | 915 | 86 | 0 | 1001 | 10.3 | 0.9 | 19.0 | 29.57 | 2.54 | 650 | 69 | 265 | 17 |
| 2011 | 17040 | 1234 | 196 | 0 | 1430 | 8.4 | 1.2 | 18.0 | 42.24 | 5.79 | 864 | 158 | 370 | 38 |
| 2012 | 21296 | 1253 | 94 | 0 | 1347 | 6.3 | 0.4 | 16.0 | 39.79 | 2.78 | 892 | 68 | 361 | 26 |
| 2013 | 15951 | 328 | 33 | 0 | 361 | 2.3 | 0.2 | 17.5 | 10.66 | 0.97 | 292 | 28 | 36 | 5 |
| 2014 | 14527 | 384 | 7 | 0 | 391 | 2.6 | 0.04 | 14.8 | 11.55 | 0.21 | 298 | 5 | 86 | 2 |
| 2015 | 16253 | 193 | 3 | 0 | 196 | 1.2 | 0.01 | 14.5 | 5.789 | 0.09 | 144 | 3 | 49 | 0 |
| 2016 | 13369 | 77 | 3 | 0 | 80 | 0.57 | 0.02 | 14.7 | 2.363 | 0.09 | 56 | 3 | 21 | 0 |
| 2017 | 8961 | 103 | 0 | 0 | 103 | 1.1 | 0.0 | 14.6 | 3.042 | 0 | 83 | 0 | 20 | 0 |
| 2018 | 32585 | 13 | 0 | 0 | 13 | 0.03 | 0.0 | 14.5 | 0.384 | 0 | 12 | 0 | 1 | 0 |
| 2019 | 32582 | 6 | 0 | 0 | 6 | 0.01 | 0.0 | 14.5 | 0.177 | 0 | 4 | 0 | 2 | 0 |

* All mixed cases are considered as P.f. case during sex wise distribution analysis.

Figures

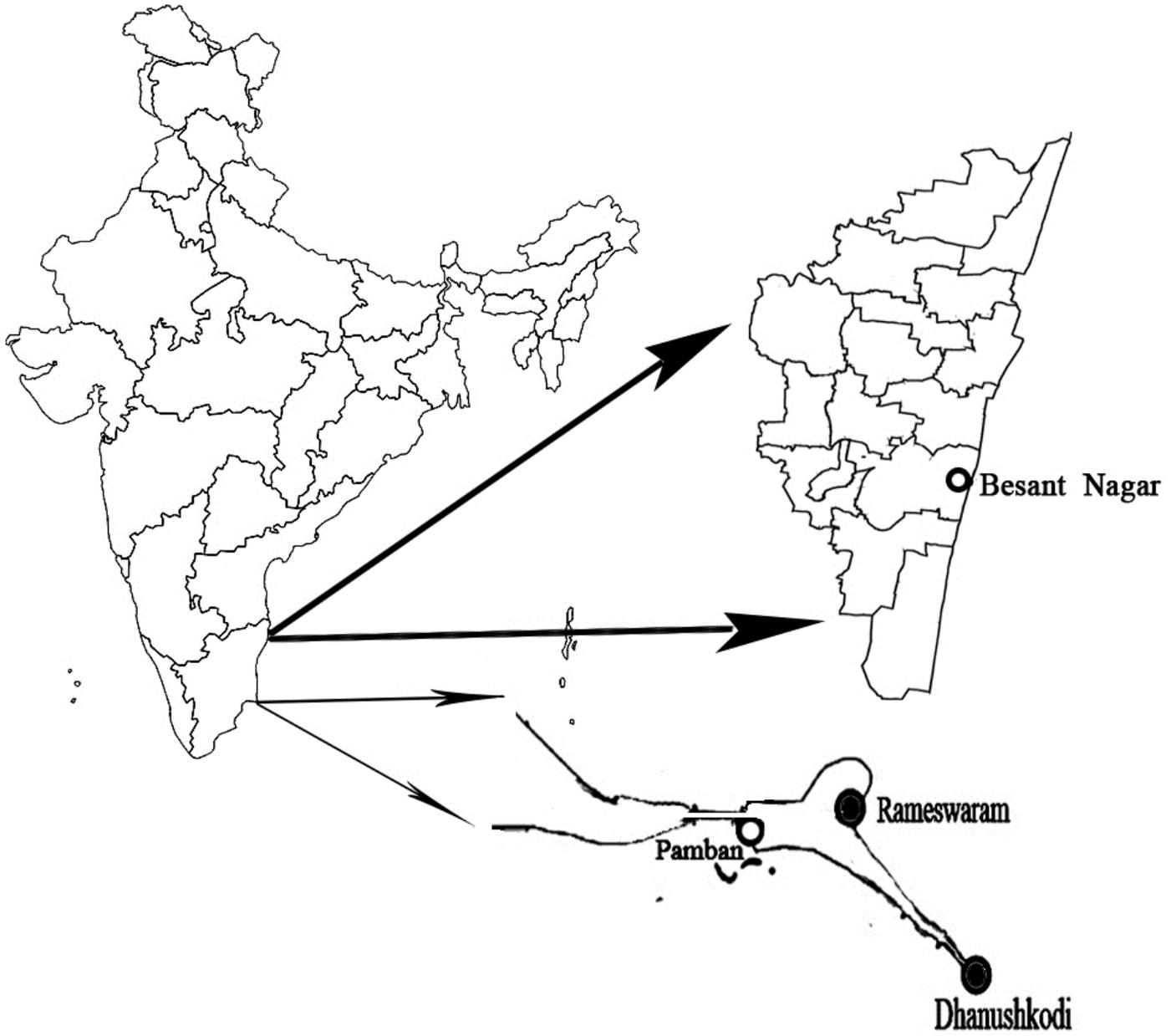


Figure 1

Diagram shows the two coastal study sites

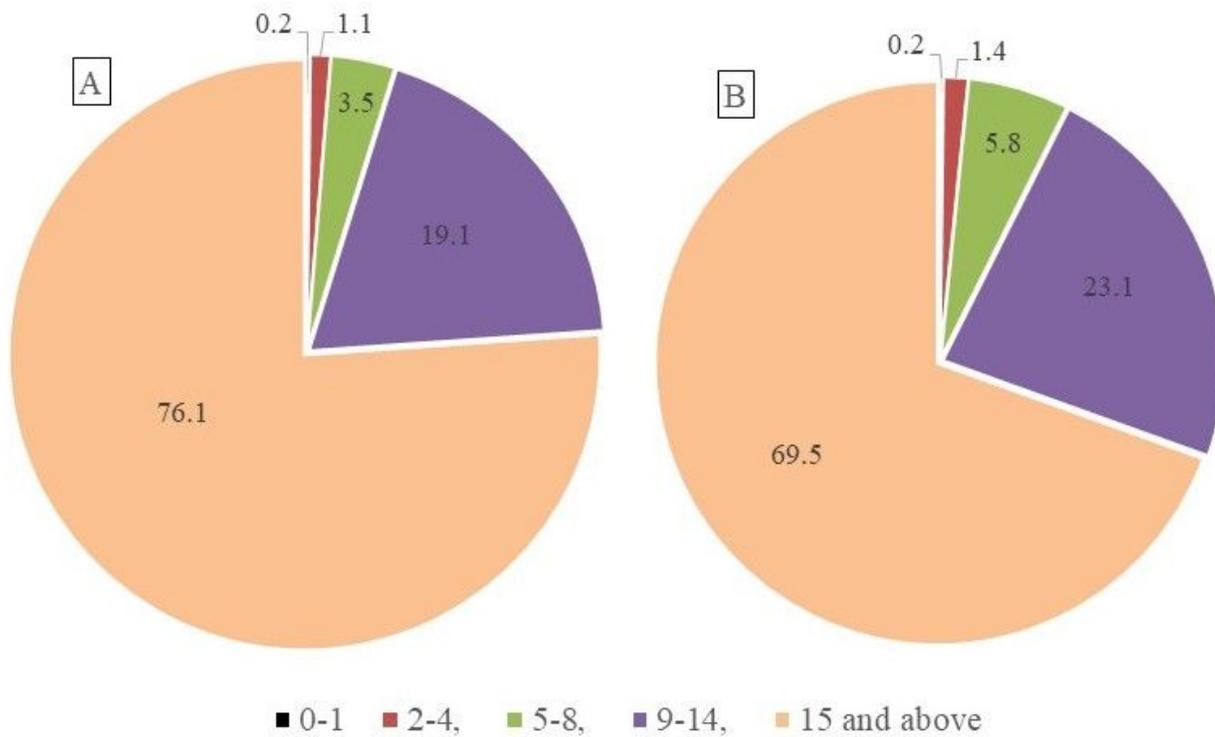


Figure 2

Figure (A) presents age wise distribution of malaria cases (P.v & P.f) in Besant Nagar (in %) and figure (B) presents age wise distribution of malaria cases (P.v & P.f) in Pamban (in %).

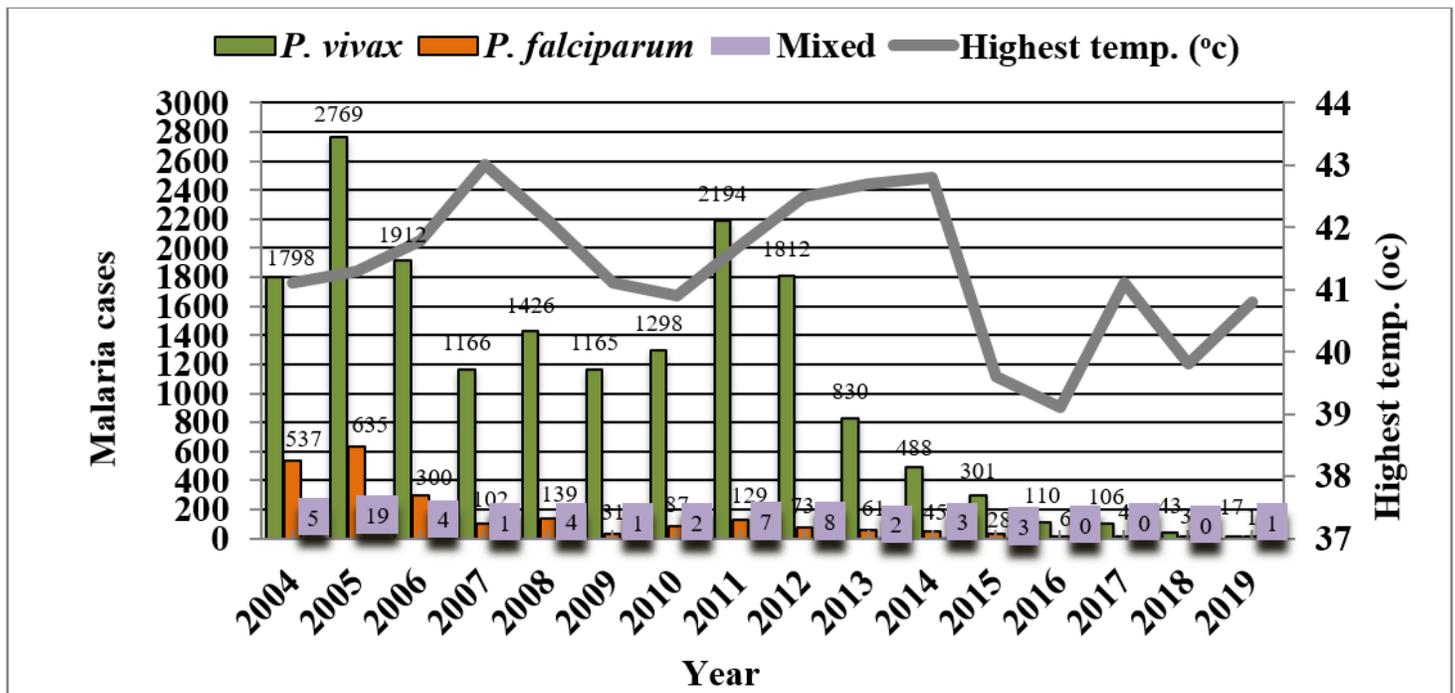


Figure 3

Besant Nagar malaria data compared with highest temperature

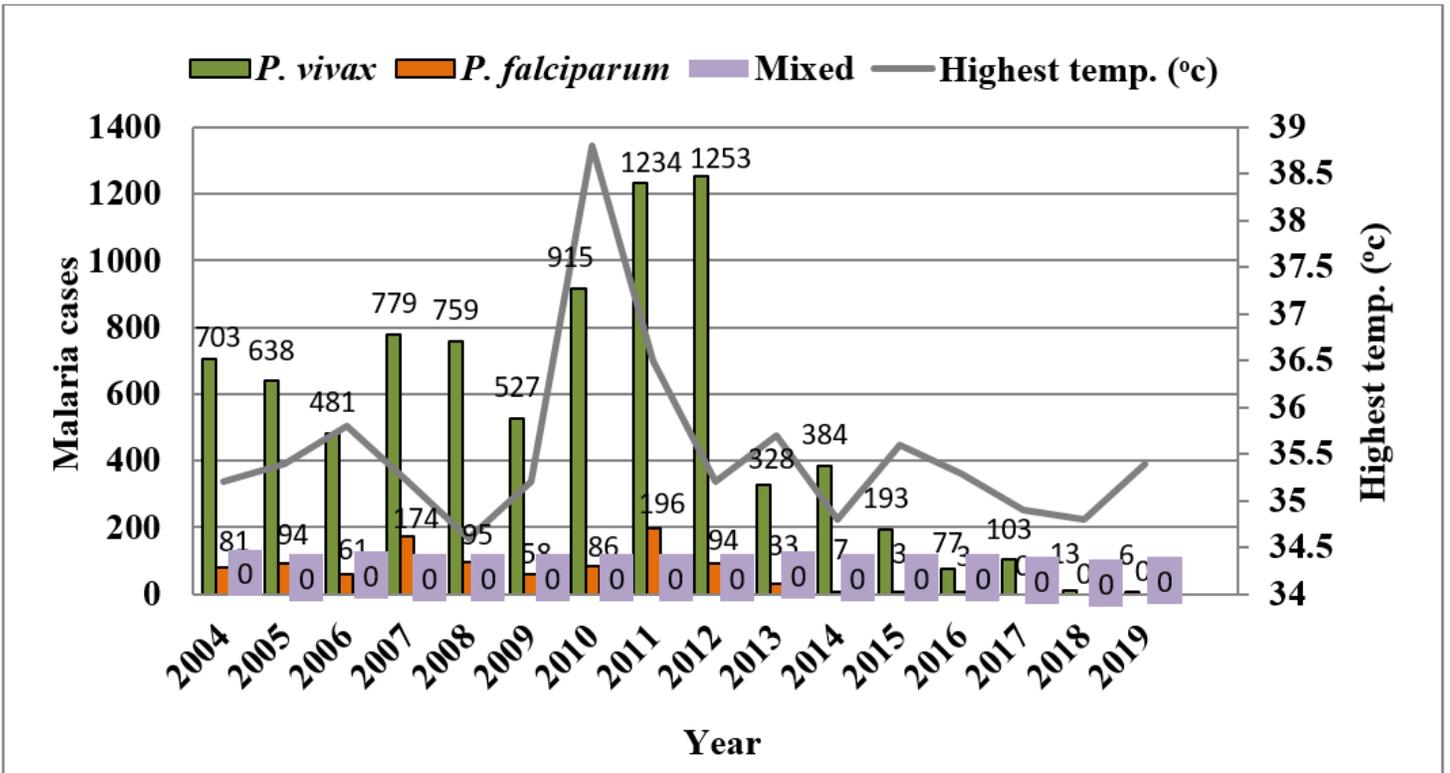


Figure 4

Pamban malaria data compared with highest temperature