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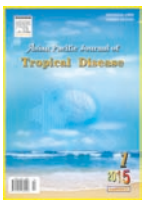

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Diversity of mosquitoes and larval breeding preference based on physico-chemical parameters in Western Ghats, Tamilnadu, India

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ABSTRACT

Objective: To study the diversity and distribution of mosquitoes in Western Ghats of Coimbatore and Nilgiris District, Tamilnadu, India.

Methods: Random collections were carried out during August-2013 to July-2014 in cesspits, animal footprints, rock holes, tree holes, drainages at study areas of Marudhamalai, Valparai, Mettupalayam in Coimbatore District and Dhottapeta, Coonoor, Gudalur in Nilgiris District of Tamilnadu, India by using suction tube and kerosene pump. Mosquitoes were identified by standard entomological procedures.

Results: A total of 1018 mosquitoes (larvae and pupae) were collected from all over the study areas comprising 6 genera and 23 species. They are, *Culex mimulus, Culex pseudovishnui, Culex quinquefasciatus, Culex vishnui, Culex khazani, Culex uniformis, Heizmannia chandi, Heizmannia grenii, Heizmannia indica, Oclerotatus anureostriatus, Oclerotatus albotaeniatis, Oclerotatus deccanus, Oclerotatus gubernatoris, Aedes aegypti, Aedes albopictus, Aedes edwardsi, Aedes krombeini, Toxorhynchites minimus, Toxorhynchites splendens, Anopheles aitkenii, Anopheles barbirostris, Anopheles culiciformis and Anopheles maculatus.* Shannon-Weaver diversity index, Margalef's index of richness and Simpsons dominance index was also studied. From 6 sites, the highest mosquitoes were collected from Marudhamalai (309) and the least mosquitoes were collected in Mettupalayam (68). The study determined whether physicochemical characteristics differ between habitats with high and low presence of mosquito larvae. Based on Margalef's index of richness (D_{mg}), the highest values were present in Mettupalayam (5.214) study area and the lowest in Marudhamalai (3.837). It can be concluded from Shanon-Weaver index of diversity that, the highest values were present in Mettupalayam (2.947) and the least value were in Gudalur (2.410) during the study period.

Conclusions: In areas with reservoirs of disease, mosquito abundance information can help to identify the areas at higher risk of disease transmission. The study identifies mosquito species density and diversity of culicine and anopheline larvae. Hence, this research contribution has more significance for basic biological research and developing control strategies for vector borne diseases.

1. Introduction

Mosquitoes are of medical, veterinary and economic concern due to their role as vectors of human and animal diseases. Mosquitoes exploit almost all types of lentic aquatic habitats for their breeding. Many species prefer habitat with vegetation, while some breed in open, sunlit pools and a few species breed in tree holes or the leaf axils of some plants[1]. Every year there are more than one billion cases and over one million deaths due to vector-borne diseases such as malaria, dengue, Schistosomiasis, human African trypanosomiasis, leishmaniasis, Chagas disease, yellow fever, Japanese encephalitis and onchocerciasis, globally[2]. The most important disease transmitting and nuisance causing mosquitoes belong to the genera *Anopheles, Culex, Aedes, Mansonia,*

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Haemogogus, Sabithes and *Psorophora*. In India, the various species of *Anopheles*, *Culex*, *Aedes* and *Mansonia* are important as carriers of vector borne disease[3].

The Southern Region of India, the physiography of which is totally different from the rest of the country is endowed with very rich flora and fauna. The high hilly terrains, foothills, deep forestation, high rainfall, high humidity, moderate climate in the plains and valleys and cold climate in high altitudes are the main ecological components of this region which has very rich mosquito fauna. Many areas of this region are endemic for different mosquito borne diseases like malaria, filariasis, Japanese encephalitis, dengue. The studies on mosquitoes in this region are limited and quite old. In India, most of the work on mosquitoes was previously carried out by Barraud and Christophers in 1930's. Tamil Nadu is the only state in India which has both the Western Ghats and the Eastern Ghats mountain ranges met in the Nilgiris hills. The Western Ghats dominate the entire western border with Kerala, effectively blocking much of the rain bearing clouds of the south west monsoon from entering the state.

Most of the mosquito faunastic studies in India have been done are related to the geographic location. They are widely distributed throughout the world and occur in a variety of habitats[4]. Malaria, filariasis, Japanese encephalitis, dengue fever and dengue haemorrhagic fever are the major mosquito borne disease in India[5]. Recently, the sudden eruptions of these diseases have been re-emerging in many parts of the world with multiple foci owing to continuous circulation in nature amid wild birds or mammals[6]. Some of the chemical properties of the larval habitat related to vegetation, pH, optimum temperature, concentration of ammonia, nitrate and sulphate have been found to affect the larval development and survival[7]. Extensive studies were carried out on these habitats in various parts of the world. But, the knowledge on the Indian mosquito species diversity based on chemical properties of breeding sites and its nature is meagre[8].

The study related to mosquitoes breeding sites provides a basic knowledge essential to evaluate for effective control measures[9]. The habitat reduction is the only way to curb the populations and its borne diseases than after arboviral eruptions with multiple magnitude effects. Earlier reports are accounted for elimination of breeding sites will be a more effective strategy to suppress disease transmittance. Studies have also revealed that convenient aquatic breeding sites for certain mosquito species[10]. Mosquitoes illustrate preference to water with suitable pH, optimum temperature, dissolved oxygen, concentration of ammonia, nitrate for their breeding[11]. The physical barriers of a tree hole aquatic habitat sustain discrete communities in it that are mostly subsets of the larger forest ecosystem[12].

The selected study areas are Marudhamalai, Valparai and Mettupalayam in Coimbatore District and Dhottapeta, Coonoor, Gudalur in Nilgiris District, Tamilnadu, India which are well known tourist places in Western Ghats. The people visit these tourist places from all over the world daily. So we select these places for mosquito diversity studies, because study areas are acting as a suitable place for vector borne disease transmission from one place to another place. The present study deals with mosquito diversity and physico-chemical parameters in various water samples, which influences mosquito larval survival, growth, development related to the species distribution under laboratory condition.

2. Materials and methods

2.1. Study area

This work was done under surveillance on experimental basis. Here, some preliminary investigation and selection of the field survey sites was done by using local government records based on mosquito vector borne disease records. The studies on the mosquito diversity, identification and analysis of larval breeding sites preference in physco-chemical parameters were also carried out in Marudhamalai, Valparai and Mettupalayam in Coimbatore District, Dhottapeta, Coonoor, Gudalur in Nilgiris District of Tamilnadu, India during August 2013 to July 2014 (Figure 1). The study areas were selected based on the human and animal intervention.

The location of the study area was closely associated with water bodies which including fresh water, polluted water, pond and plantation fields. Month wise and region wise study was carried out in the study area to monitor the prevalence of mosquitoes and collect mosquito samples for ten-month period of time.

2.1.1. Coimbatore

Coimbatore is located at the foothills of Western Ghats a mega biodiversity hot spot. It is the third largest city in Tamilnadu located at 11.0183° N, 76.9725° E. The city has an average elevation of 442 m above the sea level[3]. In Coimbatore District three sites *viz.*, Marudhamalai, Valparai and Mettupalayam were selected for the present work. The mean maximum and minimum temperature during the summer and winter varies between 35 ℃ to 18 ℃. The highest temperature ever recorded is 41 ℃ and lower is 12 ℃. The average annual rainfall is around 700 mm with the north east and the south west monsoons contributing to 47% and 28% respectively to the total rainfall[13].

2.2.2. Nilgiris

The Nilgiris is located on top of the Western Ghats hills. It has a very cool climate and lots of tea vegetation's, located in 11.4000° N, 76.7000° E. The Nilgiris District is situated at the elevation of 900 to 2636 m above the mean sea level. This region has extensive tea garden plantations, bamboo forests, reserve forests, paddy fields and is frequently affected by floods. The ecological peculiarities of this area provide ample mosquito breeding sites for mosquito. In Nilgiris District, Dhottapeta, Coonoor and Gudalur were selected for the present study based on tourist intervention and another one most important reason for chosen is inadequate facilities of the hospital service to the tribes.

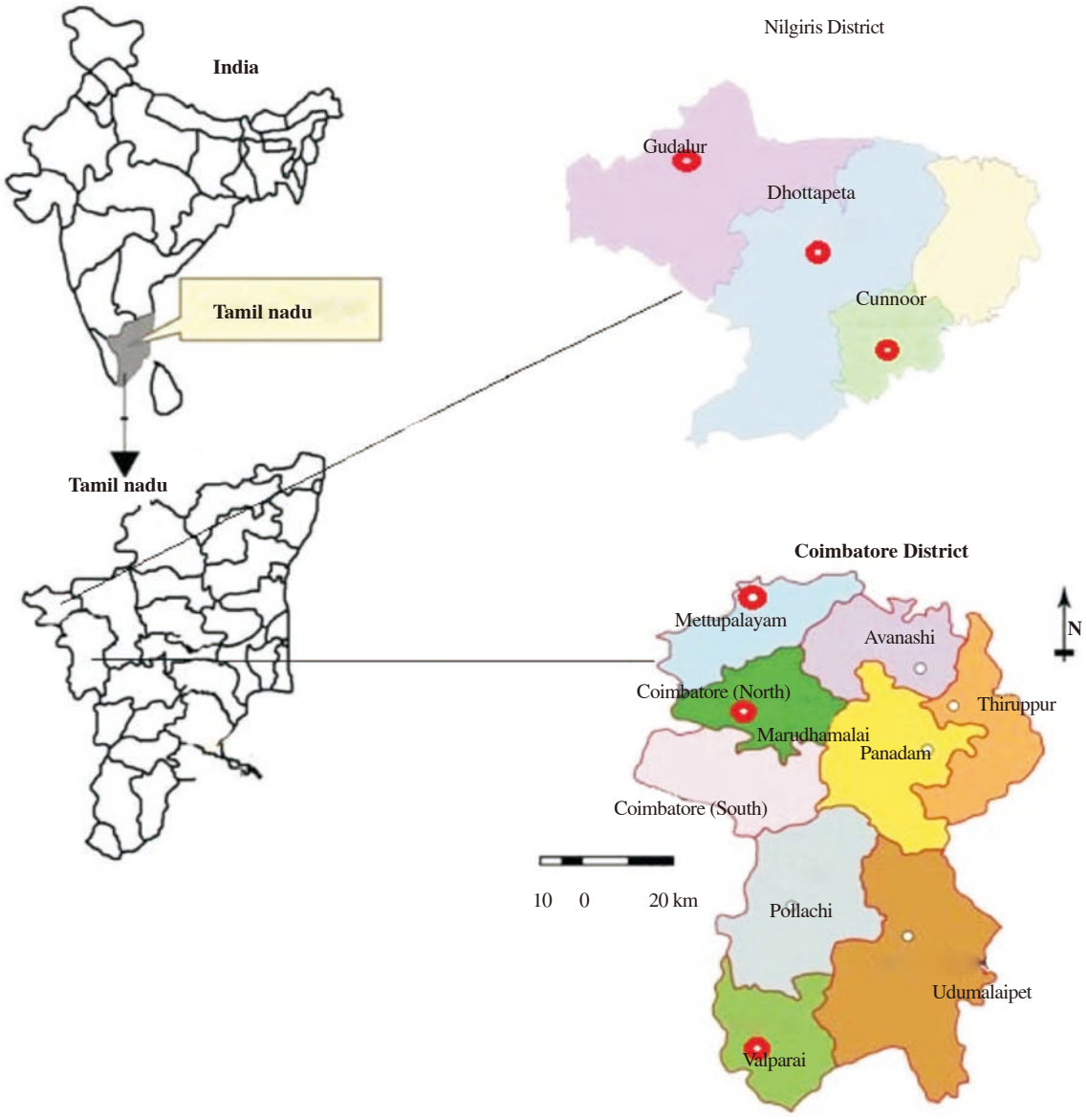

Figure 1. Study areas in Western Ghats, Tamilnadu, India.

2.2. Larval survey and collection

In each study site, the natural containers such as bamboo stumps, coconut shells, tree holes, leaf axis as well as the artificial containers such as earthen pots, plastic cups, discarded bottles and tires (Figure 2) were examined for the presence of mosquito larvae and resting adults. Sampling was made by using 250 mL dipper, adopting suggested[14] dipping methods of the World Health Organization (1975) with slight modifications. Random collections of immature larvae and pupae were also made from all temporary water bodies, created mainly after the rain. In smaller water bodies, where dipping was not possible, contents (water and immature) were collected by small siphon or kerosene pump.

The collection was avoided immediately after heavy rain, because at that time there was more possibility of the immature being washed out from their breeding places[15]. The dippers were always immersed slowly in the breeding places at an angle of 45° for the obvious reason of not to disturb the immature vectors. After each dipper the collected immatures were transferred to plastic containers (500 mL capacity) for laboratory observation by using a pipette. All the containers were properly labeled and were brought to the Department of Zoology, Annamalai University.

2.3. Identification of specimens

Field collected mosquitoes first and second instars were reared in the laboratory[8]. The collected immature (larvae and pupae) were brought to the laboratory and cultured in separate trays, fed with larval food (yeast and dog biscuits in 3:1 ratio) and then identified. Third and fourth instars were identified under hand lens or microscope in living condition. If the larvae were very active during identification they were taken in a tube and applied little chloroform vapor and then it was placed in slide. Pupae allowed to develop as adult and then identified by using standard keys[16,17]. The voucher specimens are present in Department of Zoology, Annamalai University, Tamilnadu, India.

Figure 2. Different habitats acting as breeding places of mosquitoes in the study areas of Western Ghats (Coimbatore and Nilgiris) Tamilnadu, India. a: Cess pit; b: Rock hole; c: Container; d: Forest staging water; e: Tree holes; f: Discarded tires.

2.4. Physico-chemical characteristics

Water samples were collected from all selected mosquito breeding sites in all study areas by small container each 500 mL. The bottles were covered with perforated caps, labeled properly with date and place of collection. The collected water samples carried carefully and transferred to the laboratory. The breeding water characteristics pH, dissolved oxygen (mg/L), conductivity (μS/cm), total dissolved solids (mg/L), salinity (%), turbidity (FTU), were recorded using standard procedure[18].

2.5. Data analysis

2.5.1. Quantitative analysis

The important quantitative analysis such as density, frequency, and abundance of mosquito species were determined according to Curtis and McIntosh[19].

2.5.2. Density

Density is an expression of the numerical strength of a species where the total number of individuals of each species in all the quadrats is divided by the total number of quadrats studied.

Density was calculated by the equation:

$$\text{Density} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats studied}}$$

2.5.3. Importance value index

This index is used to determine the overall importance of each species in the community structure. In calculating this index, the percentage values of the relative frequency, relative density and relative dominance were summed up together and this value was designated as the importance value index of the species[20].

2.5.4. Relative frequency

The degree of dispersion of individual species in an area in relation to the number of all the species occurred.

$$\text{Relative frequency} = \frac{\text{Number of occurence of the species}}{\text{Number of occurence of all the species}} \times 100$$

2.5.5. Species richness, diversity and dominance indices

The species richness of the mosquitoes was calculated by using the method Margalef's index of richness (D_{mg}).

$D_{mg} = (S-1)/ \ln N$

Where, S is the total number of species, N is total number of individuals.

Species diversity and dominance were evaluated by using Shannon's (1963) diversity index and Simpson's (1949) index of dominance which were calculated using important value index of species.

The formula for calculating the Shannon diversity index was

$H' = -\sum pi \ln pi$

Where, H' is the Shannon index of diversity, *p*i is the proportion of important value of the *ith* species ($pi = ni / N$), *n*i is the important value index of ith species and N is the important value index of all the species.

The equation used to calculate Simpson's index was

$D = \sum (pi)2$

Where, D is the Simpson index of dominance, *p*i is the proportion of important value of the ith species ($pi = ni / N$), *n*i is the important value index of *ith* species and N is the important value index of all the species). As D increases, diversity decreases and Simpson's index was therefore usually expressed as 1 – D or

1/ D.

3. Results

Environmental disturbances such as deforestation, urbanization and pollution have been widely acknowledged to play a key role in the emergence of many infectious diseases including mosquito-borne viruses. A random entomological survey has been conducted in the two districts of Tamilnadu like, Marudhamalai, Valaparai, Mettupalayam in Coimbatore District and Dhottapeta, Cunnor, Gudalur in Nilgiris District for collection of mosquito larvae and adults from different water bodies during August-2013 to July-2014. Overall field collected mosquito species are present in Table 1. During the field survey, we have collected 1018 mosquitoes in six genera. The collected mosquito generas are *Culex* (329), *Heizmannia* (81), *Ochlerotatus* (161), *Aedes* (286), *Toxorhynchites* (47) and *Anopheles* (114).

The highest mosquito genera collected in the selected study areas was in Marudhamalai having 30.35% (309), followed by Dhottapeta, Nilgiris District having 24.55% (250) and the least values are recorded in Mettupalayam 11% (68) (Figure 3). Mosquito species collected belongs to 23 species of 6 genera: *Aedes*: 4 spp., *n* = 286 [Marudhamalai (92), Valparai (30), Mettupalayam (11), Dhottapeta (53), Coonoor (37), Gudalur (63)]; *Culex*: 6 spp., *n* = 329 [Marudhamalai (121), Valparai (45), Mettupalayam (18), Dhottapeta (78), Coonoor (27), Gudalur (40)]; *Oclerotatus*: 4 spp., *n*=161 [Marudhamalai (50), Valparai (13), Mettupalayam (10), Dhottapeta (46), Coonoor (27), Gudalur (15)], *Heizmannia*: 3 spp., *n*=81 [Marudhamalai (18), Valparai (3), Mettupalayam (12), Dhottapeta (30), Coonoor (15), Gudalur (3)], *Toxorhynchites*: 2 spp., *n*=47 [Marudhamalai (8), Valparai (6), Mettupalayam (2), Dhottapeta (21), Coonoor (7), Gudalur (3)]; and *Anopheles*: 4 spp., *n*=114 [Marudhamalai (20), Valparai (15), Mettupalayam (15), Dhottapeta (22), Coonoor (26), Gudalur (16)].

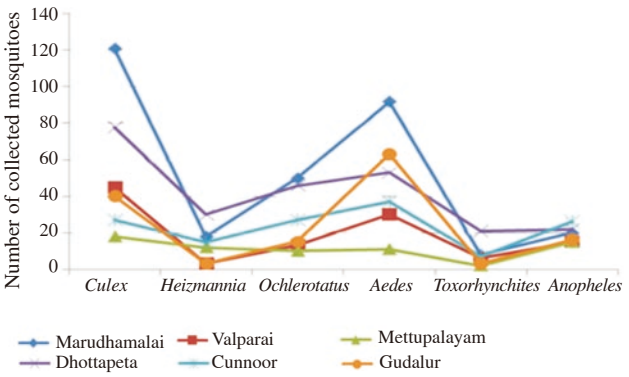

Figure 3. Mosquitoes genera collected in Coimbatore and Nilgiris Districts, Tamilnadu, India.

Based on the statistical analysis like Margalef's index of diversity (D_{mg}), the highest values were observed in 5.214 (Mettupalayam), followed by Valparai (4.662) and least species richness value are recorded in 3.837 in Marudhamalai study area during August-2013 to July-2014. The Simpson index of dominance (D) values were recorded, 13.226, 14.126, 16.514 in Coimbatore District and 17.527, 14.322 and 7.489 in Nilgiris District, Marudhamalai, Valparai, Mettupalayam and Dhottapeta, Coonoor, Gudalur study areas respectively during the study period. From the Shannon-Weaver diversity index, one of the study areas between six, Mettupalayam

Table 1
Mosquitoes species collected from the Coimbatore and Nilgiris Districts, Tamilnadu, India during August 2013- July 2014.

Name of the species	Coimbatore			Nilgiris			Total
	Marudhamalai	Valparai	Mettupalayam	Dhottapeta	Coonoor	Gudalur	
Culex mimulus	11	6	3	9	3	1	33
Culex pseudovishnui	31	11	2	17	2	4	67
Culex quinquefasciatus	33	13	6	18	10	19	99
Culex vishnui	28	6	4	16	2	12	68
Culex khazani	3	8	1	1	2	1	16
Culex uniformis	15	1	2	17	8	3	46
Heizmannia chandi	9	1	2	18	10	1	41
Heizmannia grenii	7	1	7	9	4	1	29
Heizmannia indica	2	1	3	3	1	1	11
Ochlerotatus anureostriatus	21	7	6	17	14	2	67
Ochlerotatus albotaeniatis	18	2	2	21	10	1	54
Ochlerotatus deccanus	9	3	1	7	2	1	23
Ochlerotatus gubernatoris	2	1	1	1	1	11	17
Aedes aegypti	41	9	3	14	16	37	120
Aedes albopictus	31	8	5	15	11	22	92
Aedes edwardsi	11	12	2	12	9	3	49
Aedes krombeini	9	1	1	12	1	1	25
Toxorhynchites minimus	6	2	1	12	6	2	29
Toxorhynchites splendens	2	4	1	9	1	1	18
Anopheles aitkenii	11	1	2	7	13	7	41
Anopheles barbirostris	6	2	3	1	4	2	18
Anopheles culiciformis	1	8	6	2	8	6	31
Anopheles maculatus	2	4	4	12	1	1	24
Total	309	112	68	250	139	140	1018

(2.947) having more mosquito species, followed by Dhottapeta (2.942) and the least value are recorded in Gudalur (2.410) (Table 2) during the study period August-2013 to July-2014.

Analysis of the physico-chemical characteristics of water in the collected mosquito breeding containers indicated that the pH ranged from 6.80 ± 0.13 in Valparai to 7.63 ± 0.18 in Gudalur whereas the conductivity (μS/cm) ranged from 162.9 ± 22.3 in Gudalur to 616.9 ± 93.5 in Mettupalayam. The lowest salinity (ppt) values recorded in Gudalur (0.09 ± 0.01) and the highest in Marudhamalai (0.34 ± 0.14) whereas the highest total dissolved solids (mg/L) values were recorded in Mettupalayam (302.3 ± 45.8) and the lowest in Gudalur (112.7 ± 12.1). The turbidity (NTU) of breeding water ranged from 20.70 ± 4.91 in Coonoor to 58.5 ± 76.6 in Valparai and the dissolved oxygen (%) ranged from 1.11 ± 0.06 in Coonoor to 2.11 ± 0.72 in Dhottapeta (Table 3).

During the study period of mosquito survey (larvae, pupae and adults), the *Aedes* genera had a highest relative frequency in Mettupalayam (45.0%) followed by *Culex* genera (40.17%) in Valparai of Coimbatore District and the least value were recorded in *Heizmannia* and *Toxorynchites* generas at Mettupalayam (Table 4). The occurrence of *Aedes* and *Culex* species in Coimbatore District led to cause fibrosis, chickungunya and dengue diseases in Coimbatore District. From the bar diagram (Figure 4), it was clearly evident that overall study area the *Culex* species having more density (54.83) when compared with other mosquito species followed by *Aedes* and the least value were represented by *Toxorhynchites* species.

Table 2

Statistical analysis of the richness, diversity and dominance indices in the selected study areas of Tamilnadu, India.

Name of the Measurement	Coimbatore			Nilgiris		
	Marudhamalai	Valparai	Mettupalayam	Dhottapeta	Coonoor	Gudalur
Total number of species (S)	23	23	23	23	23	23
Total number of individuals (N)	309	112	68	250	139	140
Nature log of species (In S)	3.135	3.135	3.135	3.135	3.135	3.135
Nature log of individuals (In N)	5.733	4.718	4.220	5.521	4.934	4.942
Margalef's index of richness (D_{mg})	3.837	4.662	5.214	3.984	4.458	4.452
Simpson index of dominance (D)	13.226	14.126	16.514	17.527	14.322	7.489
Shannon-Weaver index of diversity (H')	2.779	2.818	2.947	2.942	2.821	2.410

Table 3

Physico-chemical characteristics of container-breeding mosquitoes in Coimbatore and Nilgiris District, Tamilnadu, India.

Study sites	pH	Conductivity (μS/cm)	Salinity (ppt)	Total dissolved solids (mg/L)	Turbidity (NTU)	Dissolved oxygen (%)
Valparai	6.80 ± 0.13	537.4 ± 156.5	0.28 ± 0.08	263.4 ± 76.6	58.5 ± 76.6	1.46 ± 0.13
Maruthamalai	6.94 ± 0.17	411.6 ± 162.7	0.34 ± 0.14	130.8 ± 16.8	22.8 ± 7.08	1.26 ± 0.07
Mettupalayam	7.37 ± 0.06	616.9 ± 93.5	0.29 ± 0.05	302.3 ± 45.8	28.6 ± 7.18	1.14 ± 0.07
Coonoor	7.18 ± 0.08	529.6 ± 116.6	0.27 ± 0.06	260.3 ± 56.8	20.7 ± 4.91	1.11 ± 0.00
Gudalur	7.63 ± 0.18	162.9 ± 22.3	0.09 ± 0.01	112.7 ± 12.1	22.7 ± 3.08	1.30 ± 0.25
Dottapeta	7.41 ± 0.19	245.7 ± 34.8	0.18 ± 0.07	174.2 ± 65.6	21.3 ± 8.79	2.11 ± 0.72

Table 4

Relative frequency (%) of the mosquitoes species in the study areas during the study period August 2013-July 2014.

Name of the study area	Marudhamalai	Valparai	Mettupalayam	Dhottapeta	Coonoor	Mettupalayam
Culex	39.15	40.17	26.47	31.20	19.42	28.57
Heizmannia	5.82	2.67	17.64	12.00	10.79	2.14
Ochlerotatus	16.18	11.60	14.70	18.40	19.42	10.71
Aedes	29.77	26.78	16.17	21.20	26.61	45.00
Toxorhynchites	2.58	5.35	2.94	8.40	5.03	2.14
Anopheles	6.47	13.39	22.05	8.80	18.70	11.42

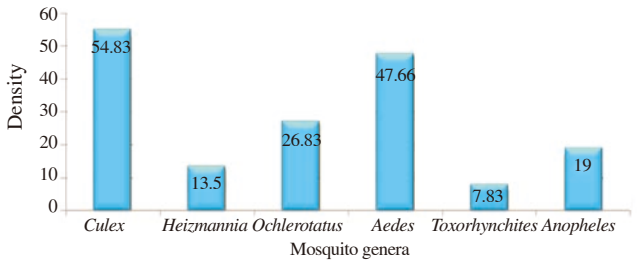

Figure 4. Density of the collected mosquitoes genera in the study areas during the study period August 2013-July 2014.

4. Discussion

The majority of the species preferred to breed in permanent breeding sites, especially natural sites in urban, semi-urban and peri-urban areas, while some species are more abundant in temporary breeding places. Moreover, South India is panic for mosquito borne disease outbreaks and more research is essential to fulfill the extensive knowledge gap regarding the ecology of culicids. Many species prefer habitat with vegetation while some breed in open, sunlit pools. A few species breed in tree holes or the leaf axils of some plants[21].

In the present study, the species diversity of all the study areas in both Coimbatore and Nilgiris Districts is comparatively high and the highest Shannon-Weaver diversity index values 2.947 was observed in Mettupalayam and the least value was observed in the Gudalur study area. This indicated that Mettupalayam study area is more possible to have mosquito borne vector diseases.

Water-holding containers produced by humans are the main important source of larval habitats for *Aedes* mosquitoes[22]. The quality of water as well as conditions of water containers seemed to contribute to the abundance of *Aedes* species in the study site. Besides, water chemistry of aquatic habitats may also play a vital role in determining the survival rate of mosquitoes. The ability of gravid mosquito females to distinguish among potential oviposition sites that will or will not support the growth, development and survival of their offspring are critical to the maintenance of the mosquito population[23].

The climate is obviously an important factor for the spread of most invasive mosquitoes. In addition to transportation, global climate changes could indeed increase the risk of vector invasion and the spread of vector-borne diseases even under temperate climate[24]. Usually Nilgiris (Dhottapeta, Coonoor and Gudalur) and Coimbatore (Marudhamalai, Valparai, Mettupalayam) Districts havE high humidity and cool climate when compared with other districts of Tamilnadu. This type of climate is suitable for mosquito development. The type of water required for mosquito oviposition is more or less specific to each species. Mosquito larvae are found in habitats possessing a wide range of physico-chemical factors, including salinity, dissolved organic and inorganic matter, degree of eutrophication, turbidity, air, water temperature, pH and sunlight[25,26].

Mosquitoes show preference for water with suitable pH, optimum temperature, dissolved oxygen, concentration of ammonia, nitrate. These physico-chemical parameters have been found to affect larval development and survival in breeding water. These physico-chemical parameters vary from one species to another. For instance, pH of 7.4 was found to be suitable for *Aedes* mosquitoes. The adult *Ae. albopictus* also known as 'Asian tiger mosquito' is the vector of chickungunya and dengue fever. Generally, as wild species they breed in rock holes and tree holes in forest areas, but due to deforestation this mosquito now adapted to breed in discarded tires in many parts of India[27].

The pH of the breeding water in the present study ranged from 6.80 to 7.63 and showed a positive correlation with larval density. The survival of *Aedes aegypti* and *Culex quinquefasciatus* larvae was found to be the maximum in the pH range of 6.94-7.41. Other factors such as dissolved oxygen might have provided a suitable environment for survival and breeding activity of the *Anopheles* species[28].

Mari and Peydro[29] reported that *Anopheles gambiae* carries out normal development when pH varies as much as from 4.0 to 7.8 as long as there is sufficient phytoplankton and zooplankton for it to consume. Also cool, still and clear water with suitable pH, temperature and nutrient composition has been found to encourage breeding in *Anopheles* species[30]. However, high water current and flooding are detrimental to *Anopheles* larval survival due to a reduction in oxygen tension and invariability physical harm to the larvae. This finding was supported by the works of other authors. For instance Afolabi *et al*.[31] stated that female mosquitoes preferred water pH range of 7.1 to 7.3 supported breeding in all the habitats sampled. Similar results were recorded by Baneres and Peydro, and Adebote *et al*. [32,33] that pH less than 5.0 and higher than 7.4 have a lethal effect on mosquito species. Both authors agreed that mosquitoes, especially *Aedes* breed in water with pH 7.4.

The pH of water has an impact on mosquitoes, influencing osmoregulation and oxygen transportation[34]. In this study of *Ae. albopictus* breeding an increase in pH resulted in a significant decrease in larval density. The container sites sampled had a comparable total dissolved solids and dissolved oxygen levels. This demonstrates that *Toxorhynchites minimus* and *Toxorhynchites splendens* mosquitoes favor a specific total dissolved solids and dissolved oxygen range for breeding. This could be an important factor in the breeding site selection and larval survival. Further studies regarding this aspect need to be carried out.

The yellow fever virus exists normally in animal reservoir (monkey) in which it is maintained by several forest mosquitoes, with human acquiring the infection by frequenting forests or their neighborhood where they becomes composed to the bites of infected wild mosquitoes. An infected person subsequently returns to the village where the virus is transmitted to non infected persons by domesticated species of mosquitoes[35]. Apart from being vectors their bites become the serious nuisance to people living around. Lack of proper maintenance in urban areas has created polluted and abandoned water puddles that are ideal for culicine mosquito breeding in many areas in Tamilnadu.

For any vector control measures to be successful, a good knowledge of the breeding ecology of mosquitoes, including the types and preference for larval habitats, spatial and temporal distribution of breeding sites, as well as, the physical, biological and chemical characteristics of the habitats is required. This study has also revealed that convenient aquatic breeding sites for certain mosquito species may be inconvenient for other species. Hence, the present study was carried out to understand the physico-chemical characteristics of the habitats in relation to the density of natural and artificial container breeding mosquitoes in Western Ghats.

It is known that the most convenient way of controlling mosquitoes is to control them in their breeding habitats. Therefore, in the light of above findings, season wise or rather a month wise vector control strategy is recommended in those habitats. Moreover, different control strategy should be tried locally and habitat wise to find an effective and suitable one.

Conflict of interest statement

We declare that we have no conflict of interest.

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