International Journal of Mosquito Research

ISSN: **2348-5906**
CODEN: **IJMRK2**
IJMR 2023; 9(6): 46-55

www.dipterajournal.com
Received: 01-11-2022
Accepted: 20-12-2022

Jiji PV
Division of Environmental Science, Department of Botany, University of Calicut, Kerala, India

Harilal CC
Division of Environmental Science, Department of Botany, University of Calicut, Kerala, India

Corresponding Author:
Jiji PV
Division of Environmental Science, Department of Botany, University of Calicut, Kerala, India

Seasonal changes in the habitat characteristics on survivability and adult emergence of *Aedes albopictus* (Skuse) from rural and urban environments of northern Kerala, India

Jiji PV and Harilal CC

DOI: https://doi.org/10.22271/23487941.2023.v10.i1a.661

Abstract
The range and spread of dengue cases can be ascribed to the breeding habitat of *Aedes albopictus*. There is a paucity of scientific information on the influence of the water quality of breeding habitats on adult emergence in *Aedes albopictus*. The objective of the present study was to evaluate the water quality characteristics responsible for the adult emergence of *Aedes albopictus* confining to selected urban and rural habitats of northern Kerala, India. Larvae of *Aedes albopictus* were collected using the dipping method, along with the collection and analysis of water samples following APHA (2017). The larvae were retained in controlled environmental conditions to assess the magnitude of adult emergence. The average larval productivity in both rural and urban areas was almost the same and exhibits a particular seasonal pattern. Both the rural and urban sectors showed substantial variations in the magnitude of adult emergence. The percentage of adult emergence followed a pattern of pre-monsoon > post-monsoon> monsoon season. With a correlation coefficient of 0.036, larval productivity and adult emergence were shown to be positively correlated. EC, TDS, salinity, Na, K, and NO_3 showed a positive correlation while temperature, pH, turbidity, chloride, and DO showed a negative correlation with the adult emergence. Multiple regression models revealed temperature (p=0.00), DO (p= 0.007), NO_3 (p=0.007), and chloride (p=0.030) as the distinguishing elements in the adult emergence of *Aedes albopictus*.

Keywords: *Aedes albopictus*, rural and urban habitats, water quality, adult emergence

1. Introduction

Aedes albopictus (Skuse) is native to the tropical and subtropical regions of Southeast Asia and have spread to other nations through intercontinental travel and transportation [40].They are one of the most invasive mosquito species with higher mammalian affinity [24] and their widespread distribution has led to significant public health issues worldwide. Kerala is an Indian state with a total area of 38,863 km^2 and with an average population density of 860, which is twice the national average (464 per sq. km). Since 2006, Kerala has turned to be endemic to a range of vector-borne diseases, with thousands of dengue cases being reported annually. A report for the year 2021 by the Directorate of health service, Kerala, enlists 3251 dengue cases with 27 fatalities. Studies revealed the occurrence of *Aedes albopictus* as a principal vector of dengue in hilly, rural, and suburban environments and are either replacing or coexisting with *Aedes aegypti* [40]. The range of habitat preferences makes them an invasive and aggressive insect vector.

Aedes albopictus is categorized as a container breeder [14] and they require water for oviposition, larval and pupal development, and adult emergence [43, 1, 17]. The quantity and quality of water are vital and this necessitates the adults to selectively choose their breeding sites [45, 46, 31]. Changes in container preferences have also been observed over time [7]. Research so far has focused on the influence of water quality concerning the breeding habitats on the larval and pupal stages of *Aedes albopictus* and there exists a lacuna on the effect of water quality on the adult emergence of this species, especially in tropical climatic conditions.

A concerted effort is needed to examine adult emergence in response to water quality and the classification of dengue vector breeding habitat is crucial in determining the distribution and control of dengue cases. The objective of this study is to assess the water quality attributes responsible for adult emergence in *Aedes albopictus* confining to selected urban and rural environments of northern Kerala, India. The findings of this study will help in elucidating strategies that could improve the efficiency of dengue vector control initiatives.

2. Materials and Methods

2.1 Study area and sampling location

Repeated cases of Dengue and Chikungunya have been reported in the Malabar region of Kerala, in recent times. Changes in habitats and species composition are reported to be the causes of disease outbreaks [34, 41]. The prevalence of such epidemics is critical in light of the higher population density of this region. Hence the present study was undertaken in the heterogeneous urban and rural habitats of Kozhikode and Malappuram districts of the Malabar region of Kerala, with special emphasis on the habitat characteristics responsible for the adult emergence of *Aedes albopictus.* Altogether 20 sampling sites were selected for the study, 10 each from Malappuram and Kozhikode Districts, representing rural and urban habitats, respectively. The outbreaks of chikungunya and dengue are reported to be linked with the seasons. Hence sampling and analysis have been carried out in response to pre-monsoon, monsoon, and post-monsoon seasons. The details of the sampling sites are represented in Table 1 and Figure 1.

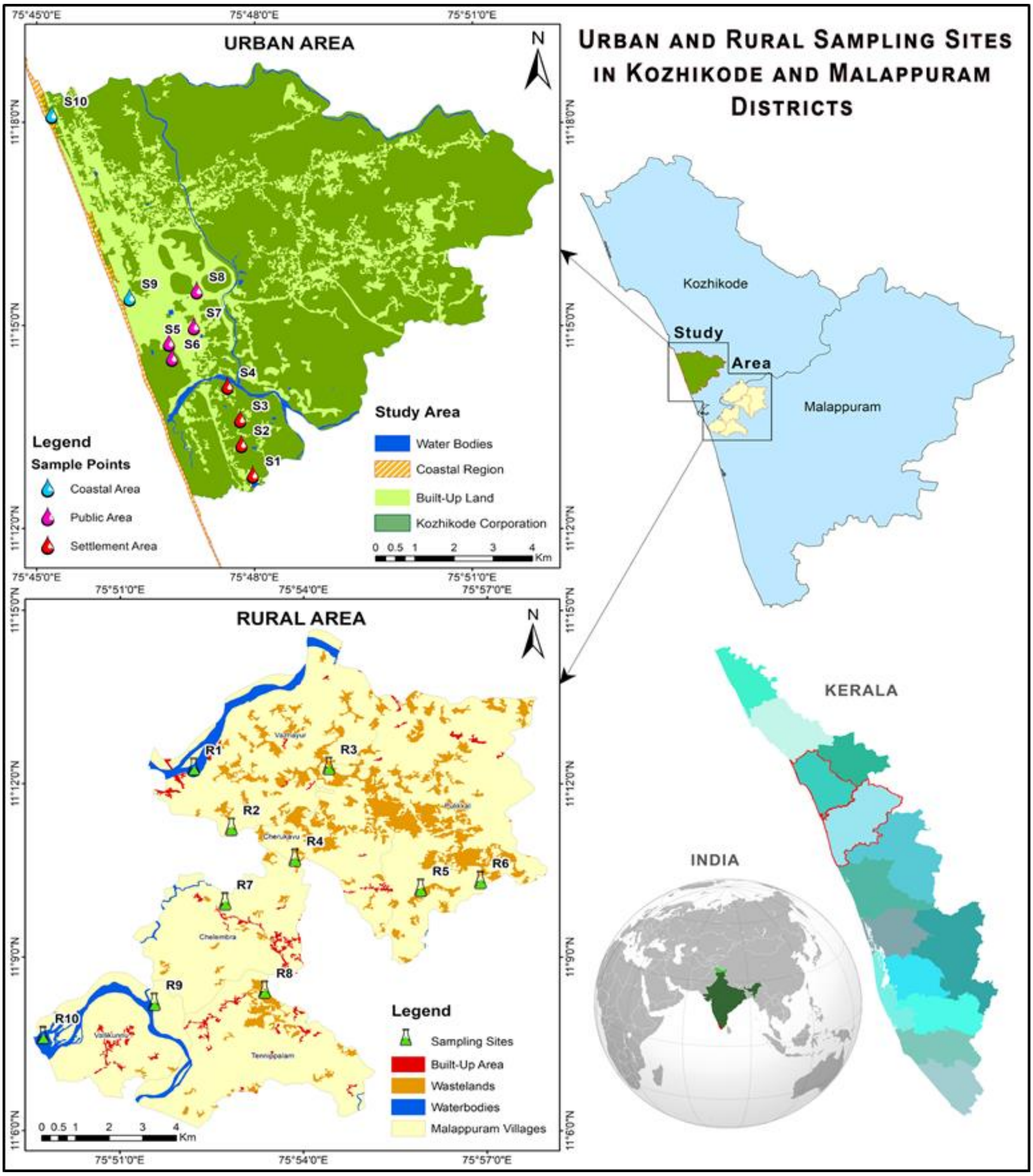

Fig 1: Sampling locations of rural and urban habitats

Table1: Sampling sites of rural and urban habitats

Sample code	Sampling location	Latitude	Longitude
Rural			
R1	Puthukode	N 11° 11’ 29.67”	E 75° 52’56.28’’
R2	Parammal	N 11° 11’20.9616’’	E 75° 52’12.3564’’
R3	Azhinjilam	N 11° 12’00.0216’’	E 75° 52’08.9364’’
R4	Ramanattukara	N 11° 10’37.5168’’	E 75° 52’27.516’’
R5	Vydairangadi	N 11° 10’45.642’’	E 75° 52’49.8072’’
R6	Thurakkal	N 11° 09’24.6636’’	E 75° 57’25.794’’
R7	Chelembra	N 11° 09’43.0128’’	E 75° 52’41.106’’
R8	Olipram Kadavu	N 11° 07’31.2456’’	E 75° 51’24.7392’’
R9	Kadalundi nagaram	N 11° 07’19.812’’	E 75° 49’38.5212’’
R10	Calicut university	N 11° 08’10.0644’’	E 75° 53’23.4312’’
Urban			
U1	Meenchanda	N 11° 12’ 48.3156”	E 75° 47’ 58.7148’’
U2	Kannancheri	N 11° 13’ 15.4146’’	E 75° 47’ 49.3188’’
U3	Panniyankara	N 11° 13’ 37.5348’’	E 75° 47’ 48.2532’’
U4	Kallai	N 11° 14’ 06.8676’’	E 75° 47’ 37.7916’’
U5	Calicut railway station	N 11° 14’ 45.1392’’	E 75° 46’ 49.44’’
U6	SM Street	N 11° 15’ 02.7432’’	E 75° 45’ 53.6196’’
U7	Palayam market	N 11° 14’ 59.712’’	E 75° 47’ 09.9708’’
U8	New bus stand, mavoor road	N 11° 15’ 31.5864’’	E 75° 47’ 12.3612’’
U9	Calicut beach hospital side	N 11° 15’ 25.3188’’	E 75° 46’ 16.7844’’
U10	Puthiyappa harbour	N 11° 19’ 09.2928’’	E 75° 44’ 47.5836’’

2.2 Mosquito sampling

Natural and man-made water-holding structures were surveyed for the presence of mosquito larvae. The collection was carried out by dipping method [38]. Samples were collected in 500 ml plastic containers. The type of habitat, nature of water, number of larvae, and the GPS coordinates of the sampling sites were recorded. Atmospheric temperature and humidity associated with the sampling sites were recorded.

2.3 Monitoring of larval growth and adult emergence

The water samples containing larvae were brought to the laboratory for species-level confirmation, following standard procedure [5, 54]. They were then retained in 50 ml of the respective water samples collected from the sites in a climate-controlled chamber having a predetermined temperature of 28±5 °C, humidity of 70±5%, and a photoperiod of LD 12:12h. The first and second instar larvae were subjected to experimentation. Subsequent developmental stages of the larvae were monitored after every 24 hours. Adult emergence was subsequently enumerated along with their sex pattern. Larval productivity, larval density, survival expressed as a percentage of adult emergence, and the percentage of mortality was estimated. (Table 2-4).

2.4 Water chemistry

The physicochemical characteristics of water from the breeding grounds, like temperature, pH, electrical conductivity, total dissolved solids, turbidity, salinity, chloride, phosphate, nitrate, sodium, potassium, and dissolved oxygen were estimated using instrumental and other analytical methods as specified in APHA (2017) [3]. The results are reported in Table 6.

2.5 Statistical analysis

The data obtained were analyzed using the Statistical Package for Social Sciences (SPSS) software (Ver. 21). The Analysis of Variance (ANOVA) test has been undertaken to assess the seasonal differences in the breeding sites. The Pearson correlation coefficient was analyzed to find out the influence of the physicochemical quality of the breeding water on adult emergence. Physicochemical factors responsible for adult emergence were tested using linear regression models.

3. Results and Discussions

A total of 60 samples were collected from 20 heterogeneous habitats representing rural and urban habitats during pre-monsoon, monsoon, and post-monsoon seasons. The species *Aedes albopictus* was found to be breeding in a wide range of habitats, some of which are natural and others made with synthetic materials (containers). The breeding habitats mostly included medium-sized discarded plastic containers, water storage tanks, coconut shells, flex sheets, and other such habitats, which were more or less similar in urban and rural environments.

3.1 Productivity, density, and mortality rate of *Aedes albopictus* larvae

The magnitude of larval productivity varied slightly between the rural and urban habitats. The productivity of larvae however followed a pattern related to the seasons. Average larval productivity during pre-monsoon, monsoon, and post-monsoon seasons in the rural and urban sectors was essentially the same (Table 2). Larval density was the highest in rural areas during monsoon but was higher in urban areas only in the pre-monsoon. In comparison to rural sites, a higher mean larval density was found in urban areas (Table 3). Moderate rain with ideal temperatures is reported to enhance the population of *Aedes* [27], whereas its abundance has been regulated by temperature rather than by precipitation [53]. Both rural and urban areas were reported to have larval mortality between 15-25%. Average larval mortality was higher during the monsoon season, with urban areas at the forefront. Heavy and continuous rainfall usually washes away the immature stages of mosquitoes and this can be linked to the present reduction in their productivity and density during monsoons [6, 12]. Also, warmer temperatures usually facilitate the development of mosquitoes and thereby viral replications [4].

Table 2: Larval productivity and average larval mortality rate of rural and urban sites during pre-monsoon, monsoon, and post-monsoon seasons

Site code	Pre-monsoon		Monsoon		Post monsoon	
	Larval Productivity (%)	Avg. Larval Mortality (%)	Larval Productivity (%)	Avg. Larval Mortality (%)	Larval Productivity (%)	Avg. Larval mortality (%)
Rural						
R1	9.65	14.77	14.92	22	17.88	10.24
R2	8.68	19.02	19.18	21	11.45	15.97
R3	6.11	12.47	1.78	14.04	8.10	20
R4	23.79	14.67	8.53	27.95	18.99	13.27
R5	5.14	19.84	2.49	22.36	12.29	12.14
R6	15.43	18.43	18.47	21.07	6.42	16.62
R7	1.61	5	24.16	20.87	1.96	8.87
R8	5.79	22.49	1.24	8.28	6.70	27.9
R9	19.29	18.74	5.15	21.71	5.31	7.64
R10	4.50	18.38	4.09	23.51	10.89	24.39
Average	9.999	16.381	10.001	20.279	9.999	15.704
Urban						
U1	23.29	21.34	20.00	20.33	5.65	8.68
U2	18.85	20.33	10.52	30	15.05	16.71
U3	19.41	16.52	25.15	23.9	17.47	22.05
U4	4.81	33.41	5.36	21.84	6.18	14.66
U5	9.24	22.53	8.66	21.79	4.30	20.7
U6	8.69	10.19	11.13	30.87	19.89	19.68
U7	8.32	12.24	2.27	34.08	7.80	14.77
U8	3.14	14.5	9.07	17.36	13.17	21.51
U9	1.29	15.38	2.06	21.46	0.81	11.45
U10	2.96	22.24	5.77	27.18	9.68	19.05
Average	10	18.868	9.999	24.881	10	16.926

Table 3: Larval density of rural and urban sites during pre-monsoon, monsoon, and post-monsoon seasons

	Larval density			
	Rural		Urban	
	Mean	Stdev	Mean	Stdev
Pre-monsoon	31.1	22.35	54.1	42.21
Monsoon	56.3	47.55	48.5	36.00
Post monsoon	35.8	19.42	37.2	23.02

3.2 Survival and adult emergence rate of *Aedes albopictus*

Both rural and urban sectors had a substantial variation in the adult emergence rate of *Aedes albopictus*. The rate of adult emergence concerning seasons exhibited a similar trend in both sectors (Table 4). Pre-monsoon season showed higher adult emergence, which was followed by post-monsoon and monsoon. Higher adult emergence was noted in the urban sector (36.39±22.78) compared to the rural (32.78±18.06). These results indicate that seasonal differences in environmental conditions were less. A similar trend was reported by Alto and Juliano (2001b)[2] in which the dynamics of *Aedes albopictus* populations in the laboratory estimated high rates of population growth with adult populations peaking early in the season in regions with relatively high summer temperatures.

The pace of development of the *Aedes albopictus* population occurs more in temperatures ranging from 25 to 30 °C [16] and this may explain the reason for the highest adult emergence during pre-monsoon season. In both rural and urban areas, the emergence of female *Aedes albopictus* was higher during the pre and post-monsoon seasons. However, both rural and urban areas had a greater number of male mosquitoes during the monsoon season (Table 5). The female-to-male ratio was found to be 1:1 during the pre-monsoon and monsoon seasons in both rural and urban sectors but was 3:1 during the post-monsoon seasons in both areas. In the yellow fever mosquito, the sex ratio was normally about 1:1 [25]. However, sex ratio abnormalities are often detected in samples from wild populations of container-inhabiting mosquitoes [29]. Similar findings were previously obtained by normal and temperature-resistant strains in India, with more females being generated at high temperatures (28 °C and 37 °C) [33].

Table 4: Adult emergence (%) of rural and urban sites during pre-monsoon, monsoon, and post-monsoon seasons

Sites	Adult emergence (%)					
	Rural (R)			Urban (U)		
	Pre Mon	Mon	Post Mon	Pre Mon	Mon	Post Mon
1	13.33	3.57	17.18	19.84	31.95	80.95
2	25.92	11.11	24.39	8.82	5.88	21.42
3	47.36	30	72.41	62.85	31.14	8.92
4	62.16	2.08	5.88	3.84	23.07	26.08
5	25	0	27.27	60	7.14	25
6	35.41	42.30	34.78	48.93	3.70	43.24
7	60	40.44	28.57	33.33	9.09	17.24
8	27.77	28.57	8.33	64.70	50.09	0
9	16.66	13.79	31.57	42.85	10	0
10	14.28	34.78	10.25	18.75	7.14	8.33
Mean	32.789	20.664	26.063	36.391	17.92	23.118
SD	18.063	16.368	19.193	22.784	15.467	24.240

Table 5: List of female and male mosquitoes that emerged during pre-monsoon, monsoon, and post-monsoon seasons

Sample Code	Pre-monsoon		Monsoon		Post monsoon	
	♀	♂	♀	♂	♀	♂
Rural						
R1	2	2	1	2	9	2
R2	5	2	7	5	7	3
R3	5	4	2	1	16	5
R4	23	23	0	1	3	0
R5	1	3	0	0	8	4
R6	7	10	20	24	6	2
R7	2	1	23	32	2	0
R8	2	3	2	0	2	0
R9	6	4	3	1	5	1
R10	1	1	6	2	3	1
Total	54	53	64	68	61	18
Grand total	107		132		79	
Percentage	50.47	49.53	48.48	51.52	77.22	22.78
Urban						
U1	16	9	14	17	13	4
U2	4	5	1	2	10	2
U3	31	35	17	20	4	1
U4	0	1	4	2	3	3
U5	16	14	1	2	3	1
U6	11	12	2	0	26	6
U7	9	6	0	1	5	0
U8	3	8	11	14	0	0
U9	4	1	1	0	0	0
U10	2	1	2	0	3	0
Total	96	92	53	58	67	17
Grand total	188		111		84	
Percentage	51.06	48.94	47.75	52.25	79.76	20.24

3.3 Characterization of the breeding habitats of *Aedes albopictus*

Breeding habitats can influence the developmental stages and hence the selection of appropriate locations is crucial in the spread and establishment of the *Aedes* population [26]. Physical and physicochemical factors that affect the breeding habitat may have a greater impact on the reproduction, development, aggregation, survival, and emergence of *Aedes* mosquitoes [21]. In the present study, the physicochemical characteristics of breeding habitats like temperature (°C), pH, electrical conductivity (µS/cm), total dissolved solids (mg/l), turbidity (NTU), salinity (ppm), chloride (mg/l), dissolved oxygen (mg/l), sodium (mg/l), potassium (mg/l), nitrate (mg/l) and phosphate (mg/l) were assessed from all the sites following the seasons and the results are depicted in Table 6.

The findings showed that the water temperature was much greater in urban environments than in rural ones. It was measured to be within 27.2-30.2 °C in urban and 27.2-29.4 °C in rural areas. The seasonal variation in mean temperature was between 27.72±0.66 to 28.82±0.31, which was consistent with the USEPA's specification of 16-32 °C, an optimum range for most mosquito species, including *Culex*, *Anopheles*, and *Aedes* [10]. Humidity and temperature, particularly within 25 – 28 °C, were also found to affect the hatching of the eggs of *Aedes* sp [51]. The development of *Aedes aegypti* was also reported to be more quickly between 20-27 °C [47]. Temperature influences insect growth as biochemical processes govern their growth and metabolism [11]. The dynamics of the mosquito population, the speed at which their development takes place, and the number of mosquitoes produced may all be impacted by higher ambient and water temperatures, yet their size may decrease [19, 32]. This could be the rationale behind the establishment of the secondary vector *Aedes albopictus* replacing the primary vector and surviving more successfully.

The average pH of water concerning the breeding habitats from rural areas was 8.22±0.54 in pre-monsoon, 8.04±0.84 in monsoon, and 7.68±0.92 in post-monsoon, whereas in urban areas it was 7.95±0.46 (pre-monsoon), 8.53±0.12 (monsoon) and 7.97±0.45 (post-monsoon), respectively. All urban water samples were found to be alkaline, compared to rural areas. The range of pH of breeding sites favouring maximum larval growth is 4–11 [13] and the pH range ideal for the growth of *Aedes aegypti* is reported to be 6.5 to 8.0 [55]. According to Woodhill (1942) [57], the percentage of adult emergence in *Aedes aegypti* has dramatically decreased at a pH range of 3.6 to 4.2. Mosquito breeding and metamorphosis are found to be impacted by acidic waters and the pH of water is found to influence the osmoregulation and oxygen transportation in mosquitoes [55]. This study affirms that *Aedes albopictus* prefer neutral or slightly alkaline water (7.68±0.92 to 8.53±0.12) for survivability and adult emergence.

The measured electrical conductivity (EC) varied from 56.6 to 3470 µS/cm in the pre-monsoon, 85.8 to 350 µS/cm in the monsoon, and 30.3 to 3870 µS/cm in the post-monsoon season in the water samples from rural environments. In urban environments, the EC was in the range of 109 to 472 µS/cm (pre-monsoon), 45.8 to 301 µS/cm (monsoon), and 104.3 to 443 µS/cm (post-monsoon). The total dissolved solid (TDS) concentration exhibited a similar trend and was found to be correlated to EC. Noticeably lower levels of EC and TDS during monsoon can be attributed to the dilution of water in the respective habitats due to precipitation. Larval abundance was reported to be impacted by EC within a range of 162.9–1,656.8 µS/cm [49].

Salinity levels were lowest during the monsoon season, ranging from 46.5 (R5) to 251ppm (R10) in rural regions and 24.9 (U9) to 146ppm (U1) in urban areas. Pre-monsoon salinity concentrations were 33.1 (R3) to 1880 ppm (R4) in rural and 55.2 (U10) to 913 ppm (U8) in urban areas. Rural areas have been found to have a greater post-monsoon salinity concentration (22.9 to 2020 ppm) than urban areas (54.3 to 215 ppm). Salinity is a significant attribute that can influence oviposition in Aedes. It is reported that when salinity concentrations are greater than 12%, oviposition declines [45, 22]. Both *Aedes albopictus* and *Aedes aegypti* are regarded as obligate freshwater species [44]. But according to a recent investigation, *Aedes aegypti* pre-imaginal stages may grow in brackish environments in Brazil and Sri Lanka and may allow expanding their ecological niche [28, 15]. However, the present study shows the salinity tolerance capability of *Aedes albopictus*, which can result in the expansion of their breeding grounds and thereby geographic extent. Salinity relative to coastal impacts is lower since these are raised in containers.

The average levels of sodium were higher in the post-monsoon seasons in both rural and urban habitats (73.39±23.44 and 70.51±19.21), respectively. Potassium concentration was noted to be higher in post-monsoon (17.73±14.98) in rural and pre-monsoon (12.41±6.92) in urban habitats. A higher concentration of these elements indicates higher water mineralization and these elements are likely to provide food and nutrients to the mosquitoes for completing their life cycles until adult emergence [8]. Compared to urban habitats (87.99 mg/l-U1), chloride was higher in rural environments (309.90 mg/l-R8). In both rural and urban habitats, the average chloride content decreased during the monsoon (27.88±21.58 & 16.48±10.73) and increased during the pre-monsoon (39.98±30.88 & 40.38±29.59). However, the levels of chloride were comparatively lower. It is also reported by Sehgal and Pillai (1970) [48] that the preferences for average chloride in the breeding habitats of *Culex* (57ppm) and *Anopheles* (173ppm) were comparatively smaller than that of *Aedes*.

The average DO content in rural areas was 5.24±1.18, 5.44±1.08 and 4.80±1.23, whereas in urban areas was 4.28±1.61, 5.28±1.15 and 5.04±0.98, respectively, during pre-monsoon, monsoon and post-monsoon seasons. Urban and rural habitats did not have significant differences in dissolved oxygen (DO) levels, but among seasons, monsoon showed a modest increase in DO. The DO varies from 1 to 20 mg/l daily and seasonally [56]. Irrespective of the nature and size of the water body, changes in DO can happen following various factors like temperature, pressure, aeration, diffusion, decomposition, photosynthesis, and respiration. It is reported that the oviposition behavior of *Aedes aegypti* mosquitoes depends on the DO content [37].

Water turbidity may affect mosquito sustenance and female mosquitoes prefer murky water to lay their eggs. Greater turbidity may lessen the probability of being preyed upon owing to poorer visibility, as, predation is widely thought to be a key component explaining the high mortality rates that are reported in natural breeding locations [36]. Moreover, particles that contribute to turbidity may directly interfere with larval nutrition [58]. Another study by Elmalih *et al*., (2018) [20] shows that high water turbidity was favoured by the pupal stage of mosquitoes, which boosts the adult emergence rate. In rural areas, turbidity ranged from 2.86±2.18, 5.27±3.42 and 2.62±1.32, and in urban areas from 1.92±1.66, 2.88±2.50 and 0.57±0.36 during pre-monsoon, monsoon and post-monsoon seasons, respectively. According to Thangamathi *et al*, (2014) [50], *Aedes albopictus* prefers more turbid water while *Aedes aegypti* prefers less. However, marked differences in the levels indicate the wide range of tolerances of *Aedes albopictus* to turbidity.

Generally, ammonia, nitrate, and phosphate content have been reported to impact larval growth and survival [35]. In both rural and urban environments, increased average nitrate concentrations (0.37±0.19 & 0.31±0.19) were detected during the post-monsoon seasons. The concentrations were determined to be below the EPA maximum permissible limit of 50 mg/L for nitrates in natural and wastewater bodies [52]. The decreased nitrogen levels with increasing larvae densities imply that nitrogen may be a limiting resource in the larval environment. According to Beserra *et al*. (2010) [9], *Aedes aegypti* may grow in a range of environments that are having access to organic resources such as total nitrogen, ammoniacal nitrogen, and total dissolved phosphate. In the present study, none of the samples taken from the rural or urban environments contained phosphates within a specific range, as reported in earlier studies by Sehagl and Pillai (1970) [48]. Similarly, the levels of nitrogen and phosphorus in the breeding habitats were not significantly affected the emergence of adult mosquitoes [23].

Table 6: Results of the physicochemical characteristics of water samples from the rural and urban breeding habitats during pre-monsoon, monsoon, and post-monsoon seasons

Parameters	Mean ± Std. Dev					
	Rural			Urban		
	Pre monsoon	Monsoon	Post monsoon	Pre monsoon	Monsoon	Post monsoon
Temp	27.72±0.66	28.68±0.18	28.82±0.31	28.45±1.04	28.67±0.15	29.03±0.70
PH	8.22±0.54	8.09±0.84	7.68±0.92	7.95±.46	8.53±0.12	7.97±0.45
EC	1074.77±1455.48	203.47±87.94	619.73±1154.12	250.07±104.49	138.19±83.24	211.71±101.41
TDS	762.98±1033.20	144±62.57	652.86±962.60	177.54±74.18	97.60±59.04	149.65±71.80
Turbidity	2.86±2.18	5.27±3.42	2.62±1.32	1.92±1.66	2.88±2.50	0.57±0.36
Salinity	563.30±767.06	114.95±63.02	330.89±599.95	203.84±253.76	70.27±39.93	104.07±48.02
Chloride	39.98±30.88	27.88±21.58	79.97±91.25	40.38±29.59	16.48±10.73	25.48±12.34
DO	5.24±1.18	5.44±1.08	4.80±1.23	4.28±1.61	5.28±1.15	5.04±0.98
Na	36.30±33.93	54.74±31.34	73.39±23.44	54.68±30.35	39.67±33.99	70.51±19.21
K	12.21±12.95	8.79±7.69	17.73±14.98	12.41±6.92	5.80±5.34	11.12±9.83
NO_3	0.15±0.99	0.24±.0.60	0.37±0.19	0.25±0.19	0.17±0.17	0.31±0.19

A study on the correlation of larval productivity with adult emergence revealed a resultant coefficient of 0.036 (Figure 2) and was positive. Similarly, the correlation between the adult emergence and physicochemical characteristics of water indicated a positive relationship with EC, TDS, salinity, Na, K, and NO_3 to an extent of 0.06, 0.07, 0.13, 0.08, 0.02, and 0.13, respectively. Adult emergence was negatively correlated with temperature, pH, turbidity, chloride, and DO with correlation coefficients, of -0.37, -0.04, -0.12, -0.08 and -0.28 correspondingly. However, none of these correlations were statistically significant ($p>0.05$) while a significant negative correlation was observed between temperature and DO with adult emergence ($p = 0.002$ and $p = 0.015$) (Table 7)

Table 7: Correlation Matrix of water quality parameters and adult emergence

	Adult emergence	Site	Season	Temp	PH	EC	TDS	Turbidity	Salinity	Chloride	DO	Na	K	NO3
Adult Emergence	1.000	-.018	-.207	-.376	-.044	.068	.079	-.124	.136	-.084	-.281	.088	.023	.139
Site		1.000	0.000	.219	.131	-.272	-.309	-.362	-.246	-.241	-.120	.002	-.151	-.027
Season			1.000	.485	-.165	-.126	-.046	-.134	-.159	.113	.053	.348	.083	.331
Temp				1.000	-.223	-.281	-.224	-.097	-.301	.049	.008	.272	.004	.322
PH					1.000	-.104	-.141	.191	-.111	-.283	.222	-.291	-.337	-.294
EC						1.000	.896	-.060	.968	.710	-.220	.324	.496	.045
TDS							1.000	-.064	.866	.626	-.156	.369	.402	-.011
Turbidity								1.000	-.022	-.004	.039	-.150	-.021	-.053
Salinity									1.000	.672	-.303	.289	.457	.067
Chloride										1.000	-.291	.414	.470	.334
DO											1.000	-.140	-.234	-.104
Na												1.000	.589	.344
K													1.000	.218
NO_3														1.000

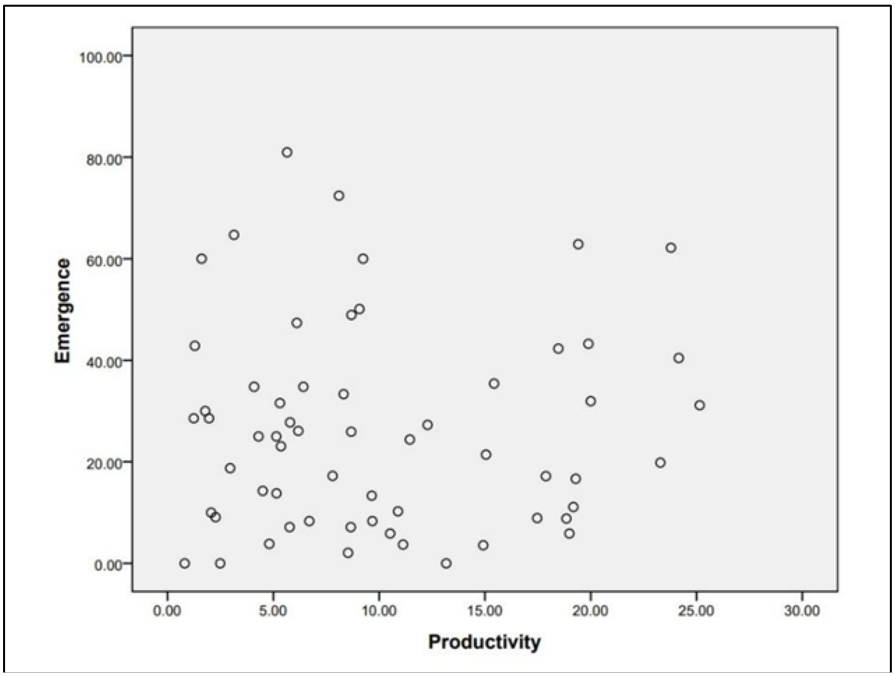

Fig 2: Correlation Scatterplot of larval productivity with adult emergence

The seasonal variations toward various breeding sites were estimated using the test of Analysis of Variance (ANOVA). Results revealed significant differences in adult emergence (p=0.045), temperature (p=0.00), turbidity (p=0.004), and Na (p=0.009) in all the breeding habitats. Findings of multiple regression analysis indicate that temperature (p=0.00), DO (p=0.007), NO_3 (p=0.007), and chloride (p=0.030) are the key components influencing the adult emergence of *Aedes albopictus* (Table 8).

Table 8: Results of linear regression model

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
(Constant)	422.646	91.970		4.595	.000
Temp	-13.178	3.244	-.472	-4.062	.000
DO	-5.134	1.847	-.319	-2.780	.007
NO_3	40.082	14.202	.347	2.822	.007
Chloride	-.117	.053	-.270	-2.224	.030

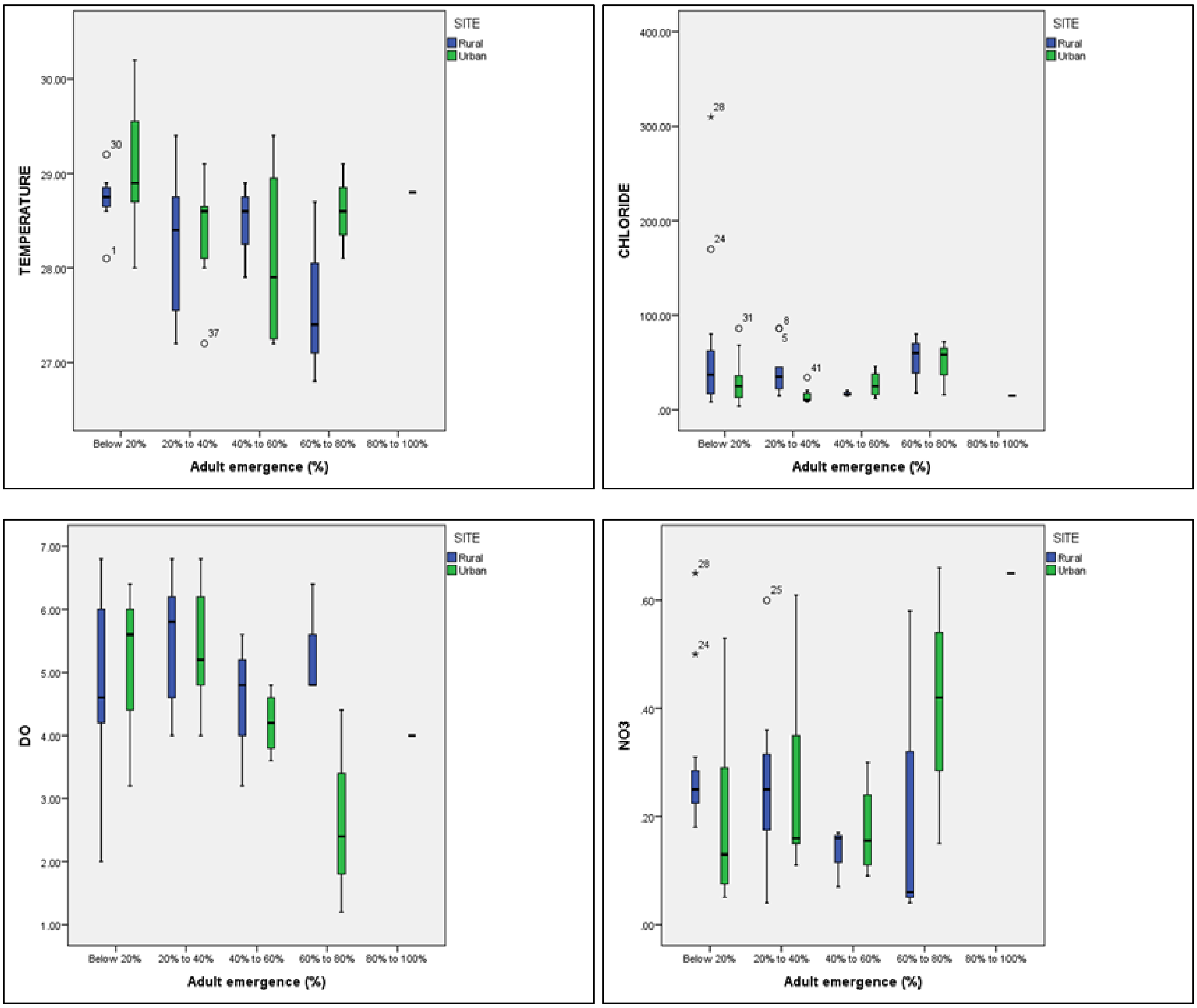

Fig 3-6: Relationships between adult emergence with temperature, chloride, DO, and NO_3

Though larval production was noticed in almost all habitat types, adult emergence has not followed a specific pattern. The quality of water concerning the breeding habitats is found to affect the oviposition and developmental phases in the *Aedes* species [39, 42]. The ability of female mosquitoes to lay eggs and the subsequent development of the eggs into adult stages depends critically on the quality of the water. To plan and intervene in future mosquito management programmes, particularly at the source reduction stage, and to estimate the number of adults produced in various habitats, the baseline data on water quality, as depicted in this study, will be useful.

4. Conclusion

There is an extensive body of literature on *Aedes albopictus* breeding habitats, but there has been little research on the relationship between water quality and adult emergence. In conclusion of the present study, it is noted that water quality plays a significant role in the development and adult emergence of mosquito species. The productivity of *Aedes albopictus* larvae followed a pattern concerning the seasons. Adult emergence was noticeably high during pre-monsoon, which was followed by post-monsoon and monsoon. Adult emergence was positively correlated with larval productivity, EC, TDS, salinity, Na, K, and NO_3 while temperature, pH, turbidity, chloride, and DO indicated a negative correlation. However, none of these correlations were statistically significant. Linear regression model proved temperature, chloride, dissolved oxygen, and nitrate as the distinguishing elements of *Aedes albopictus* adult emergence and effective survival. The findings of the present study will serve as a baseline for the management of dengue vector mosquitoes.

5. Acknowledgments

The authors are grateful to Dr. Girish Babu. M, Assistant Professor & Head, Department of Statistics, CHMKM Govt. Arts and Science College, Koduvally, Kozhikode for his assistance in statistical analysis. This work has been funded and supported by Directorate of Climate Change (DoECC/A1/3232/2021 dated 22/11/2021), Government of Kerala.

6. References

1. Afrane YA, Zhou G, Lawson BW, Githeko AK, Yan G. Life-table analysis of *Anopheles arabiensis* in western Kenya highlands: Effects of land cover on larval and adult survivorship. Am. J Trop. Med. Hyg. 2007;77(4):660.
2. Alto BW, Juliano SA. Precipitation and temperature effects on populations of *Aedes albopictus* (Diptera: Culicidae): Implications for range expansion. J. Med. Entomol. 2001;38(5):646-656.

3. APHA (American Public Health Association). Standard methods for the examination of water and wastewater, 22 st edition, American Public Health Association, Washington DC; c2017.
4. Bangs MJ, Larasati RP, Corwin AL, Wuryadi S. Climatic factors associated with epidemic dengue in Palembang, Indonesia: Implications of short-term meteorological events on virus transmission. Southeast Asian J. Trop. Med. Public Health. 2006;37:1103-1116.
5. Barraud PJ. The Fauna of British India, including Ceylon and Burma. Diptera. Family Culieldae. Tribes Megarhinini and Culicini. The Fauna of British India, including Ceylon and Burma. Diptera. Vol. 5. Family Culieldae. Tribes Megarhinini and Culicini, 1934, 5.
6. Baruah S, Dutta P. Seasonal prevalence of Aedes aegypti in urban and industrial areas of Dibrugarh District, Assam. Trop. Biomed. 2013;30:434–43.
7. Becker N, Petric D, Zgomba M, Boase C, Madon M, Dahl C, Kaiser, A. Mosquitoes and their control. SSBM; c2010.
8. Bentley MD, Day JF. Chemical ecology and behavioral aspects of mosquito oviposition. Annu. Rev. Entomol. 1989;34(1): 401-421.
9. Beserra EB, Fernandes CR, de Sousa JT, de Freitas EM, Santos KD. The effect of water quality in the life cycle and in the attraction for the egg oviposition of *Aedes aegypti* (L.), (Diptera: Culicidae). Neotrop. Entomol. 2010;39(6):1016-1023.
10. Bradley P, Kutz, FW. Proceedings of the Workshop on Stormwater Management and Mosquito Control. U.S Environmental Protection Agency, Office of Research and Development; c2006. EPA/903/R-06/004.
11. Byrd JH, Castner JL. Forensic Entomology: The utility of arthropods in legal investigations. 1st edition, Boca Raton, CRC Press; c2001. p. 418.
12. Shamna AK, Vipinya C, Sumodan PK. Detection of Aedes albopictus (Diptera: Culicidae) breeding in brackish water habitats in coastal Kerala, India and its implications for dengue scenario in the state. Int. J. Entomol. Res. 2022;7:214-6.
13. Caputo B, Ienco A, Cianci D, Pombi M, Petrarca V, Baseggio A, Della Torre A. The "auto-dissemination" approach: A novel concept to fight Aedes albopictus in Urban Areas; c2012.
14. Clark TM, Flis BJ, Remold SK. pH tolerances and regulatory abilities of freshwater and euryhaline Aedine mosquito larvae. J. Exp. Biol. 2004;207(13):2297-2304.
15. De Brito Arduino M, Mucci LF, Serpa LL N, de Moura Rodrigues M. Effect of salinity on the behavior of Aedes aegypti populations from the coast and plateau of southeastern Brazil. J Vector Borne Dis. 2015;52(1):79.
16. Delatte H, Gimonneau G, Triboire A, Fontenille D. Influence of temperature on immature development, survival, longevity, fecundity, and gonotrophic cycles of Aedes albopictus, vector of chikungunya and dengue in the Indian Ocean. J. Med. Entomol. 2009;46:33-41.
17. Dieng H, Saifur RG, Hassan AA, Salmah MC, Boots M, Satho T, AbuBakar S. Indoor-breeding of *Aedes albopictus* in northern peninsular Malaysia and its potential epidemiological implications. PloS One. 2010;*5*(7):e11790.
18. Eisen L, Monaghan AJ, Lozano-Fuentes S, Steinhoff DF, Hayden MH Bieringer PEJ.. The impact of temperature on the bionomics of *Aedes* (*Stegomyia*) *aegypti*, with special reference to the cool geographic range margins. J. Med. Entomol. 2014, 51: 496-516.
19. Elmalih EBI, Almugadam BS, Tamomh AG, Hassan SM. Influence of Environmental factors on breeding habitats of mosquito species in Kosti City, White Nile State, Sudan. J. HEALTH Sci. 2018;12(4):0-0.
20. Francisco P, Castro JD, Walter FS, Mauricio M, Filho LDL, Almeida RPD, *et al*. Ciclo de vida de Aedes (Stegomyia) aegypti (Diptera, Culicidae) emaguas com diferentes caracteristicas. Iheringia, Serie Zoologia. 2009;99:281–285.
21. Getachew D, Tekie H, Gebre-Michael T, Balkew M, Mesfin A. Breeding sites of *Aedes aegypti*: potential dengue vectors in Dire Dawa, East Ethiopia. Interdiscip Perspect Infect Dis; c2015.
22. Gimnig JE, Ombok M, Otieno S, Kaufman MG, Vulule JM,Walker ED. Density-dependent development of Anopheles gambiae (Diptera: Culicidae) larvae in artificial habitats. J. Med. Entomol. 2002;39(1):162-172.
23. Hawley WA. The biology of *Aedes albopictus*. J. Am. Mosq. Control Assoc., Suppl. 1988;1:1-39.
24. Hickey WA, Craig Jr GB. Distortion of sex ratio in populations of *Aedes aegypti*. Can J Genet Cytol. 1966;8(2):260-278.
25. Honorio NA, Castro MG, Barros FS MD, Magalhaes MD AFM, Sabroza PC.The spatial distribution of *Aedes aegypti* and *Aedes albopictus* in a transition zone, Rio de Janeiro, Brazil. Cadernos de Saúde Pública. 2009;25(6):1203-1214.
26. Jeelani S, Sabesan S. Aedes vector population dynamics and occurrence of dengue fever in relation to climate variables in Puducherry, South India. Int. j. curr. Microbiol. Appl. Sci. 2013;2:313–22.
27. Jude PJ, Tharmasegaram T, Sivasubramaniyam G, Senthilnanthanan M, Kannathasan S, Raveendran S, Surendran SN. Salinity-tolerant larvae of mosquito vectors in the tropical coast of Jaffna, Sri Lanka and the effect of salinity on the toxicity of *Bacillus thuringiensis* to *Aedes aegypti* larvae. Parasites & vectors. 2012;5(1):1-8.
28. Lounibos LP, O'Meara GF, Juliano SA, Nishimura N, Escher RL, Reiskind MH, Greene K. Differential survivorship of invasive mosquito species in South Florida cemeteries: do site-specific microclimates explain patterns of coexistence and exclusion? Annals of the Entomological Society of America. 2010;103(5):757-770.
29. Madzlan F, Dom NC, Zakaria N, Hasnan SNA, Tiong CS, Camalxaman SN. Profiling of dengue vectors breeding habitat at urban residential areas in Shah Alam, Malaysia. Serangga. 2018;22:2.
30. Marinho RA, Beserra EB, Bezerra-Gusmao MA. Porto Vde S, Olinda RA, Dos Santos CA. Effects of temperature on the life cycle, expansion, and dispersion of *Aedes aegypti* (Diptera: Culicidae) in three cities in Paraiba, Brazil. J Vector Ecol. 2016;41(1):1-10.
31. Mourya DT, Yadav P, Mishra AC. Effect of temperature stress on immature stages and susceptibility of *Aedes aegypti* mosquitoes to chikungunya virus. Am. J. Trop. Med. Hyg, 2004, 70(4), 346-350.
32. Murray KA, Daszak P. Human ecology in pathogenic landscapes: two hypotheses on how land use change drives viral emergence. Curr Opin Virol. 2013;3(1):79-

83.
33. Mutero CM, Kabutha C, Kimani V, Kabuage L, Gitau G, Ssennyonga J, Oganda M. A transdisciplinary perspective on the links between malaria and agroecosystems in Kenya. Acta Trop. 2004;89(2):171-186.
34. Mwangangi JM, Muturi EJ, Shililu J, Muriu SM, Jacob B, Kabiru EW, Novak R. Survival of immature *Anopheles arabiensis* (Diptera: Culicidae) in aquatic habitats in Mwea rice irrigation scheme, central Kenya. Malar. J. 2006;5(1):1-8.
35. O'gower AK. Environmental stimuli and the oviposition behaviour of *Aedes aegypti* var. queenslandis Theobald (Diptera, Culicidae). Anim Behav. 1963;11(1):189-197.
36. O'MALLEY C. Seven ways to a successful dipping career. Wing Beats, 1995, *6*, 23-24.
37. Oyewole IO, Ibidapo CA, Okwa OO, Oduola AO, Adeoye GO, Okoh HI, Awolola TS. Species composition and role of *Anopheles* mosquitoes in malaria transmission along Badagry Axis of Lagos Lagoon, Lagos, Nigeria. Int. J. Insect Sci. 2010;2:IJIS-S4698.
38. Patz JA, Daszak P, Tabor GM, Aguirre AA, Pearl M, Epstein J. Working Group on Land Use Change Disease Emergence. Unhealthy landscapes: policy recommendations on land use change and infectious disease emergence. Environ. Health Perspect. 2004;112(10):1092-1098.
39. Paupy C, Delatte H, Bagny L, Corbel V, Fontenille D. *Aedes albopictus*, an arbovirus vector: from the darkness to the light. Microbes Infect. 2009;*11*(14-15):1177-1185.
40. Piyaratne MK, Amerasinghe FP, Amerasinghe PH, Konradsen F. Physico-chemical characteristics of *Anopheles culicifacies* and *Anopheles varuna* breeding water in a dry zone stream in Sri Lanka. J. Vector Borne Dis. 2005;42(2):61.
41. Preechaporn W, Jaroensutasinee M, Jaroensutasinee K. The Larval Ecology of *Aedes aegypti* and *Ae. Albopictus* in Three Topographical Areas of Southern Thailand; c2006.
42. Ramasamy R, Surendran SN, Jude PJ, Dharshini S, Vinobaba M. Larval development of *Aedes aegypti* and *Aedes albopictus* in peri-urban brackish water and its implications for transmission of arboviral diseases. PLoS Negl Trop Dis. 2011;5(11):e1369.
43. Rao BB, Harikumar PS, Jayakrishnan T, George B. Characteristics of *Aedes* (Stegomyia) *albopictus* Skuse (Diptera: Culicidae) breeding sites. Southeast Asian J. Trop. Med. Public Health. 2011;42(5):1077-1082.
44. Reiskind MH, Zarrabi AA. Water surface area and depth determine oviposition choice in *Aedes albopictus* (Diptera: Culicidae). J. Med. Entomol. 2012;49(1):71-76.
45. Rueda LM, Patel KJ, Axtell RC, Stinner RE. Temperature-dependent development and survival rates of *Culex quinquefasciatus* and *Aedes aegypti* (Diptera: Culicidae). J. Med. Entomol. 1990;27: 892-8.
46. Sehgal SS, Pillai MK. Preliminary studies on the chemical nature of mosquito-breeding waters in Delhi. Bull. World Health Organ. 1970;42(4):647.
47. Sultana A, Hasan S, Raheman M, Mamun M. Rainy season and physico-chemical properties of mosquito breeding habitats stimulate the prevalence of *Aedes Aegypti* in old Dhaka city, Bangladesh. Int. J. Nat. Sci, 2016;7:265-272.
48. Thangamathi P, Ananth S, Kala N, Maheshwari R, Gnanasoundrai A, Nagamani N. Seasonal variations and physicochemical characteristics of the habitats in relation to the density of dengue vector *Aedes aegypti* in Thanjavur, Tamil Nadu, India. Int. J. Nat. Sci, 2014;5(2):271-276.
49. Thomas SM, Obermayr U, Fischer D, Kreyling J, Beierkuhnlein C. Low-temperature threshold for egg survival of a post-diapause and non-diapause European aedine strain, *Aedes albopictus* (Diptera: Culicidae). Parasites & Vectors, 2012; 5: 100.
50. Tiimub BM, Afua MAD. Determination of selected heavy metals and Iron concentration in two common fish species in Densu River at Weija District in Greater Accra region of Ghana. Am. Int. J. Biol. 2013;1(1):45-55.
51. Toma T, Sakamoto S, Miyagi I. The seasonal appearance of *Aedes albopictus* in Okinawajima, the Ryukyu archipelago, Japan. Mosq. New. 1982;42:179–83.
52. Tyagi BK, Munirathinam A, Venkatesh A. A catalogue of Indian mosquitoes. Int. J. Mosq. Res. 2015;2(2):50-97.
53. Umar A, Don Pedro KN. The effects of pH on the larvae of *Ae. Aegypti* and *Cx. quinquefasciatus*. Int. J. Appl. Sci. 2008;2:58-62.
54. Campbell KM, Lin CD, Iamsirithaworn S, Scott TW. The complex relationship between weather and dengue virus transmission in Thailand. Am. J. Trop. Med. Hyg. 2013;89:1066–80.