

Air versus water temperature of aquatic habitats in Delhi: Implications for transmission dynamics of *Aedes aegypti*

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Abstract

The present study was planned to characterize the microclimate experienced by *Aedes* larvae in different breeding habitats by determining the temperature variations in water kept in containers during different months under natural conditions. The study was conducted in three municipal zones of Delhi. In each site, four types of container material (plastic, cement, iron and ceramic) were chosen for recording the water temperature in the containers. Daily air and water temperatures (mean, maximum and minimum values) recorded by HOBO and Tidbit data loggers, respectively, were compared using analysis of variance and Tukey's honest significant difference (HSD) tests. Mean monthly temperature of water varied from 16.9 to 33.0 °C in tin containers, 17.3 to 35.6 °C in plastic containers, 14.3 to 28.5 °C in ceramic pots, 23.3 to 30.4 °C in cemented underground tanks (UGT) and 15.8 to 35.1 °C in cemented overhead tanks (OHTs). Corresponding values for the air temperature ranged from 17.7 to 36.1 °C. The difference

between temperature of water in the containers and air temperature was highest for ceramic pots. Daily mean, maximum and minimum temperatures recorded by different data loggers differed significantly ($P < 0.05$). When Tukey HSD test was applied for data analysis, the daily mean air temperature differed significantly from the water temperature in tin and ceramic pots as well as cemented OHTs. The temperature of water in the different breeding habitats investigated was lower than the air temperature. Moreover, actual air temperature as recorded by HOBO was higher than the temperature recorded by local weather stations. Considering the ongoing climate change, cemented UGT and earthen pots may be more productive breeding habitats for the *Aedes* mosquito in the near future, while plastic and cemented OHTs might no longer be suitable for *Aedes* breeding.

Introduction

Mosquitoes are important vectors of diseases like dengue, malaria, Japanese encephalitis, *etc.* that cause a great amount of morbidity and mortality among human populations. They are poikilothermic in nature and temperature affects several aspects of their biology like development, longevity, gonotrophic cycle and vector competence (Calado and Navarro-Silva, 2002; Rúa *et al.*, 2005; Paaijmans *et al.*, 2011; Ciota *et al.*, 2014). Mosquito breeds in aquatic habitats and their development from egg to pupae are completed in water, whose temperature affects the fitness of the emerging adults (Oda *et al.*, 2002; Westbrook *et al.*, 2010). Several studies have shown the effect of water temperature on larval biology in a number of mosquitoes including *Aedes aegypti* (Bar-Zeev, 1958; Tun-Lin *et al.*, 2000; Mohammed and Chadee, 2011).

Ae. aegypti, the principal vector of dengue and chikungunya in India, generally breeds in a variety of habitats either natural or man-made. Man-made habitats are the containers made of different materials, *i.e.* plastic, iron, cement, glass, ceramic, rubber, *etc.* Laboratory studies have shown that there is a significant difference between the temperature of water in the breeding containers and the environmental temperature. Moreover, inter-container temperature variations also exist (Kumar *et al.*, 2016a). The air temperature varies significantly during different months resulting in differences between temperature of air and water. Studies with *Anopheles* mosquitoes have shown that the water temperature in breeding habitats differs from air temperature (Paaijmans *et al.*, 2008). In Kenya, the mean water temperature of the breeding habitats was 4-6 °C higher than corresponding mean air temperatures (Paaijmans *et al.*, 2010; Paaijmans and Thomas, 2013). Moreover, diurnal variations in temperature also exist that may affect the life history traits of mosquitoes and disease transmission (Lambrechts *et al.*, 2011; Mohammad and Chadee, 2011; Carrington *et al.*,

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2013b). Most of the studies undertaken so far have recorded and analyzed the variations of temperature only for a limited duration (Paaijmans *et al.*, 2010; Paaijmans and Thomas, 2013) rather than the whole year. There may be monthly differences in the temperature of water with respect to air temperature that may affect larval breeding. Hence, there is a need to generate longitudinal data for the variations in temperature between air and water affecting the development of *Ae. aegypti*.

The present study was undertaken to find out the variations in temperature of water in container material during different months under natural conditions that may affect breeding and development of *Ae. aegypti*. Further, understanding the impact of temperature of different environmental niches with regard to *Ae. aegypti* population dynamics will help improving our knowledge towards dengue transmission dynamics.

Materials and Methods

Administratively, Delhi is divided into 12 municipal zones which fall under three municipal corporations - East MCD, North MCD and South MCD. Based on the prevalence of dengue, three zones namely, the South zone, the Shahdara North zone and the Najafgarh zone were selected for the study (Figure 1). At each site, four types of containers based on the construction material (plastic, cement, iron and ceramic) were chosen for recording the temperature of container-held water. In the Shahdara zone, cemented containers were mostly overhead cement tanks (OHTs), while in the other two zones cemented containers were underground tanks (UGTs). In each container, one temperature data logger, the UTBI-001 Tidbit v2 (Onset, Cape Cod, MA, USA) was placed nearly 20 cm below the water surface to record hourly temperature. Volume of water in all the containers was maintained by adding water after every one or two days. Air temperature was also recorded by installing HOBO data loggers, Onset Temperature/RH data logger U14-001 (Onset, Cape Cod, MA, USA), which were placed on outer wall of room under shade. The data was recorded from March 2015 to May 2016. Overall, 16 Tidbit data loggers were installed for recording water temperature at different sites and three HOBO loggers were installed for recording the air temperature. The position of the data loggers was recorded using a global positioning system instrument from Garmin (<https://www.garmin.com/en-US/company/about/>). Recorded data were downloaded on a monthly basis from the data loggers using a computer. Monthly weather data from the Delhi weather station was downloaded from the National Oceanic and Atmospheric Administration's (NOAA) National Climate Data Center.

Daily maximum, minimum and mean temperatures were calculated for each of the loggers. Additionally, monthly maximum, minimum and mean temperatures were also calculated. Data from NOAA were used to analyse the differences in temperature data recorded by HOBO and that provided meteorologically. Due to loss or technical problems in HOBO and Tidbit data loggers installed in the Najafgarh zone, air and water temperature of plastic containers could not be recorded for the duration of March-April 2015. In the Shahdara zone, there was a loss of water temperature data for plastic containers for the period April- May 2016.

Daily and monthly mean, maximum and minimum temperatures recorded by the HOBO and Tidbit data loggers were compared using the analysis of variance (ANOVA) approach ([and-statistics/hypothesis-testing/anova/\) and also the Tukey honestly significant difference \(HSD\) test \(<https://www.statisticshowto.datasciencecentral.com/tukey-test-honest-significant-difference/tests>\). Variations in the diurnal temperature range were also analysed statistically using ANOVA and Tukey HSD. Comparison of the temperature recorded by the local weather station and HOBO data loggers was done using the paired sample t test \(<http://www.statisticssolutions.com/manova-analysis-paired-sample-t-test/>\). All the analyses was done with help of SPSS 16.0 statistical software and online web statistical calculator \(astatsa.com\).](https://www.statisticshowto.datasciencecentral.com/probability-</p>
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Results

The temperature of water in different containers was generally lower than the temperature of air recorded by HOBO (Figure 2). The mean monthly temperature of water varied from 16.9 to 33.0 °C in tin containers, 17.3 to 35.6 °C in plastic containers, 14.3 to 28.5 °C in ceramic pots, 23.3 to 30.4 °C in cemented UGTs and 15.8 to 35.1 °C in cemented OHTs (Table 1). Corresponding values for the air temperature ranged from 17.7 to 36.1 °C. Temperature of water in cemented UGTs was observed to be higher than the temperature of air from October to March. Further, the difference between the water temperature in containers and air temperature was highest for ceramic pots. Daily mean, maximum and minimum temperatures recorded by different data loggers differed significantly ($P < 0.05$). When results were analysed using Tukey HSD test, significant differences were observed between the daily mean air temperature and water temperature in different containers such as tin, ceramic pot and cemented OHT (Tables 1 and 2). Similarly, daily maximum and minimum air temperatures differed significantly ($P < 0.05$) from water temperature in tin, ceramic pots and cemented OHT. Interestingly, the difference between air and water temperature in plastic containers was insignificant for the mean,



Figure 1. Map of Delhi showing the study sites with latitude and longitude.



maximum and minimum daily temperatures.

Temperature recorded by the local weather station was generally lower than the temperature recorded by HOBOS installed at three different zones. When the t test was applied, a significant variation ($P<0.05$) was observed in temperature recorded by HOBO and temperature recorded by local weather stations in the South and Shahdara North zones except in the Najafgarh zone (Figure 3).

Discussion

This study has elucidated the variations observed in temperature of water in different breeding containers for the *Aedes* mosquito with respect to corresponding air temperatures. The temperature of water in all types of containers differed significantly from air temperature except for plastic containers. Similar findings have been reported under laboratory conditions where the temperature of water in four different containers was recorded and found to be lower than the temperature of environmental chamber

Table 1. Monthly variations in mean water temperature in different containers with air temperatures.

| Month | HOBO measurements of the air temperature (n=3) | | Temperature of water in different containers | | | | | | | | | |
|--------|--|------|--|--------------------|--------------------|-------------------|-----------|------------|------|------------|------|------------|
| | Mean temp. | ±SE | Plastic (n=3) | Cemented UGT (n=2) | Cemented OHT (n=1) | Ceramic pot (n=3) | Tin (n=3) | Mean temp. | ±SE | Mean temp. | ±SE | Mean temp. |
| Mar-15 | 24.1 | 0.48 | 23.5 | 0.6 | 24.6 | 2.8 | 21.3 | - | 20.5 | 0.2 | 22.7 | 0.7 |
| Apr-15 | 30.7 | 0.42 | 29.9 | 0.9 | 26.9 | 1.8 | 29.1 | - | 25.1 | 0.9 | 28.8 | 0.7 |
| May-15 | 36.1 | 1.11 | 35.6 | 1.3 | 29.1 | 0.4 | 35.1 | - | 27.2 | 0.5 | 31.9 | 1.9 |
| Jun-15 | 34.2 | 1.03 | 33.7 | 1.0 | 29.8 | 0.0 | 33.3 | - | 28.2 | 0.2 | 31.2 | 1.5 |
| Jul-15 | 31.3 | 0.54 | 31.4 | 0.6 | 30.1 | 0.3 | 30.9 | - | 28.5 | 0.2 | 29.9 | 0.6 |
| Aug-15 | 31.0 | 0.34 | 30.8 | 0.8 | 30.2 | 0.3 | 30.7 | - | 28.4 | 0.7 | 29.3 | 0.2 |
| Sep-15 | 31.5 | 0.54 | 32.0 | 1.1 | 30.4 | 0.5 | 31.4 | - | 28.1 | 1.1 | 29.3 | 0.7 |
| Oct-15 | 29.1 | 0.27 | 29.3 | 0.7 | 29.3 | 0.1 | 28.6 | - | 24.3 | 0.7 | 27.6 | 0.6 |
| Nov-15 | 23.6 | 0.56 | 24.6 | 0.6 | 27.4 | 1.7 | 22.6 | - | 18.8 | 0.2 | 22.4 | 0.4 |
| Dec-15 | 18.0 | 1.05 | 18.7 | 0.9 | 24.8 | 3.4 | 17.0 | - | 14.3 | 0.1 | 17.7 | 1.1 |
| Jan-16 | 17.7 | 1.40 | 17.3 | 0.9 | 23.3 | 4.1 | 15.8 | - | 14.7 | 0.6 | 16.9 | 1.2 |
| Feb-16 | 20.8 | 0.47 | 20.4 | 0.7 | 23.3 | 3.9 | 19.3 | - | 16.7 | 0.1 | 20.6 | 1.5 |
| Mar-16 | 25.9 | 0.01 | 25.5 | 1.1 | 25.2 | 2.9 | 24.5 | - | 21.0 | 0.7 | 26.0 | 1.6 |
| Apr-16 | 32.6 | 0.74 | 32.5 | 0.4 | 27.8 | 1.5 | 30.9 | - | 26.0 | 1.8 | 33.0 | 1.7 |

SE, standard error; UGT, underground tank; OHT, overhead tank.

Table 2. Effects of container material on mean, maximum and minimum water temperature in response to air temperature.

| Temperature | Treatment | Tukey HSD Q statistic | Tukey HSD P value | Tukey HSD inference |
|---------------|--------------------------------|-----------------------|-------------------|---------------------|
| Daily mean | Air temperature X tin | 5.2720 | 0.002 | **P<0.01 |
| | Air temperature X plastic | 0.5078 | 0.899 | insignificant |
| | Air temperature X ceramic pot | 17.4300 | 0.001 | **P<0.01 |
| | Air temperature X cemented UGT | 1.2141 | 0.899 | insignificant |
| | Air temperature X cemented OHT | 4.3979 | 0.023 | *P<0.05 |
| Daily maximum | Air temperature X tin | 8.6500 | 0.001 | **P<0.01 |
| | Air temperature X plastic | 1.1424 | 0.899 | insignificant |
| | Air temperature X ceramic pot | 20.8799 | 0.001 | **P<0.01 |
| | Air temperature X cemented UGT | 8.8935 | 0.001 | **P<0.01 |
| | Air temperature X cemented OHT | 11.5834 | 0.001 | **P<0.01 |
| Daily minimum | Air temperature X tin | 3.3153 | 0.176 | insignificant |
| | Air temperature X plastic | 0.0532 | 0.899 | insignificant |
| | Air temperature X earthen pot | 14.2695 | 0.001 | **P<0.01 |
| | Air temperature X cemented UGT | 0.3975 | 0.899 | insignificant |
| | Air temperature X cemented OHT | 8.2628 | 0.001 | **P<0.01 |

HSD, honest significant difference; UGT, underground tanks; OHT, overhead tanks.

(Kumar *et al.*, 2016a). In contrast, the water temperatures of artificial water pools made in the ground were generally higher than the corresponding air temperatures in a field study conducted in Kenya for determining the development rate of the *Anopheles* mosquito (Paijmans *et al.*, 2010). In that study, the water temperature was recorded in open ground water pools directly exposed to sunlight, while in the current study the water temperature was recorded in different containers covered with a lid and hence not exposed to direct sunlight.

The temperature recorded by the local weather station was

generally lower than the temperature recorded by HOBO installed at three different zones. The finding is in line with previous studies wherein similar differences were observed between temperatures recorded locally and those recorded by weather stations (Paijmans and Thomas, 2011; Cator *et al.*, 2013). These variations occur due to the variation in location of weather station and data logger sites highlighting the importance of micro niches for understanding the dynamics of vector populations in the context of temperature variability. Data loggers at weather stations are generally installed in an open space in an instrument shelter (Stevenson screen), while

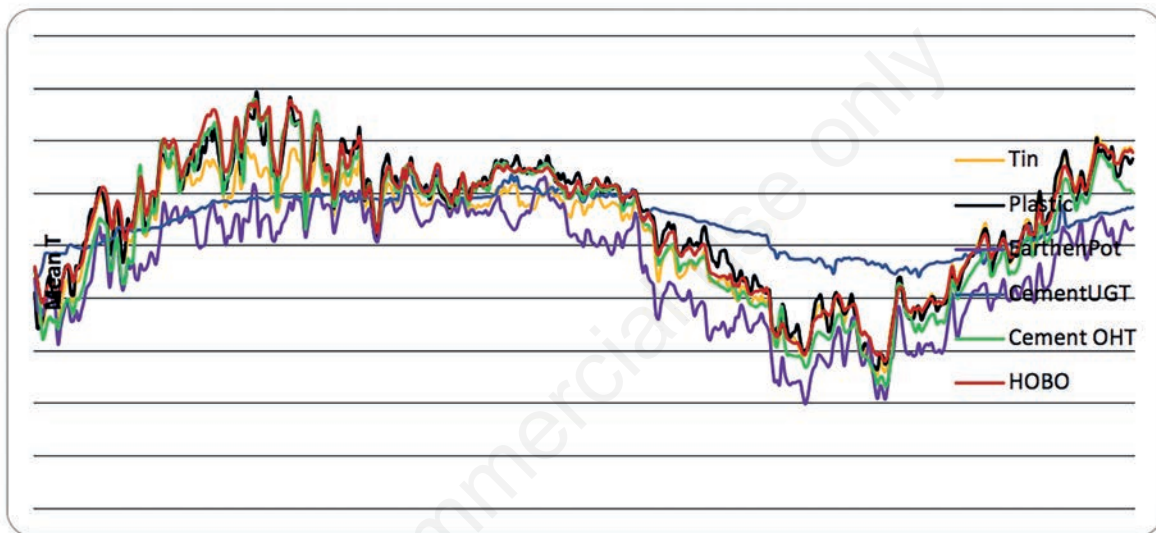


Figure 2. Daily mean temperature of water in different containers with the corresponding air temperatures. UGT, underground tank; OHT, overhead tank.

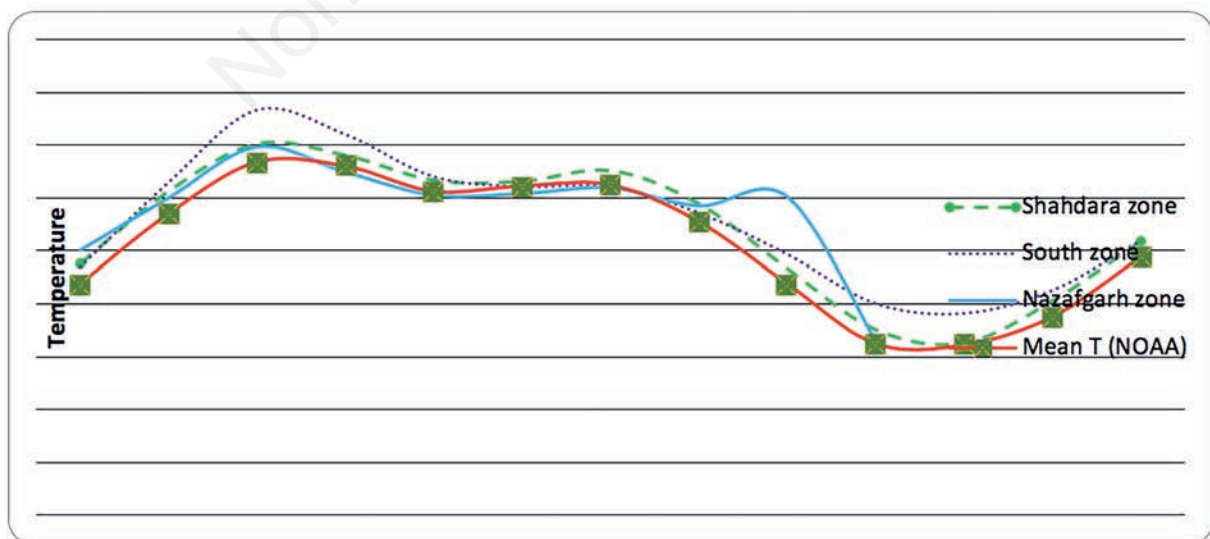


Figure 3. Mean monthly temperature recorded by National Oceanic and Atmospheric Administration's (NOAA) and HOBO installed at three zones of Delhi.



the HOBOS in our study were installed on the outer wall of houses situated in a dense building locality.

An important finding of the study was the temperature of water during winter months (December-February) which was significantly higher (23.3-24.8 °C) in cemented UGTs than the temperature in other containers (14.2-20.6 °C). It indicates that the temperature remains suitable for the breeding and development of *Ae. aegypti* in UGTs even in winter months. In a recent study, it was observed that *Ae. aegypti* did not oviposit at temperatures below 20 °C and was reproductively inefficient at low temperatures (Carrington *et al.*, 2013a). The same study reported that it took 31.7 days for development from egg to pupa at 16°C. Thus, adult *Aedes* mosquitoes developing in UGTs will be more efficient than mosquitoes developing in other types of containers during the winter months and may sustain populations of *Aedes* during the non-transmission period of dengue. During the peak summer months (April-June), the water temperature in UGTs (26.9-29.8°C) and ceramic pots (25.1-28.2°C) was near the optimum for *Aedes* larval development (27 ± 1°C). While in plastic containers and cemented OHTs, the water temperature reached the upper threshold for *Aedes* development. It suggests that plastic and cemented OHTs are not suitable for the growth of *Aedes*.

One limitation of the current study was that plastic containers selected were OHTs. It has been previously reported that plastic containers (Plastic tub/drum/tanks/OHT) are the most positive containers and remains so throughout the year (Singh *et al.*, 2014; Kumar *et al.*, 2016b). Hence, further investigations should incorporate plastic containers used for storing water inside the houses like plastic drums, buckets *etc.*, *vis-a-vis* plastic containers kept on the rooftop.

So far, only a few studies have been undertaken to understand the actual environment experienced by larvae of mosquito vectors. These studies have been done mostly on anopheline vectors (Paijmans *et al.*, 2010; Cator *et al.*, 2013; Asare *et al.*, 2016). There is a scarcity of literature on environmental temperature conditions experienced by *Ae. aegypti* under natural field conditions (Hemme *et al.*, 2009), and it is an important aspect as temperature required for larval development is a key factor which not only determines the life history traits (Carrington *et al.*, 2013b) but also affects the insecticide resistance status (Polson *et al.*, 2012) and vectorial capacity of adult mosquitoes (Alto and Bettinardi, 2013). Hence, the current study was an effort in understanding the temperature dynamics experienced by *Aedes* larvae in breeding containers made up of different materials. Here, environmental temperatures ranged from 17.7 °C to 36.1 °C, and the corresponding water temperatures ranged from 14.3 °C to 35.5 °C in different breeding containers. Other studies have reported that >35 °C temperature of water is inimical for *Aedes* larval development (Kumar *et al.*, 2016a). The Intergovernment Panel on Climate Change (IPCC) has projected increases in average temperatures in tropical countries of 1.4 °C-5.8 °C by the year 2100 due to climate change (IPCC, 2007). The projected increase in temperature is expected to affect the development and survival of *Ae. Aegypti* larvae. In the present study we observed that the mean temperature of water in plastic and cemented overhead tanks reached the threshold temperature during the summer season. Hence, these containers may no longer be suitable for the breeding of *Aedes* in the near future. Further, cemented UGTs and ceramic pots may emerge as preferred containers for the development of *Aedes* larvae.

Conclusions

The current study has characterized the microclimate experienced by the *Aedes* larvae in different breeding containers. The temperature of water in different breeding habitats was found to be lower than the air temperature. Moreover, actual air temperatures as recorded by home data loggers were generally higher than the temperature recorded by local weather stations. Considering the ongoing changes in climate, cemented UGTs and ceramic pots may emerge as better breeding habitats for *Aedes* mosquito in near future while plastic and cemented OHTs might no longer be suitable for larval breeding. The results of this study will be useful in developing temperature-driven dynamic dengue risk models and improvement of early forecast systems.

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