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ORIGINAL RESEARCH ARTICLE

Observation and Simulation of Mosquito Breeding Site Water Temperature for Malaria Transmission at Kaita Local Governmet Township of Katsina State, Nigeria.

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ABSTRACT

Studies showed that transmission of malaria is influenced by environmental factors such as temperature. This work is aimed at finding the impact of mosquito's breeding site water temperature on mosquito's larva development time. An artificial mosquito's breeding habitat was created. The water temperature of the habitat was measured at an hourly interval, then it is averaged into daily time scale. Weather variables of the experimental site were inpu into the the energy balance model to simulate the breeding habit water temperature. The mosquito's larva development time was then predicted by inputting both the observed water and simulated water temperature into the vector borne disease community model (VECTRI) .The daily maximum, and minimum observed water temperatures were 27.9°C, 32.6°C and 21.7°C, respectively. The daily mean, maximum, and minimum simulated water temperatures were 29.8°C, 35.6°C, and 23.5°C respectively. These temperatures are within the temperature range that supports mosquito's larva development. Mosquito's larva development was predicted using the VECTRI model. According to this study larva development reached completion in 7.1 days using the observed water temperature, 6.03 days using the simulated water temperature and 8.01days using the observed air temperature. This energy balance model is an improved water temperature scheme over the assumption that air temperature is equal to air temperature. This work shows the importance of water temperature and the value of degree day required for emergence of an adult mosquito in the simulation of aquatic stage development. Both the observed water and simulated water temperatures are higher than the on observed air temperature, thus air temperature cannot be used as the water temperature in the simulation of the mosquito's larva development time. The finding of the work can be used as source toward mosquito's larval control through water temperature. It is however clear from the finding that could be as result of temperature due to shorter time predicted for mosquito's larval development.

ARTICLE HISTORY

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KEYWORDS

water temperature; energy balance model; Mosquito's larva development time and VECTRI model.

INTRODUCTION

Temperature is an abiotic factor affecting the life cycle of the malaria parasite and its vector. Water temperature in particular influences the aquatic state development of the malaria vector especially larval stage. Larval stage is the most important stage that determines vital adult characteristics such as survival rate, abundance and pupation rate. The Life cycle of mosquito is completely live on water from egg to adult. Immature mosquito larva stays between water – air interface, this makes water temperature vital to larva development. In the other hand adult mosquitoes leave aquatic habitat to land, their environmental temperature influences some of its traits such as biting rate feeding and egg lying. The malaria parasite develops in the mosquito thus environmental temperature affects its development rate. In this work two different models were used: The energy balance model and the larva growth simulation model.

Malaria is a deadly disease spread by a mosquito, when it bites the mosquito inject the malaria parasite into your the bloodstream. Malaria is caused by parasites not by virusesus or any type of bacteria. Malaria is common in a tropical area where it is hot and humid. In 2020 there were about 241 million reported cases of malaria throughout the world, with 627,000 deaths due to malaria. The majority of the cases occur in Africa and South Asia. Malaria occurs all over the world and happens most often in developing countries and areas with warm temperatures and higher humidity, including Africa, central and south America. The Dominican Republic, Haiti and other area.

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Several studies confirmed the effect of water temperature on mosquito's larva development period on malaria transmission. This work tries to provide literature on the relationship between the water temperature of the region and malaria transmission in the region. The region is one of the regions of the state that suffers from malaria disease every year. This work failed to record water temperature during the night, and incorporating the effect of cement plaster on the water temperature. The possible sources of error in this work would be: error due measuring instrument, error due to parallex, error due to influence of cement plaster, and error due to some constant values chosen.

Energy balance model has been used for simulation of water temperature but Asare et al., 2016; simplified it so that it can be run using the weather input variables that are easily found at most of the weather station. This makes this simplified model better and easy to used compare to other energy balance model that require weather input variables that are not found in most of the weather station. Asare et al., 2016; discovered 27.2°C as mean daily temperature that supports larva development. 8.2 days and 8.4days were predicted as mosquito's larva development in Ghana (Asare et al., 2016). Gimning et al., 2002; Observed 8.4 days as mosquito's development. Paaijmans et al., 2008; Paaijmans et al., 2010 found that water temperature was higher than air temperature. Kirby and Lindsay (2004) observed the effect of low and higher water temperature on the emergence and mortality rate of adult mosquitoes. Bayoh and Lindsay (2003) identified adult mosquito existence under constant laboratory temperature of 18°C and 34°C while there was no existence below 18°C and above 34°C. Moreover, Lyitmo et al 1992 found 27°C as favourable temperature for mosquito anopheles larva development in the laboratory. Bayoh and Lindsay (2004) discovered the larva survival rate of anopheles gambiae between 10 and 38 days under constant temperature of 18 while at 34 survival rates fluctuated between 5 and 13 days. Kirby and Lindsay (2009) noticed quick development rate, decrease in survival rate for both anopheles gambiae and anopheles aranbiensis increase due increase in water temperature. The aim of this simulation work is to simulate the mosquito breeding site water temperature of mosquito habitat for the prediction of malaria transmission for Kaita local government of Katsina State.

MATERIALS AND METHOD

Study location and data

The study was conducted at Kaita local Government area of Katsina state, Nigeria. Between August 01 and September 2021 an hourly water temperature of single mosquito developmental habitat was observed using mercury in glass thermometer. The thermometer was placing during measurement. The pond is sunlight pond due the fact that the majority malaria vector (Anopheles gambiae Senso lato) in the region prefers sunlight pond. Weather variables applied in this study were obtained from Umaru Musa Yar'adua University automatic weather station at an hourly interval. The observed hourly water temperatures and observed hourly weather variables were however average into daily time scale.

Description of the energy balance model for the water temperature

Energy balance model is a physics base model that represents the change of heat per unit time absorbed in or release out from the water column. The model is described by the equation bellow:

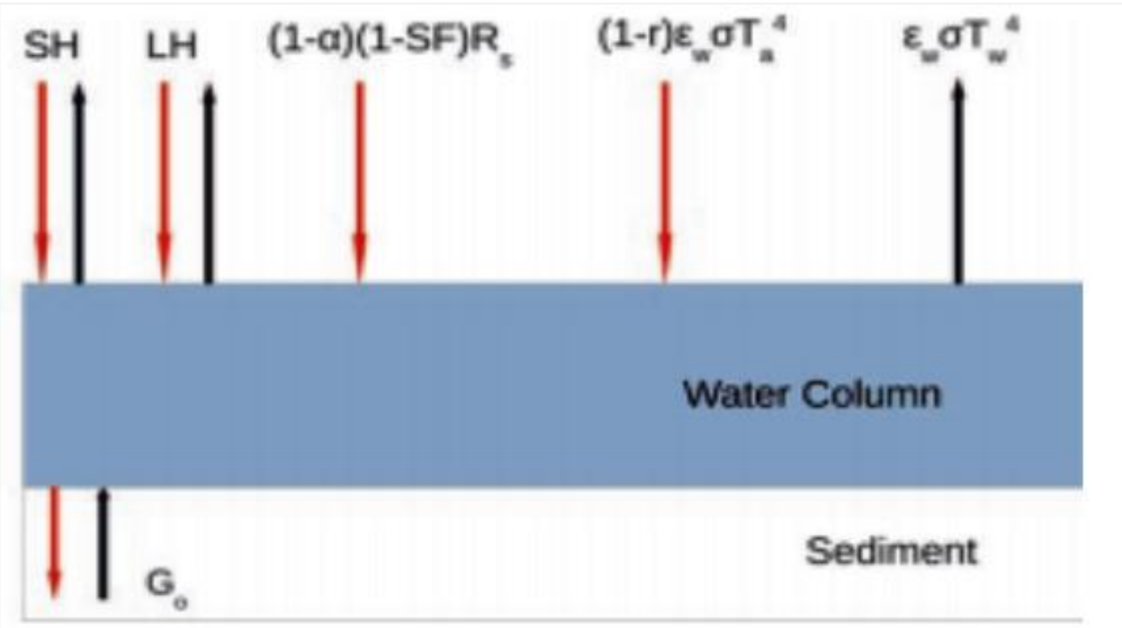

Fig 1.0 Representation of the energy balance model

$$\frac{dQ}{dt} = R_{net} - LH - SH - G_0 \quad eq1.0$$

here $\frac{dQ}{dt}$ is the rate of heat flow in or out of the water surface, R_{net} is the net radiative flux (the sum of the net solar and long wave radiation), LH is the latent heat flux, SH is the sensible heat flux and G_o is the soil heat flux.

R_{net} is determined as:

$$R_{net} = (1-\alpha)(1-SF)R_s + (1-r)\varepsilon_a \sigma T_a^4 - \varepsilon_w \sigma T_w^4 \quad eq1.1$$

$$R_{net} = (1-\alpha)(1-SF)R_s + (1-r)\varepsilon_a \sigma T_a^4 - \varepsilon_w \sigma T_w^4 \quad eq1.2$$

$R_s = R_a k$

$$R_a = I_{sc}E_o(\sin\sigma\sin\varphi + \cos\varphi\cos w_i) \quad eq1.3$$

Declination angle σ and hour angle w_s were computed using the following relation:

$$\delta = 23.45\sin\left(360 \times \frac{284+n}{365}\right) \quad eq1.4$$

Where n is the number of days

Where p is the air pressure, T is the air temperature and es is the saturated vapour pressure RH is the relative humidity and e is the vapour pressure.

Where ρ_a is the air density, C_p is the specific heat capacity of air at constant pressure, U_a is the wind speed, q_w is the water surface specific humidity, q_a is the air humidity, L_v is the latent heat of vaporization, C_{DH} and C_{DE} are aerodynamic coefficient.

The soil heat flux G_o is defined as:

$$G_o = FR_{net} \quad eq2.1$$

F is the fraction constant.

The artificially predicted breeding site water temperature equation is described as:

$$T_w(t+\Delta t) = T_{w(t)} + \frac{1}{\rho C_w d}\left(\frac{dQ}{dt}\right)\Delta t \quad eq2.2$$

Where d is the water depth, Δt is the time and t is the time step used

Vectri Model

Vectri means the vector borne disease community model of the international centre for theoretical physics. Vectri incorporates mosquito larva growth rate scheme based on degree day. The model is described by the equation below:

$$R_L = \frac{T_w - T_{Lmin}}{K_L} \quad eq2.3$$

$$w_s = \cos^{-1}(-\tan\emptyset\tan\delta) \quad eq1.5$$

Where φ is the latitude and δ is the declination angle

Where α is the short wave albedo of water, SF is the shade factor, R_s short wave solar radiation, r is the albedo of the water surface to long wave radiation, ε_a is the emissivity of the atmosphere, R_a is the extra-terrestrial radiation, T_{max} is the daily air temperature, T_{min} is the daily minimum air temperature, k is the empirical co-efficient, I_{sc} is the solar constant, E_0 is the eccentricity correction, δ is the solar declination, φ is the latitude and w_i is the hour angle.

Sensible heat SH and latent heat LH are defined as:

$$SH = \rho_a C_p C_{DH} U_a (T_w - T_a) \quad eq1.6$$

$$LH = \rho_a L_v C_{DH} U_a (q_w - q_a) \quad eq1.7$$

$$q_w = \frac{0.622 \times e}{P} \quad eq1.8$$

$$e = es \times \frac{RH}{100} \quad eq1.9$$

$$es = 6.112 \times \exp\left(\frac{17.67T}{T+243.5}\right) \quad eq2.0$$

Where R_L is the growth rate, T_{Lmin} is the threshold temperature below which larval development stops and K_L is the degree days required for adult emergence. According to laboratory studies, K_L it has two values, 90.9 according to Jepson approximation (JA) and 200 according to Bayoh approximation (BA)

Model Evaluation

The performance of the model will be determined using three statistical concepts namely:

a) Nash Sutcliffe efficiency (NSE) which is defined as:

$$NSE = 1 - \frac{\sum_{i=1}^{N}(O_i - S_i)^2}{\sum_{i=1}^{N}(O_i - \overline{O}_i)^2} \quad eq2.4$$

b) Coefficient of determination R^2 which is defined:

$$R^2 = \left(\frac{\sum_{i=1}^{N}(O_i - \overline{O})(S_i - \overline{S})}{\sqrt{\sum_{i=1}^{N}(O_i - \overline{O})^2 \sum_{i=1}^{N}(S_i - \overline{S})^2}}\right)^2 \quad eq2.5$$

c) Mean Bias Error(MBE) which is defined as:

$$MBE = \frac{1}{N}\sum_{i=1}^{N} O_i - S_i \quad eq2.6$$

Where S_i is the i_{th} simulated value, O_i is the i_{th} is the observation $\bar{O}$ is the mean observed value, $\bar{S}$ is the mean simulated value and N is the total number of observation. The NSE ranges between minus infinity and one (perfect mod) but NSE values <<0.0 signifies unacceptable model performance.

RESULTS AND DISCUSSION

The maximum, minimum and mean of the observed water temperature based on the daily time scale were 32.6°C, 21.7°C and 27.9 °C respectively. Using similar time scale, the maximum, minimum and mean simulated water temperatures were found to be 35.6°C, 23.5°C and 29.8°C respectively. While for the observed air temperature, the maximum, minimum and mean values were 31.3°C, 24°C and 27.2°C respectively.

The difference between maximum simulated and observed temperatures was 3.0°C, while the difference between their minimum was 1.8 0°C and the differences in their mean observed water temperature 1.9°C. However, the differences between observed water maximum, minimum and mean temperatures and their respective observed air temperatures was 1.3°C, 2.3°C and 0.7°C. It is evident from the results that the variations between observed water and simulated temperature on one hand are higher than the variations between the observed water and observed air temperature.

The maximum diurnal range (the difference between daily maximum and minimum temperatures) of the observed water, simulated and observed air temperatures are 24 °C, 24.2°C and 9.8 °C and their minimum values are 6.0 °C, 9.2, and 3.1 °C respectively. However, their mean values were found as 16.1°C, 19.9°C, and 7.1°C respectively.

According to values of water temperatures, temporary bodies of surface water are highly variable. Mosquito larvae would be exposed to temperatures ranging from 21.7°C to 32.6°C with the daily average of 27.9°C. This observed mean temperature is within the optimal temperature range for aquatic stage development based on laboratory studies (Lyitmo et al., 1992; Bayoh, 2001; Bayoh and Lindsay 2003). However, in the real field experiment Koenraadt et al (2004) in Western Kenya, observed similar mean of about 28°C. In Gambia Bayoh (2001) observed 20.7, 36.9 and 27.0 °C as minimum, maximum and mean temperatures. Paaijmans et al., 2008 a was however observed 27.4 °C as daily mean temperature. Asare et al., 2016 in Ghana observed 24°C, 29.2°C and 27.2°C as daily minimum, daily maximum and mean daily water temperatures respectively. The observed minimum water temperature from this potential mosquito developmental habitat is greater than the threshold temperature of 16°C that support larvae development under constant temperature in the laboratory experiments (Bayoh and Lindsay 2003). The maximum temperature recorded exceeded the upper temperature threshold of 35°C that support larvae development in the laboratory by Bayoh and Lindsay (2003) and is less than the water temperature threshold of 41°C lethal to larvae even for a short time found by Haddow (1993).

The percentage difference between hourly observed maximum water temperature and hourly simulated maximum water temperature was 10.5%, while the percentage difference between hourly observed minimum water and hourly observed minimum simulated water was 17.5%. In addition, the percentage difference between hourly observed maximum water temperature and hourly observed maximum air temperature was 15.6%, while that between hourly observed minimum water and hourly observed minimum air temperature was 19.7%. However, the percentage difference between daily observed maximum, minimum , mean water temperatures and daily maximum, minimum and mean simulated water temperatures were 8.4%, 7.7% and 6.4%, while the difference between observed water maximum, minimum, mean temperatures and observed maximum, minimum, mean air temperatures was 2.5%, 3.9.0% , and 9.6% ..

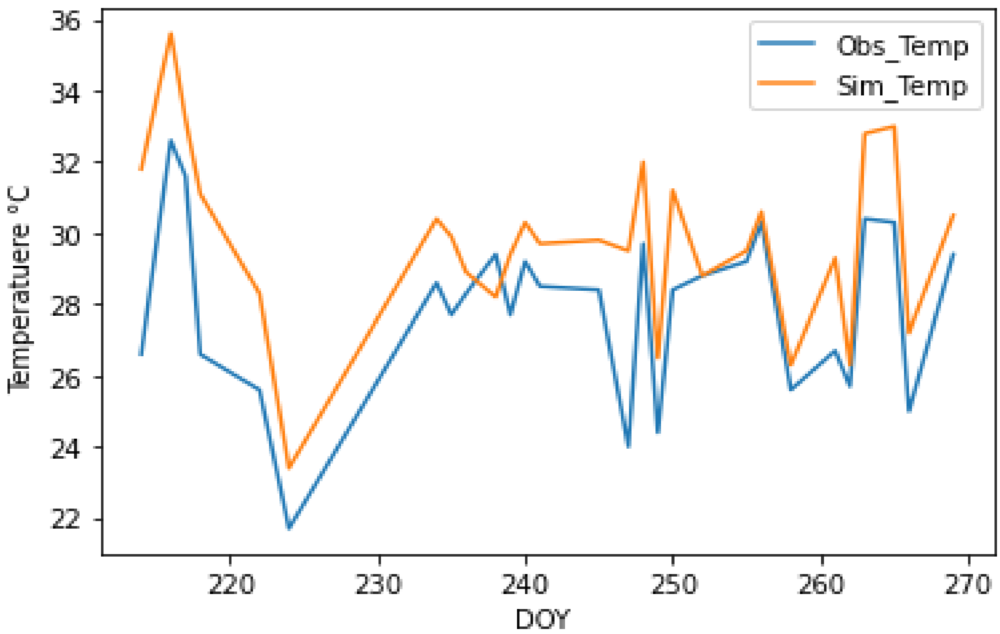

Fig 2.0 Comparison of daily observed water temperature and simulated water temperatures.

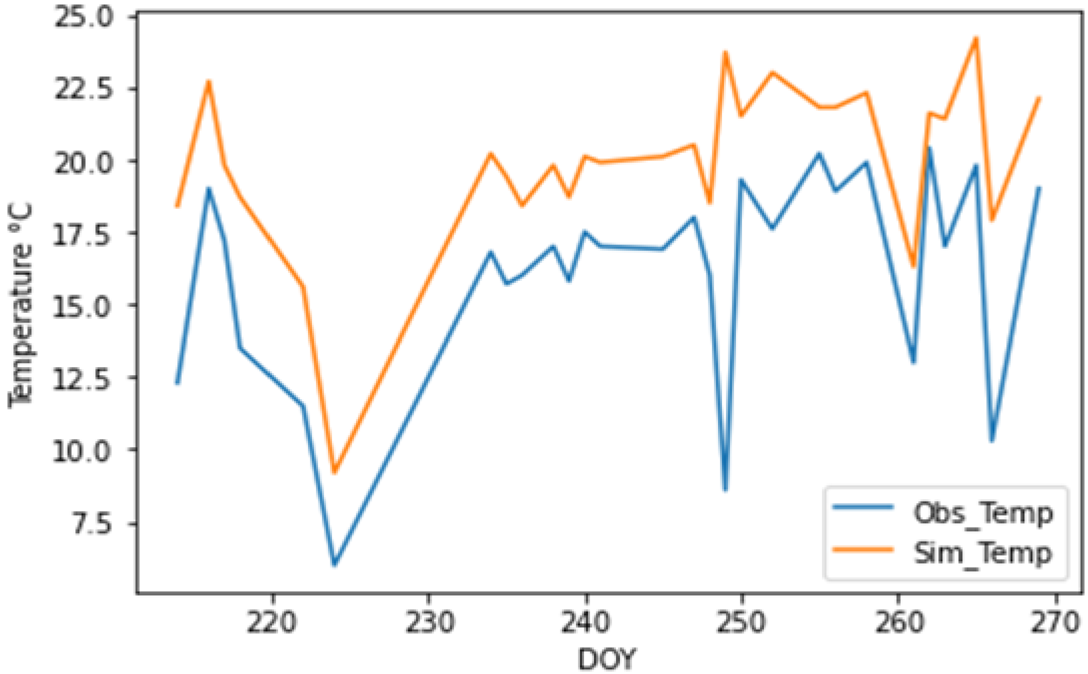

Fig 3.0 Comparison of diurnal temperature range of observed water and simulated water

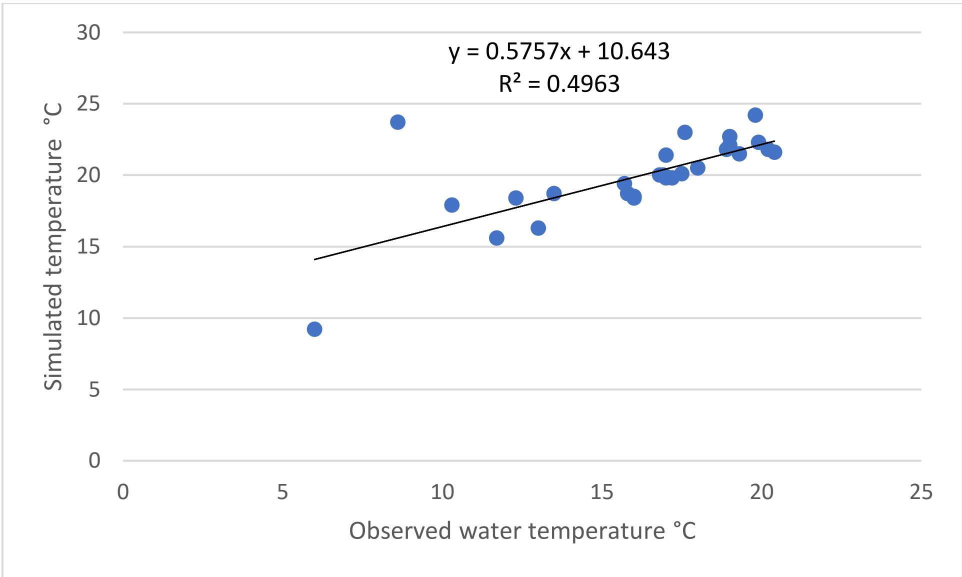

Figure 4.0. Correlation between observed and simulated water temperatures.

The larva's development time was predicted using the Jepson approximation (JA) and Bayoh approximation (BA). On the daily time scale, larvae development became complete in 7.1days (observed water) and 6.03 days (simulated water) all under JA scheme. While using BA scheme the development reached completion in 17.01 days (observed water) and 14.03 days (simulated water). The larvae development using air temperature became complete in 8.01 days (JA) and 18.05 days (BA).

The difference in larva's development time between observed water temperature and simulated was 1.07 days (JA scheme) equivalent to 15.1%, while using BA scheme was 3.02 days equivalent to 17.8%.

The larva's development time found by Asare et al., 2016 using the observed water was 8.2 days and 8.4 days using the simulated water temperature under JA scheme. In addition, Gimning et al., 2002 found 8.4 days. The difference between the predicted values is due to the difference in temperatures recorded. We discovered 21.7°C and 32.6°C as daily minimum and maximum observed water temperature while Asare et al., 2016 found 24°C and 29.2°C, while Gimning obtained 25°C and 32°C.

Larva's development time predicted under JA scheme using air temperature was 0.91 days, which is greater than development time predicted using observed water temperature. This is 1.98 days greater than larvae development predicted using simulated temperature. This is an indication that air temperature overestimated mosquito larvae development time.

Table 1.0 represent the statistical performance of the two models. According to R^2, N.S.E and M.B.E values imply that the energy balance model and VECTRI model have performed well in simulating the water temperature and predicting mosquitos' larvae development time using both schemes. The higher value of $R^2 = 0.669$ (observed water and simulated water), higher efficiency NSE = 0.995 and minimum MBE = -3.817 signifies that the observed water and the simulated water temperature show a similar trend. However, a similar trend was recorded between larva development predicted using observed water and simulated water temperature. In addition, the $R^2 = 0.0369$ and MBE = 0.0596 values indicated poor performance of the VECTRI model to prediction of larva's development times using air temperature. This means they are not related and thus cannot be used in the prediction of mosquito's larva development time.

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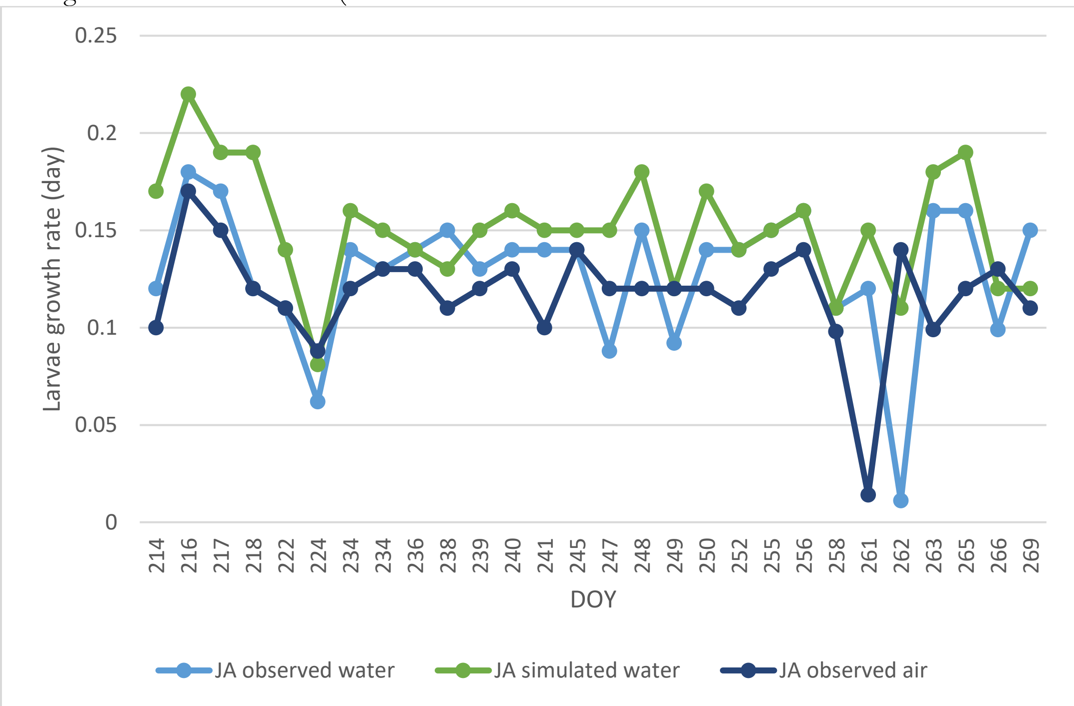

Fig 5.0. Comparison of the daily Jepson approximation scheme of mosquito larvae development time (R_L /JA) using observed water, simulated water and observed air temperature.

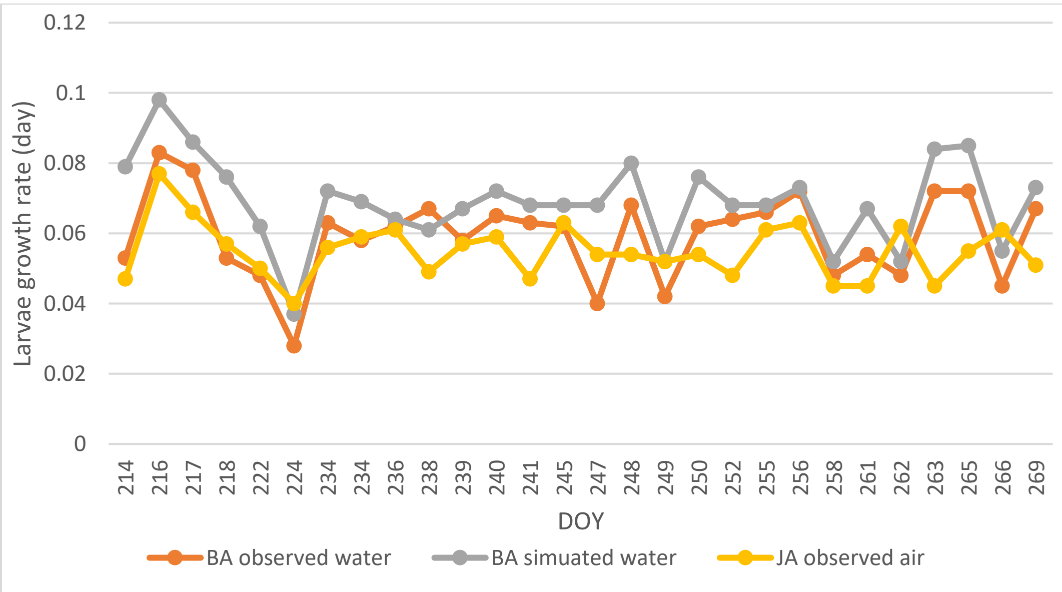

Fig 6.0 Comparison of the daily Bayoh approximation scheme of mosquito larvae development time R_L / BA) using observed water, simulated water and observed air temperatures.

Table 1.0 Summary of Computed Statistic for Model evaluation

	Diurnal temperature range DTR	Daily temperature	LD (T_{OB} /T_{SIM})		LD (T_{OB} / T_{Air})	
			JA	BA	JA	BA
R^2	0.496	0.669	0.468	0.676	0.0369	0.234
NSE	0.939	0.995	0.947	0.971	0.992	0.999
MBE	-3.817	-1.193	-0.0285	-0.00968	0.0596	0.00439

CONCLUSSION

Mosquito's breeding site water temperature was simulated using the energy balance model. The simulated temperature recorded is within the temperature range that supports malaria mosquito's larval development. In addition mosquito's larva development time was predicted using the VECTRI model. The finding showed that malaria mosquito's larva can fully developed in less than 8 days. The finding of this work can be applied for malaria mosquito's larva control through the water temperature. It is contribution to the literature on relationship between malaria and water temperature. In addition this finding can be considered by governmental and non governmental organization in malaria planning and control strategies in the region.

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