WATER TEMPERATURE SIMULATION OF OWENA RIVER AT OWENA DAM SITE USING HEC-RAS MODEL

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ABSTRACT

Water temperature happens to be one of the most important physical parameter used in describing water quality. Temperature affects almost all processes and other water quality parameters. The processes include stratification, biotic processes and chemical fate processes. Water temperature affects other water quality parameters such as Dissolved Oxygen and Biochemical Oxygen demand (BOD). Today, with recent technological advances, several computer-based hydrologic/water quality models have been developed for applications in hydrologic modelling and water resources studies. The *HEC-RAS* (Hydrologic Engineering Centers Rivers Analysis) model performs one-dimensional steady flow, unsteady flow, sediment transport/mobile bed computations, and water temperature modeling. This study tries to simulate the water temperature of Owena dam using *HEC-RAS* model. The input data for the simulation are geometric data, steady flow data, and meteorological data. Input data was entered in the various data editor windows and interfaces of the model in a logical sequence using a series of components parts of the model that direct the program to accept, process, compute and store various parameters and their corresponding values. The results obtained were compared with the observed temperature data of Owena dam for the months of January, June and July. The result of the observed and simulated water temperature shows a correlation of determination (R^2) of 0.92, 0.83 and 0.6 for the months of January, June and July respectively. From the result, it can be concluded that *HEC-RAS* can actually simulate water temperature of Owena River in Ondo state of Nigeria.

1. INTRODUCTION

Water quality is defined as the physical, chemical and biological characteristics of water. Water quality determines the ‘goodness’ of water for particular purposes. Water quality parameters include temperature, dissolved oxygen, nutrients (phosphates and nitrates), pH, turbidity, biochemical oxygen demand (BOD), alkalinity, acidity, carbon dioxide, and specific conductance. Water quality is greatly influenced by the geological structure and the lithology of the watershed or aquifer, the chemical reactions that takes within the watershed or aquifer, as well as the type of land uses, anthropogenic activities and the climatic characteristics of the watershed or basin (Tsakiris and Alexakis, 2012). One of the man-made problems associated with water quality is thermal pollution. Thermal pollution is the introduction of warm water or other substrates into an aquatic ecosystem. Sources include industries such as power plants and also storm-drain runoff which has been warmed on streets, parking lots and sidewalks. In addition, human activities such as construction of roads, deforestation and the removal of vegetation around the water can lead to an increase in water temperature.

Of all the above listed water quality parameters, water temperature is the easiest and often least costly to monitor in field conditions. It is usually measured by thermometer, thermocouple or thermostat. Water temperature is one of the most important physical characteristics of water. It is an important property that determines water suitability for human use, industrial applications and aquatic ecosystem functioning. Temperature impacts both the chemical and biological characteristics of surface water. Park and Clough (2012), described temperatures as driving variable which force systems behave in certain ways. Temperature affects both the processes in the aquatic system and other water parameter. Virtually all processes are temperature-dependent. They include stratification; biotic processes such as decomposition, photosynthesis, consumption, respiration, reproduction, and mortality; and chemical fate processes such as microbial degradation, volatilization, hydrolysis, and bioaccumulation(Park and Clough, 2012).

Temperature exerts a major influence on aquatic organisms with respect to selection/occurrence and level of activity of the organisms. Increase in temperature also cause changes in aquatic plants and animals. As the temperature increases, the rate of photosynthesis increases. At temperatures above 32^{o}C, the rate of photosynthesis will start to level off and then begin to decrease as the temperature continues to increase. As photosynthesis increase, the number of aquatic plants increases. This can lead to an increase in the number of plants which die and are decomposed by aerobic bacteria which consume oxygen in the process. Long-term shifts in temperature can also result in a change in the composition of organisms that make a stream their home. In general, increasing water temperature results in greater biological activity and more rapid growth. Temperature also affects the metabolic rate of aquatic animals, rates of development, timing and success of reproduction, mobility, migration patterns and the sensitivity of organisms to toxins, parasites and disease. Life cycles of aquatic organisms are often related to changes in temperature (Stephanie, 2008). Temperature also affects other water quality parameter like Dissolved Oxygen (DO), an important water characteristic that strongly affects many aquatic organisms. The solubility of oxygen increases as temperature decrease. This means that cold water holds more oxygen than hot water. The reason for this is, when water boils, water is converted to water vapour. The water vapour released contains dissolved oxygen. The amount of oxygen that will dissolve in water increases as temperature decreases. Water at 0^{o}C will hold up to 14.6 mg of oxygen per litre, while at 30^{o}C it will hold only up to 7.6 mg/L. Generally, an increase in temperature will decrease the solubility of oxygen. Temperature also affects the biochemical oxygen demand. An increase in temperature brings about a decrease in dissolved oxygen, which will increase the metabolic rate, thereby increasing biochemical oxygen demand (BOD).

With recent technological advances, several computer-based hydrologic/water quality models have been developed for applications in water resources studies. The need for more scientifically sound analyses has led to the creation of a large number of water quality models. Technologically-based tools such as models and geographic information systems (GISs) can provide increased clarity on probable or alternative outcomes, and thus enable decision-makers to more effectively use traditional planning tools. Models are described as an approximate description of a class of real-world objects and phenomena expressed by mathematical symbolisms (Agoshkov, 2002). A detailed list of Hydrological and water quality models is given by (Moriasi et al., 2012; Berit and Jonas, 2004). With the predictive ability of models, they serve as management tool for decision makers. Examples include HSPF (Bicknell et al., 2001), QUAL2K (Chapra et al., 2008), WASP (Ambrose et al., 1993), AQUATOX (Park and Clough, 2012), SPARROW (Schwarz et al., 2006), SWAT (Arnold et al., 1993), HEC-RAS (HEC-RAS, 2010) to mention a few. The modeling results from these models under different pollution scenarios are very important components of environmental impact assessment and can provide a basis and technique support for environmental management agencies to make right decisions (Qinggai et al., 2013). Water quality studies carried out using models include the following: Vasudevan, M. et al. (2011) applied the QUAL2K model to access waste loading scenario in River Yamuna; Picket (1997) used the WASP5 for Total Maximum Daily Load (TMDL); for the Black River in Washington State, US. (Love and Donigian, 2002) applied the HSPF model for nutrient loadings on Long Island Sound watersheds in Connecticut; Abbaspour et al. (2007) applied the SWAT to predict nitrate and total phosphorus on the 1700 km^2 Thur River basin in Switzerland; Gassman et al. (2007) gave a detailed application of the SWAT model.

The HEC-RAS model performs one-dimensional steady flow, unsteady flow, sediment transport/mobile bed computations, and water temperature modeling. This component of the modeling system is intended to allow the user to perform riverine water quality analyses. An advection-dispersion module is included with this version of HEC–RAS, adding the capability to model water temperature. This new module uses the quickest-ultimate explicit numerical scheme to solve the 1-Dimensional advection-dispersion equation using a control volume approach with a fully implemented heat energy budget. Transport and Fate of a limited set of water quality constituents is now also available in HEC-RAS. The currently available water quality constituents are: Dissolved Nitrogen (NO_3-N, NO_2-N, NH_4-N, and Org-N); Dissolved Phosphorus (PO_4-P and Org-P); Algae; Dissolved Oxygen (DO); and Carbonaceous Biological Oxygen Demand (CBOD). Amod et al., (2012) applied the HEC-RAS model in hydrologic and water temperature modeling in Alameda creek.

Thus this study was undertaken to simulate water temperature of Owena River at Owena Dam site using the HEC-RAS.

2. METHODOLOGY

2.1 Study Area

The study area is located in Ondo State of Nigeria, and lies between the latitudes 7^0 35' and 7^0 00' and longitudes 4^0 50' and 5^0 15'. The dam axis lies about 17km north of the point where the Owena River crosses the Ondo-Akure road and is located on latitude 7^0 18' and longitude 5^0 00'. The Owena Multipurpose Dam is an earth dam with a total fill volume of 1,014,729m3 and a height of 24.2m above river bed, the dam crest level being at elevation 313.2m. It is 1457m long along the crest and it is designed to impound 30 million cubic metres of water in its reservoir that has a total surface area of 7.4 square kilometres. The dam axis cuts across a valley which has a fairly symmetrical cross-section, with an average transverse slope of approximately 6.5% on the left bank and 5.0% on the right bank. Cocoa plantations cover most of the right bank area and a forest reserve is located on the left bank. The river flows mainly in the North-South direction. Its width is in the range of 10-15m; its banks are steep and about 2m in height on either side. The site lies within the South Western basement area of Nigeria in which the bedrock is essentially of the basement complex series. The basement out-crops at some places, especially along the river bed. Outcrops equally abound at both the abutments as well as within the reservoir area. The catchment area of the dam is 738 km^2. Figure 1 shows the map of the study area.

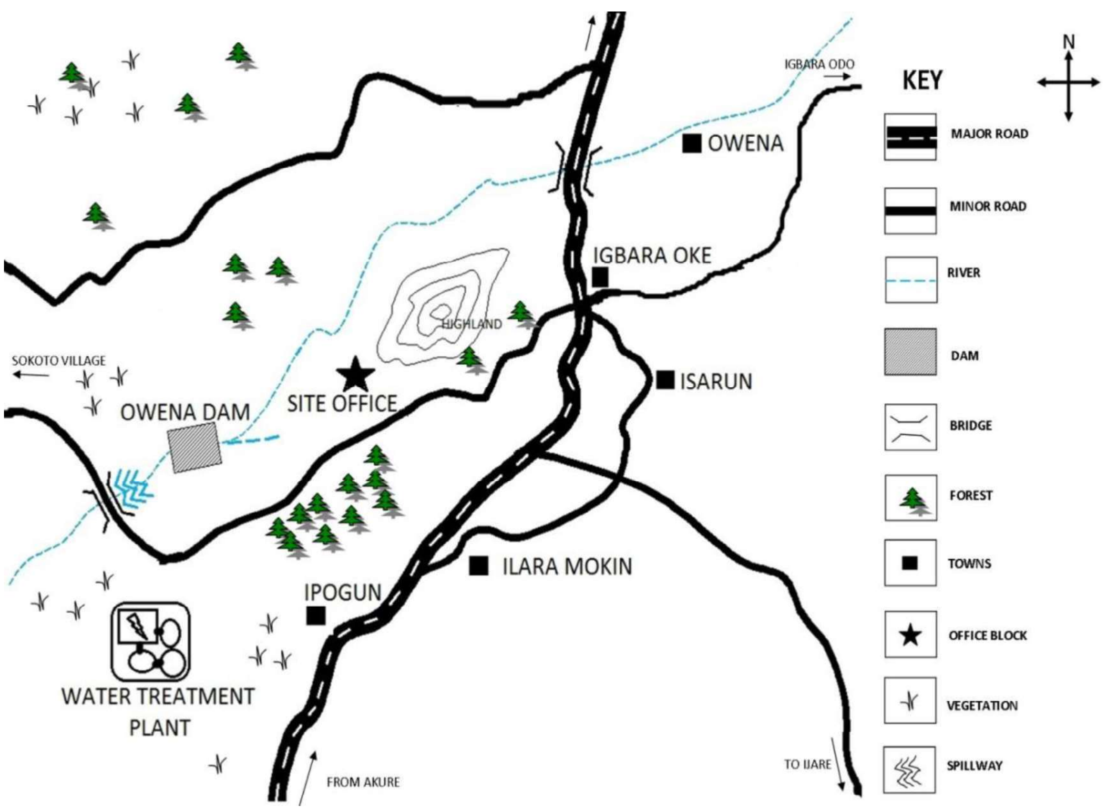

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Figure 1: Map of the study area showing features around it.

2.2 Data Requirements and Organization

The water quality data entry menu, which manages input data, calibration of parameters, and finally output tools menu which manage output files to facilitate viewing and exporting model results was used. Water quality boundary data, meteorological data (atmospheric pressure, air temperature, humidity (vapor pressure, relative humidity, wet bulb or dew point), solar radiation, wind speed, and cloudiness) and source and sink parameters were entered in the water quality data window. This window was accessed from the main water quality input either through the menu bar by selecting *EDIT*- water quality data or by selecting the water quality data icon.

The water quality data entry window opened when *Edit* was selected or alternatively by selecting the water quality data icon. This water quality data entry window is divided into three panes. The navigation bar is oriented as a vertical column at the far left. Its tree structure allows the user to access all input data and parameters. The two panes to the right of the navigation bar change in response to the selection on the left. To start a new water quality analysis, top row of the Navigation Bar (the line that says New Water Quality File) was selected, and a name for the data set was entered. Next, in the constituent selection panel, temperature modeling was then turned on to start the modeling.

Entering and editing table data and meteorological data involves the following steps: time series generation tool, entering initial conditions, entering an initial distribution, entering dispersion coefficients and entering meteorological data. In order to model water temperature, at least one full meteorological data set must be available. The model supports multiple meteorological data sets. Each water cell was individually assigned to a particular data set. The entry of meteorological data set for the simulation followed a sequential order as arranged below: atmospheric pressure; air temperature; humidity (vapor pressure, relative humidity, wet bulb or dew point); solar radiation; wind speed; and cloudiness. A time series of air temperature, humidity, and wind speed radiation with a sampling frequency of at least once per three hours was necessary for simulation of water temperature variation. In addition to meteorological time series, each data set includes a limited amount of physical information including latitude, longitude, and site elevation.

3. RESULTS AND DISCUSSION

Table 1 shows results of simulated water temperature at Owena dam for the months of January, June and July respectively.

Simulated water temperature obtained using HEC-RAS was compared with the observed water temperature data of Owena dam. The time series plots for simulated and observed water temperature of Owena dam for the months of January, June and July are shown in Figures 2-4.

Table 1: Simulated water temperature at Owena dam for the months of January, June and July

Date	Time(Hours)	Simulated Water Temperature (^{0}C) at Owena Dam		
		January, 2011	June, 2011	July, 2011
1	09:00:00	17.20	19.20	19.20
2	09:00:00	18.99	20.06	19.03
3	09:00:00	19.38	18.34	19.70
4	09:00:00	21.17	21.24	18.70
5	09:00:00	22.34	19.28	17.70
6	09:00:00	22.10	18.73	19.53
7	09:00:00	22.18	16.30	20.11
8	09:00:00	22.49	20.61	17.87

9	09:00:00	23.27	17.08	17.37
10	09:00:00	23.35	18.10	18.04
11	09:00:00	23.51	16.06	17.62
12	09:00:00	23.89	14.41	18.20
13	09:00:00	23.51	16.53	18.29
14	09:00:00	24.05	17.86	18.54
15	09:00:00	24.83	20.06	18.87
16	09:00:00	25.68	18.89	17.37
17	09:00:00	25.84	22.73	19.20
18	09:00:00	27.09	18.26	20.20
19	09:00:00	26.07	18.49	20.95
20	09:00:00	27.32	17.87	22.69
21	09:00:00	27.48	19.83	20.36
22	09:00:00	27.16	21.40	20.45
23	09:00:00	26.85	19.51	19.87
24	09:00:00	25.61	20.77	18.12
25	09:00:00	26.54	19.59	18.04
26	09:00:00	26.62	19.91	15.71
27	09:00:00	26.39	20.22	15.29
28	09:00:00	27.32	18.89	14.96
29	09:00:00	27.48	21.08	15.04
30	09:00:00	26.85	22.18	16.37
31	09:00:00	26.23		17.45

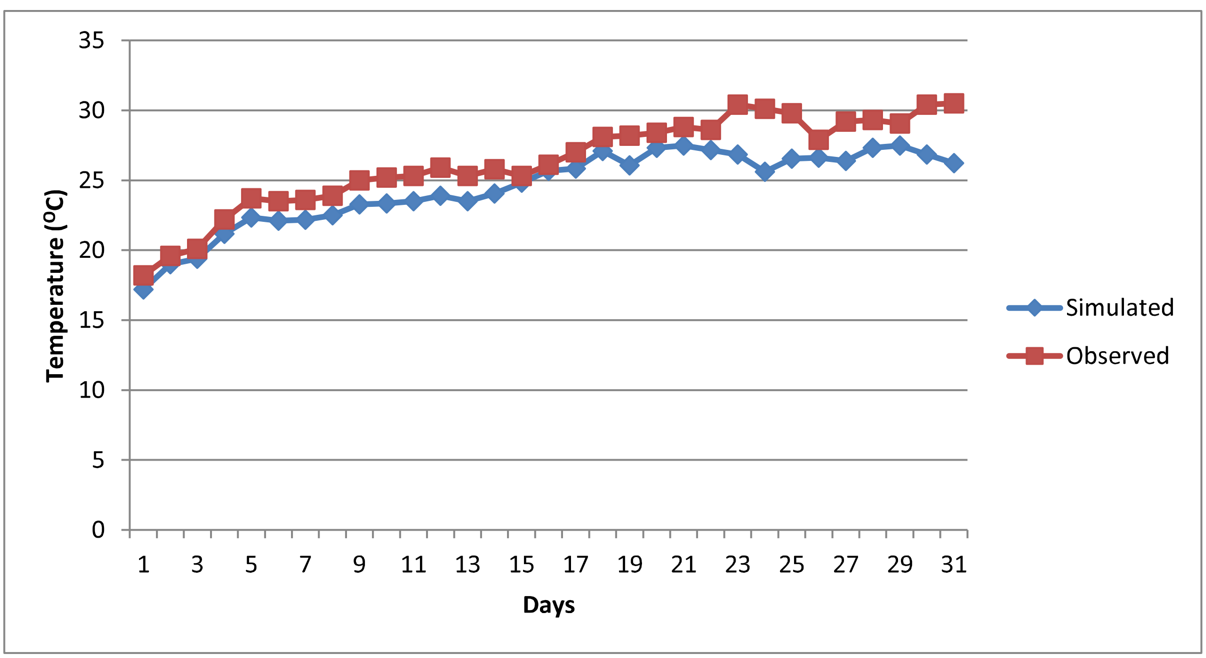

Figure 2: Time series plot for simulated and observed water temperature for January

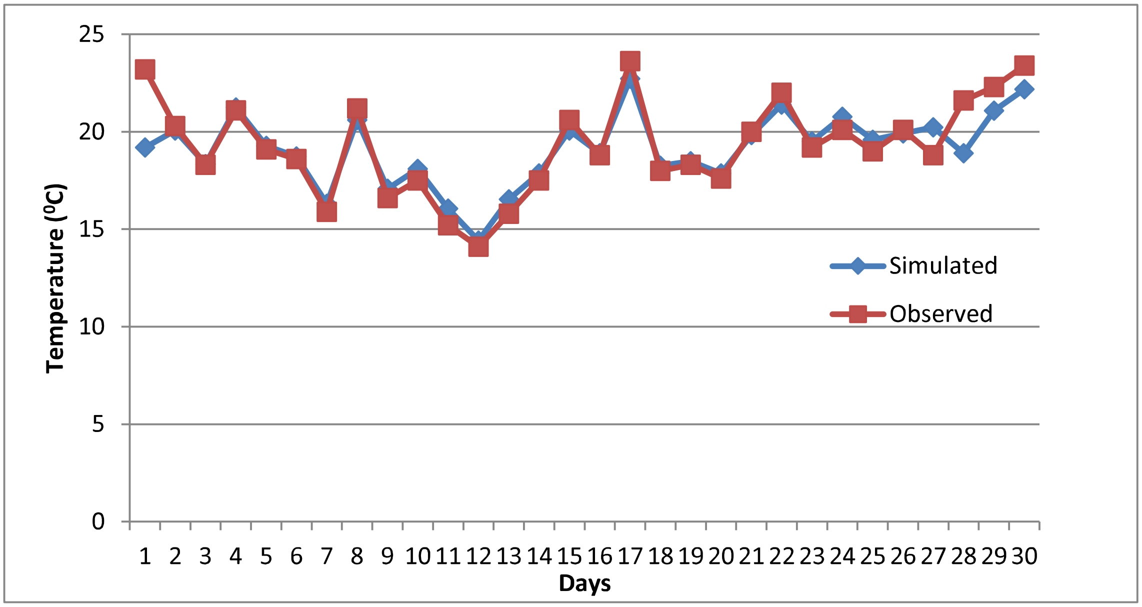

Figure 3: Time series plot for simulated and observed water temperature for June

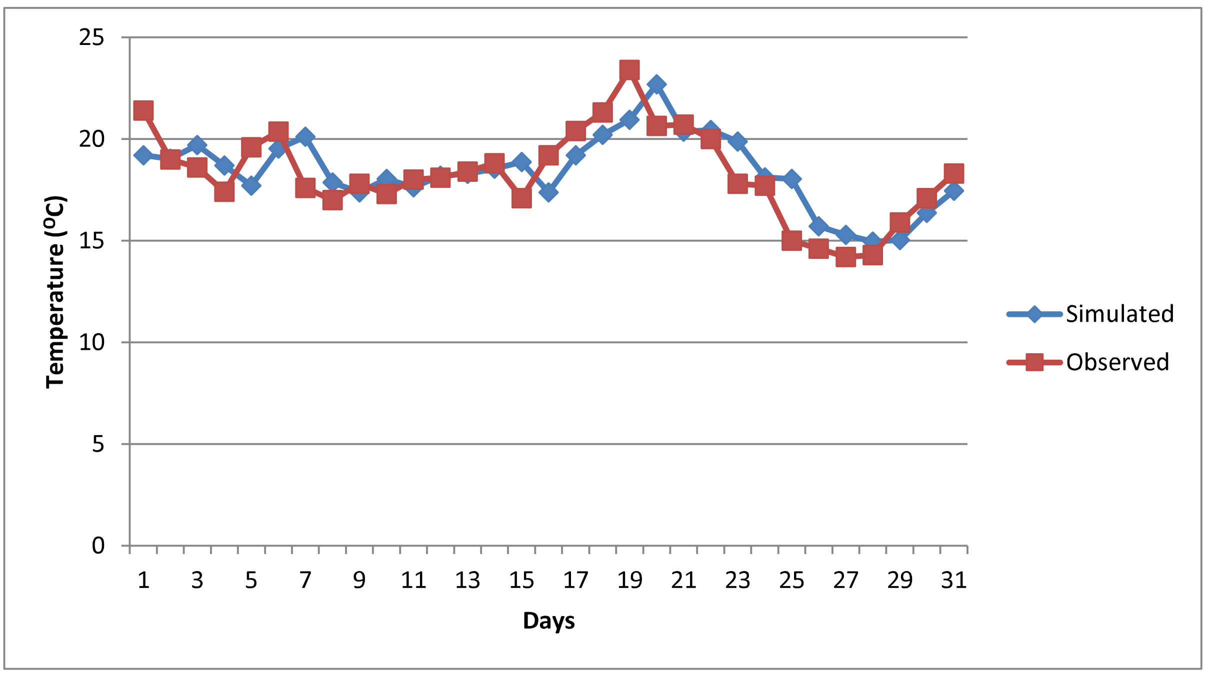

Figure 4: Time series plot for simulated and observed water temperature for July

From the figures and table, both the simulated and observed water temperature closely follows the same trend and pattern. This close trend observed between the simulated and observed data is further strengthened by the coefficient of determination (R^2) value. Coefficient of determination (R^2) measures the proportion of the total variation in the data that is explained or accounted for by the regression model (Udom, 2011; Krause et al., 2005; Moriasi et al., 2007). The R^2 values for January, June and July are 0.92, 0.83 and 0.6 respectively. Figures 5-7 show fit linear regression graphs using the model predicted values as independent variable and the measured values as dependent variables.

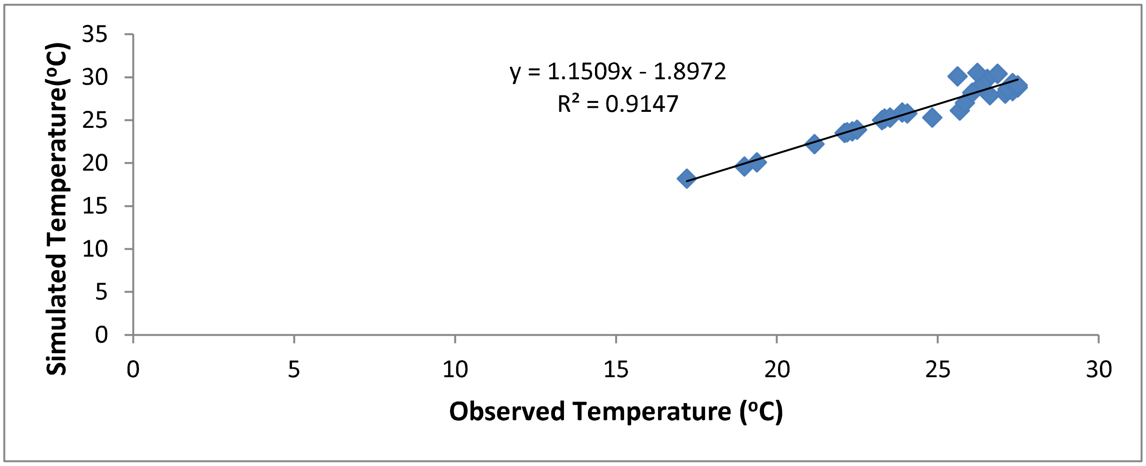

Figure 5: Regression analysis of simulated and observed temperature for January

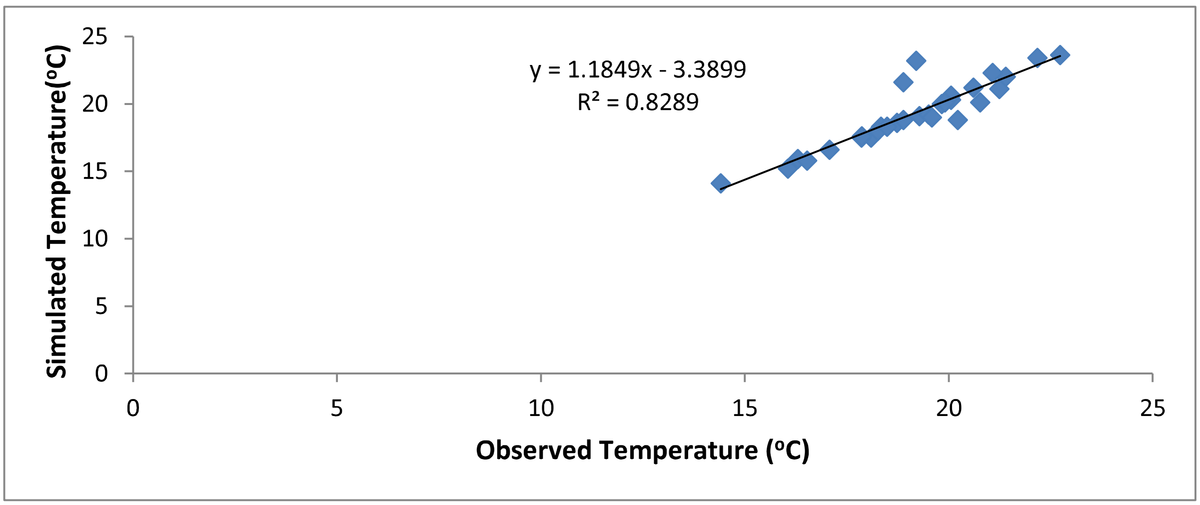

Figure 6: Regression analysis of simulated and observed temperature for June

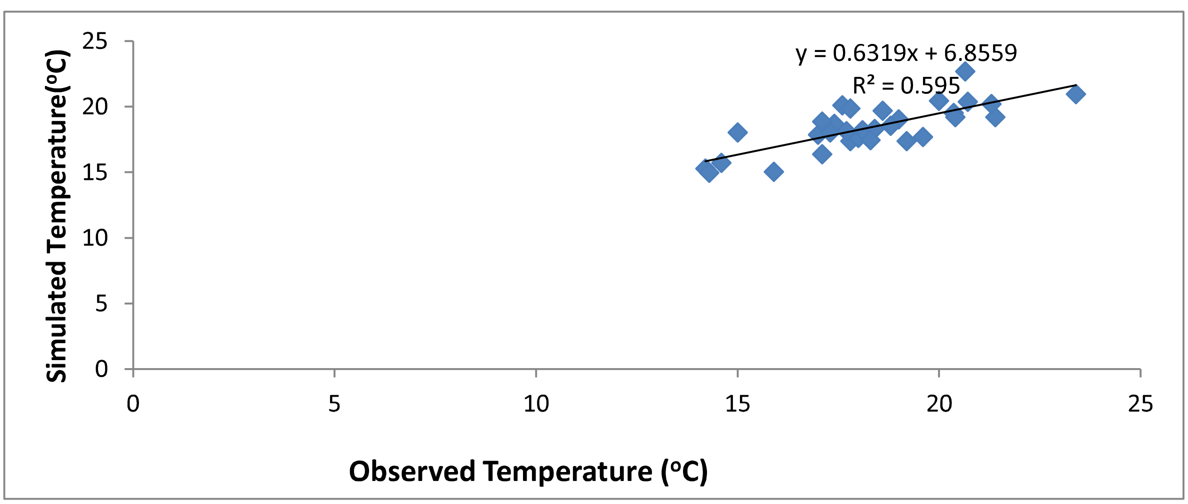

Figure 7: Regression analysis of simulated and observed temperature for July

4. CONCLUSIONS

The need for water quality standard, measurement and monitoring cannot be overemphasized. Water temperature is one of the most important physical characteristics. Its importance is seen because of its great influence on the process occurring in the water ecosystem and its effects on other water quality parameters. Hydrologic/water quality models have been shown to be used to monitor and predict water quality parameters. HEC-RAS model was used to simulate water temperature of Owena dam in this study. From the results obtained, it can be concluded that HEC-RAS can actually simulate water temperature of Owena dam in Ondo state of Nigeria.

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