

Evaluation of HEC-HMS Model for Simulation of Sediment in Shika Dam, Zaria-Nigeria

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ABSTRACT

Sedimentation is a critical concern for Dams used for irrigation and water supply in Nigeria. This study evaluates the HEC-HMS model for simulating sediment yield and transport processes in Shika Dam, Zaria, Kaduna State. The daily continuous recording of rainfall-runoff and sediment discharge of Zaria (Shika) Dam was carried out for the period of two years (1st January, 2019 to 31st December, 2020). Physical measurements of the Dam's height and width were taken using standard measuring tools, while drainage surface area data were obtained from aerial images via Google Earth. Sediment samples and stream flow data were collected using a sediment Sampler and Current meter, while Total Suspended Solids (TSS) was analyzed in the laboratory. Geographic parameters were extracted through digital elevation models (DEM), GIS, and Remote Sensing techniques. The Calibration results indicated RMSE of 0.3, PBIAS of -17.69%, NSE of 0.880, and R^2 of 0.9824. Validation results yielded RMSE standard deviation of 0.20, NSE of 0.98, PBIAS of -16.05%, and R^2 of 0.87, demonstrating very good model performance and a strong correlation between simulated and observed flows. Overall, the HEC-HMS model exhibited strong validation for observed and simulated values, peak discharge, and outflow volume. The study concludes that the model is effective for simulating watershed runoff and sediment transport, making it valuable for predicting future hydro-meteorological events and enhancing water conservation management in Zaria and its surrounding areas.

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INTRODUCTION

Semi-arid environments are often exposed to the hazard of water deficit that the available freshwater resources fail to meet the water demand in the domestic, agricultural and industrial sectors. Water availability in this area often relies on the retention of river runoff in reservoirs through creation of Dams. However, the water storage in reservoirs is often adversely affected by sedimentation because of severe soil erosion in headwater catchments (Mamede, 2008). The consequences of Reservoir

sedimentation can have serious impact on the local and regional economic situation related to drinking water supply, irrigation and power generation. Reduction of water availability is a major impact of reservoir silting for semi-arid region (Araujo et al., 2006). Calibration is the process of adjusting the parameters of the model within reasonable ranges until the simulated results are close enough to the observed values (Zeckoski et al., 2015). HEC-HMS has a module to search the best parameter values. By comparing the generated hydrograph to the

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measured hydrograph, the software computes the index of goodness-of-fit. Algorithm searches for the model parameters that yield the best value of the index, also known as the objective function (USACE, 2000). Validation is the process for ensuring that the calibrated model is capable of reproducing a set of observations or predicting future conditions without any further adjustment to the parameters (Zheng et al., 2012). Model calibration and validation require the examination of the accuracy of results to ensure valid representation of hydrological processes in basins. A number of watershed development and management programs are now going on in Zaria and environs. Reviews of literatures reveals that not much work has been done on simulation of sediment yield and transport process using any watershed model including HEC-HMS in Zaria and environs. The objective of the present study is to evaluate HEC-

HMS model for simulation of sediment in Shika dam, Zaria-Nigeria.

MATERIALS AND METHODS

Study area

The study area is Zaria (Shika) dam located on latitudes 11°07'45"E to 11°08'20"E and longitudes 07°46'N to 07°48'N in Zaria near Shika village, within the upper Galma river drainage basin (Figure 1), which is one of the sub-basins of the river Kaduna basin, itself being a sub-basin of the river Niger (Nnaji et al., 2007). The river is a major source of water supply for both irrigation and domestic usage to a number of communities located along its course. Due to poor management practices like extensive vegetation clearance for agricultural and urban development, intensive grazing, livestock tracks and anthropogenic activities, the dam watershed is adversely affected by sedimentation.

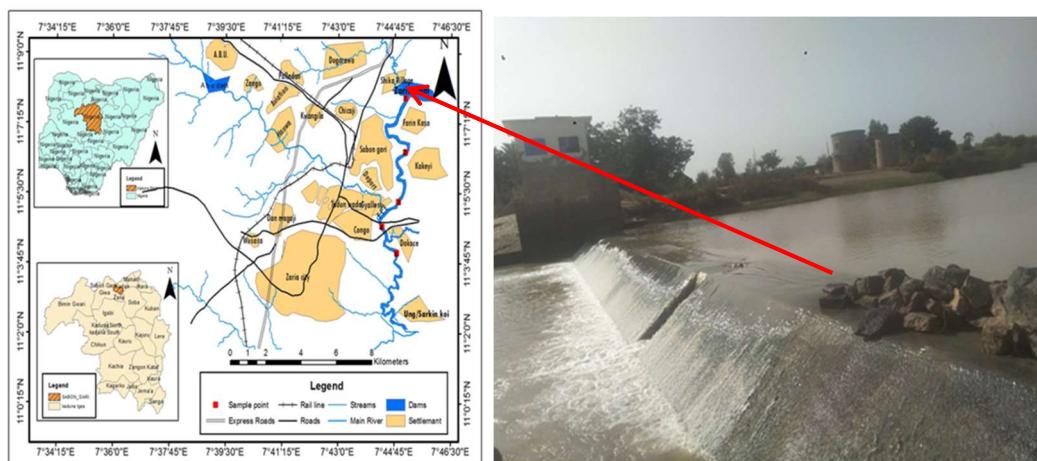


Fig. 1: Map of Zaria showing Sample Area of Zaria (Shika) dam reservoir

Data acquisition

The daily continuous recording of rainfall-runoff and sediment discharge of Zaria Dam was carried for the period of two years (1st January, 2019 to 31st December, 2020). The land use and land cover classes (water body, agricultural land, vegetation, build and bare land) were obtained from satellite imageries of the basin using Google Earth version 6.0.3.2197.

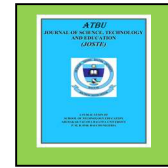
With the help of locally made canoe for transportation to the site, the physical data of the height and width of the Dam were measured at the weir location using staff and measuring tape, respectively. The aerial image using Google earth was used to measured drainage surface area of the Dam. The soil sampler and current meter were used to obtain the Total Suspended Solute (TSS) and stream flow of the Dam,

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respectively. The meteorological data (precipitation, cloud cover, wind speed, solar radiation, dew point temperature, and evaporation) were obtained from the IAR (Institute for Agricultural Research) Samaru, Zaria and NOAA (National Oceanic and Atmospheric Administration) under the US Department of Commerce (<http://www.noaa.gov/>). The daily observed streamflow records of the Zaria Dam were measured from the weir location constructed across the Dam. The digital elevation model data used for the watershed delineation were obtained from the Global Data Explorer (<https://gdex.cr.usgs.gov/gdex/>) and. Other parametric data of the Dam were obtained from

Federal Ministry of Water Resources (FMWR), which was integrated with the spatial data to produced final DEM of 5 m/pixel resolution used in the 2D hydraulic modeling of the Dam. Other land-use data extracted from remote sensing data were obtained from the United States Geological Survey (USGS) EROS Data Center via the USGS Global Visualization Viewer. The imageries captured by Landsat 4-5 (thematic mapper) and Landsat 7 (enhanced thematic mapping) and operational land imager sensors, respectively, were used to produce historical land-use and land-cover (LU/LC) data of the dam watershed. The soil map was obtained from the Federal Ministry of Agriculture (FMOA). The table 1 shows input data used in this study.

Table 1: Data sources and their properties

Data type	Data name	Resolution	Sources	Period covered
Meteorological data	Rainfall, temperature, wind speed, cloud cover, solar radiation, and evaporation	Daily	NIMET, FMWR, IAR and NOAA climate data online	2019–2020
Hydrological	Streamflow	Monthly/Daily	Zaria (Shika) Dam and Kaduna State Water Corporation	2019–2020
Spatial	Digital Elevation Model (DEM)	5 × 5 m	USGS global data explorer/depth data points	2019– 2020
Spatial	Land use (Landsat 8 OLI)	30 × 30 m	Remote sensing data	2019–2020
Spatial	Soil	1:250,000	Federal Ministry of Agriculture	2020

METHODOLOGY FRAME WORK

The methodological frame work of this study on the modeling process comprised of three phases. Phase I include data collection, model input preparation, and parameter evaluation, i.e., all the steps needed to setup a model, characterization of the watershed, and preparation for model executions. Phase II is the model testing phase which involves calibration and validation. This is the phase in which the model is evaluated to assess whether it can reasonably represent the watershed response, for the purposes of the study. Phase III includes the ultimate use of the model, as a decision

support tool for management and regulatory purposes. The Figures 3 shows the hierarchy of processes required to carry out this study.

HEC-HMS Model Set up

HEC-HMS was applied for modelling Zaria (Shika) Dam Reservoir Sedimentation. The model requires spatial and hydro-climatic data for hydrological simulation. The spatial data include digital elevation model (DEM), soil and land use maps of the area while the hydro-climatic data are rainfall, temperature (minimum and maximum), relative humidity, wind speed and solar radiation. The spatial data used are Digital

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Elevation Model (DEM), soil and land use maps as stated in Table 1. These data were used to generate various components of the hydrological catchment. The HEC-HMS 4.11 version software also automatically generates model input files through the use of parameters and specifications contained in databases and allow users to create operational sequence and simulation period based on the input data time series.

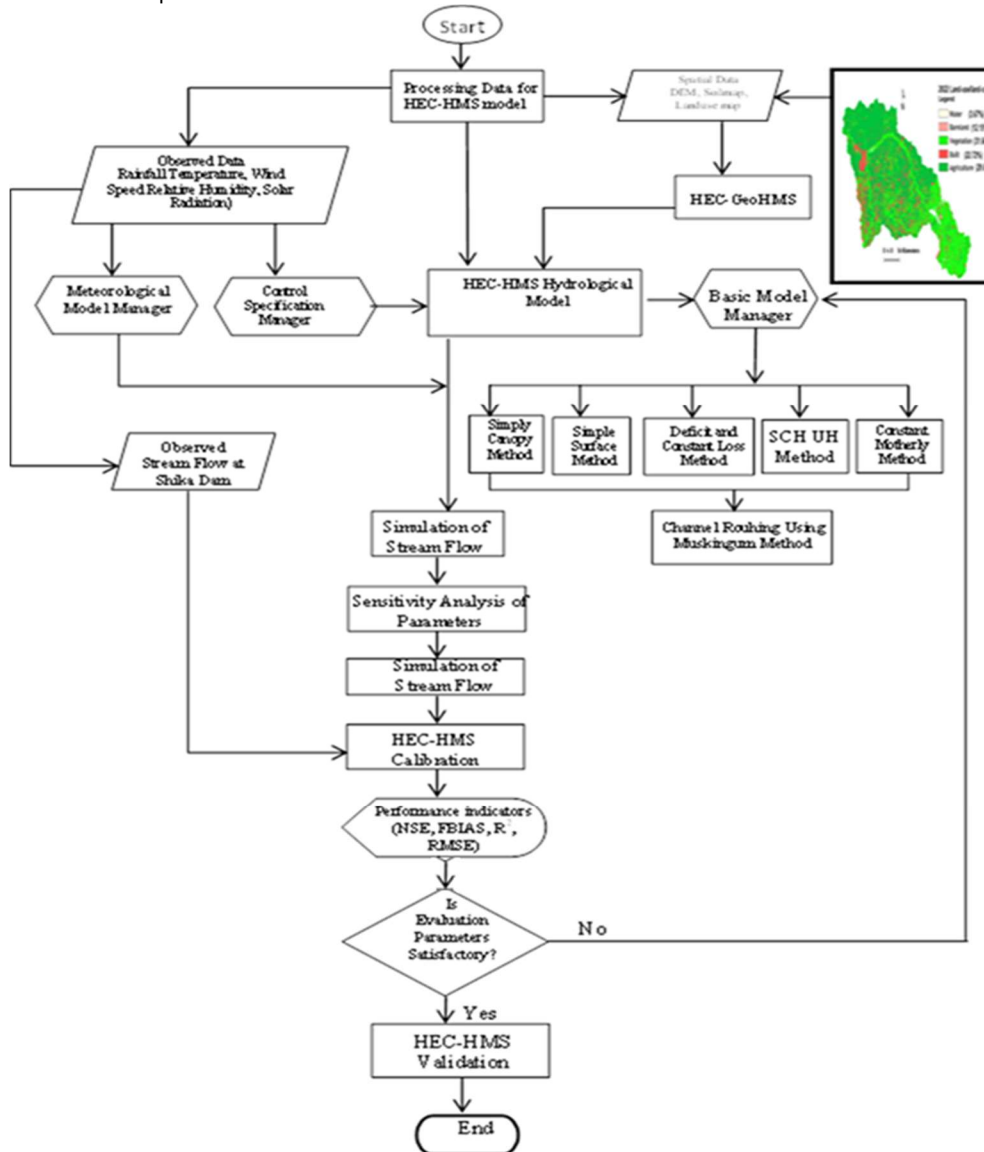


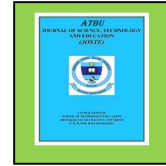
Figure 3. : Flowchart of the Methodology Adopted for the Study

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Sensitivity Analysis

The model parameter sensitivity analysis is usually conducted during or before model calibration since model parameters are associated with the local basin physical characteristics. Before calibrating the model for hydrology and sediment, the local sensitivity analysis known as one-variable-at-a-time method was used to describe the sensitivity of model results based on the required calibration parameters related to hydrology and sediment. The selection of this method, each of the outputs was evaluated based on total daily output results covering the period of the model simulation (2019-2020). The method utilized by White and Chaubey (2005), was used in this study, by increasing parameter values one at a time from the calibrated value by $\pm 5\%$, $\pm 10\%$, $\pm 20\%$ or $\pm 25\%$ in each simulation run. The parameter sensitivity Index was determined using the method illustrated by White and Chaubey (2005) and also applied by Bracmort *et al.* (2006) for perturbing model parameters and determining a linear sensitivity parameter (S_r), defined in Equation (1).

$$S_r = \left[\left(\frac{x}{y} \right) \frac{\Delta y}{\Delta x} \right] \quad (1)$$

Where $\Delta y = y_2 - y_1$ and $\Delta x = x_2 - x_1$, where x is the calibrated value of parameter, y is the predicted output value from the calibration result, and x_1 and x_2 correspond to ± 5 , 10 20 percent increment of the initial calibrated parameter values and y_1 and y_2 are the corresponding predicted output values, respectively, However, parameters were selected for sensitivity analysis by reviewing previously calibration parameters and documentation from the HEC-HMS mode result.

Model Simulation

In this study, the physical parameters measured from the gauged sub catchments were transferred from the gauged to the ungauged sub catchments to allow for runoff model simulation. This was done manually on the HEC-HMS interface by identification of the sub catchments with the same physical characteristics. The HEC-

HMS model components such as basin models, meteorological models, and control specifications had been created and populated with data to enable the simulations with various inputs. The model allows many combinations of different model parts to run for various scenarios. The Soil Moisture Accounting Loss, Transform Clark Unit hydrograph, Modified USLE, Baseflow Recession, Kinematic Wave Routing and Sediment Uniform Equilibrium methods were selected for each component of the runoff process as runoff depth, direct runoff, soil loss and channel routing as stated earlier, respectively. These were chosen on the basis of applicability and limitations of each method, availability of data, suitability for the same hydrologic condition, stability, wide acceptability, and well-established researcher recommendations.

Model Calibration

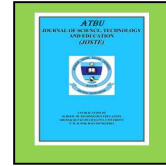
Calibration is the process of adjusting the parameters of the model within reasonable ranges until the simulated results are close enough to the observed values (Zeckoski *et al.*, 2015). The 4.11 HEC-HMS model software has a module to search the best parameter values. By comparing the generated hydrograph to the measured hydrograph, the software computes the index of goodness-of-fit. Algorithm searches for the model parameters that yield the best value of the index, also known as the objective function (USACE, 2000). When a satisfactory fit is obtained the best parameter values are reported according to the performance evaluation criteria, which are RMSE, PBIAS, NSE and R^2 values. Since it is a continuous model, daily time steps was created for this calibration exercise. The daily observed stream flow, other hydro-meteorological data obtained from the gauge station as explained in Table (1) were imported into the HEC-HMS model software simulated for 1st January, 2019 to 31st December, 2019. To improve the calibration, the auto-calibration methods provided in HEC-HMS software were inefficient with parameters provided. As explained in sensitivity analysis, the manual calibration was therefore applied for the

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parameters of the selected method until observed and calibrated flows are in good agreement.

Evaluation of Model Performance

The performance of the model was evaluated comparing daily and monthly simulated

discharge with the observed discharge. The statistical tools such as Nash-Sutcliffe Efficiency (NSE), Coefficient of determination (R^2) and percentage bias (PBIAS) were used to measure the model outputs.

Nash-Sutcliffe Efficiency:

It is calculated as,

$$NSE = 1 - \frac{\sum (Q_{obs(t)} - Q_{sim(t)})^2}{\sum (Q_{obs} - \bar{Q}_{obs})^2} \quad (2)$$

Where,

NSE is Nash-Sutcliffe Efficiency, $Q_{obs(t)}$ is observed discharge at time t , $Q_{sim(t)}$ is simulated discharge at time t and \bar{Q}_{obs} is average observed discharge. The “ t ” used in the calculation is the time period used. The value varies from $-\infty$ to 1. With the increase in performance, the numerical value increases and becomes maximum 1 in ideal case when simulated and observed hydrograph exactly match each other (Nash and Sutcliffe, 1970)

Coefficient of determination (R^2)

The R^2 value is an indicator of strength of relationship between the observed and simulated values. It is the magnitude linear relationship between the observed and the simulated values. Determination coefficient

ranges from 0 (which indicates the model is poor) to 1 (which indicates the model is good), with higher values indicating less error variance, and typical values greater than 0.6 are considered acceptable (Santhi et al., 2001). The R^2 is calculated using equation 8.

$$R^2 = \frac{(\sum Q_{obs(t)} - \bar{Q}_{obs}) \sum (Q_{sim(t)} - \bar{Q}_{sim(t)})}{\sum (Q_{obs(t)} - \bar{Q}_{obs(t)})^2 \sum (Q_{sim(t)} - \bar{Q}_{sim(t)})^2} \quad (3)$$

Where Q_{obs} and Q_{sim} are observed and simulated discharge; \bar{Q}_{obs} and \bar{Q}_{sim} are mean observed and simulated discharge (Krause et al., 2005).

Percentage Bias

Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Gupta et al., 2000). The optimal value of PBIAS is 0.0, with low-magnitude values indicating

accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias. For stream flow PBIAS values up to ± 20 are considered acceptable (Gupta et al., 1999). PBIAS is computed using equation 9;

$$PBIAS = \frac{(V_{sim} - V_{obs})}{V_{obs}} * 100 \quad (4)$$

Where, V_{sim} and V_{obs} are average simulated and observed volume of stream flow.

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Root Mean Square Error (RMSE)

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (Q_o - Q_p)^2} \quad (5)$$

RMSE is always greater than 0, and closer the values to 0 better the model performance (Singhie *et al.*, 2004). Where Q_o

and Q_p are observed and predicted run off respectively. Table 2: Performance Rating of Recommended Statistics (Moriasi *et al.*, 2015).

Table 2: Performance evaluation criteria for basin-scale models

Performance Rating	NSE	PBIAS	RMSE	R ²
Very good	0.75 < NSE ≤ 1	Pbias < 10	0.0 < RMSE ≤ 0.5	0.8 < R ² < 1
Good	0.65 < NSE < 0.75	10 < Pbias ≤ 15	0.5 < RMSE ≤ 0.6	0.65 < R ² < 0.8
Satisfactory	0.5 < NSE ≤ 0.65	15 < Pbias < 25	0.6 < RMSE < 0.7	0.5 < R ² < 0.65
Unsatisfactory	NSE ≤ 0.5	Pbias ≥ 25	RMSE > 0.7	R ≥ 0.5

Model Validation

Validation is the process for ensuring that the calibrated model is capable of reproducing a set of observations or predicting future conditions without any further adjustment to the parameters (Zheng *et al.*, 2012). The HEC-HMS model is validated using the hydro-meteorological dataset based of 1st January, 2020 to 31st December, 2020 and run into the HEC-HMS software model. The result obtained as it was done in the calibration process was compared with observed/measure values.

Sensitivity analysis

The initial values obtained before sensitivity analysis for PBIAS, RMSE and NSE between simulated and observed value of the simulation were -71.84, 0.8, and 0.295 respectively. This shows that the value of NSE falls in the range of unsatisfactory results. However, the results of the sensitivity analysis is presented in Table 3, indicating that the ground water percolation, tension storage, impervious percentage, and soil stroge were more sensitive, the second more sensitive, sensitive and sensitive parameters of the model respectively.

RESULTS AND DISCUSSION

Table 3: Results of sensitivity analysis during the mode calibration

Parameter	Change	R2	NSE	PBIAS (%)	RMSE (SD)
Ground water Percolation 1	-25%	0.87	0.30	-71.89	0.80
	-15%	0.88	0.66	-49.01	0.60
	-10%	0.89	0.83	-35.24	0.40
Calibrated		0.98	0.88	-17.69	0.30
	+10%	0.82	0.82	-16.95	0.49
	+15%	0.95	0.77	-15.36	1.00
	+25%	0.85	0.74	-29.71	1.83
Impervious Percentage	-25%	0.87	0.84	-16.27	1.01
	-15%	0.81	0.91	-17.23	0.58
	-10%	0.79	0.82	-13.61	0.47
Calibrated		0.98	0.88	-17.69	0.30
	+10%	0.86	0.81	-17.91	0.60

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	+15%	0.95	0.78	-19.09	0.76
	+25%	0.90	0.69	-19.35	0.57
Soil Storage	-25%	0.89	0.72	-17.11	0.44
	-15%	0.90	0.89	-11.59	0.44
	-10%	0.91	0.84	-18.76	0.75
Calibrated		0.98	0.88	-17.69	0.30
	+10%	0.95	0.90	-21.64	0.60
	+15%	0.92	0.81	-14.62	0.45
	+25%	0.96	0.86	-11.34	0.66
Tension Storage	-25%	0.87	0.87	-15.51	0.70
	-15%	0.87	0.82	-12.90	0.67
	-10%	0.83	0.85	-21.41	0.55
Calibrated		0.98	0.88	-17.69	0.30
	+10%	0.92	0.90	-13.57	0.59
	+15%	0.94	0.93	-13.84	0.44
	+25%	0.96	0.92	-14.47	0.46

Model calibration

The HEC-HMS model was run and then calibrated to optimize the parameters using the hydro-meteorological dataset of 1st January to 31st December, 2019. The results of RMSE, PBIAS, NSE and R² obtained for calibration with optimization method and sensitivity analysis as shown in Table 5 and figure 4 respectively which is classified as very good according to the performance evaluation criteria by Moriasi et al., (2007). The negative value of PBIAS indicates over estimation of the model which can be used

to predict the minimum discharge. The results further indicated that the model can simulate stream flow efficiently and accurately. Moreover, the resultant values obtained from table 4 of the model calibration shows that the computed peak discharge and total volume are close to the observations with a very small error, although the model tended to overestimate the runoff and the total volume before optimization. However, the calibration of the model improved the results greatly by decreasing the overestimated volume and the runoff.

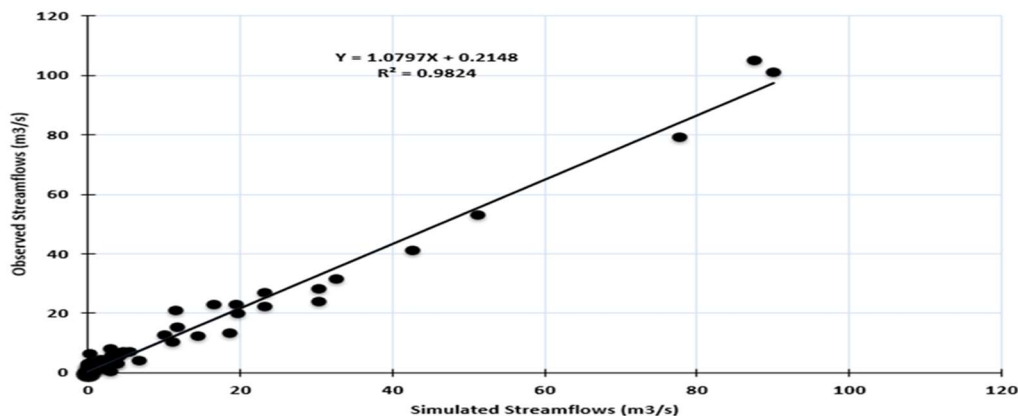


Figure 4: Oserved and Simulated Streamflow during Calibration Period

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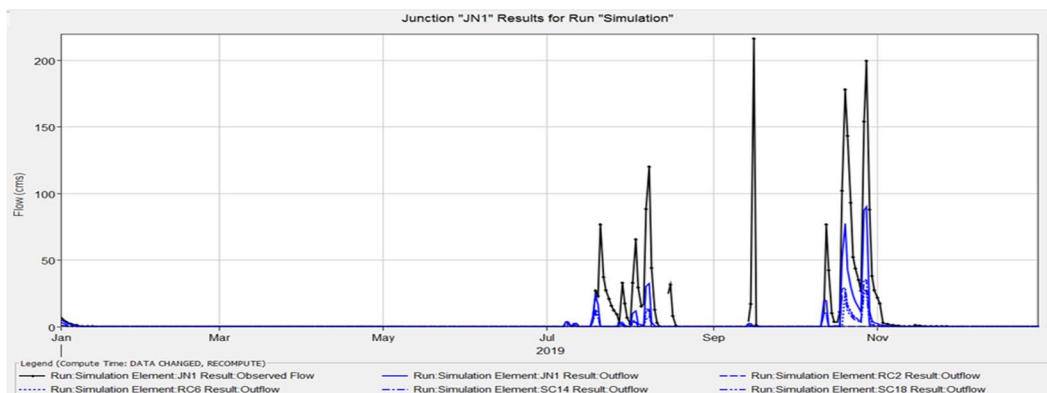


Figure 5: HEC-HMS Run Simulation of Zaria (Shika) Dam during Calibration

Table. 4: Summary Simulated Parameters for Shika Dam Reservoir during Calibration

Result	Peak Discharge (M ³ /s)	Volume (mm)	Date of Peak Discharge	Time of Peak Discharge
Computed	90.0	9.53	28th Oct, 2019	00:00
Observed	105.2	11.35	27th Oct, 2019	00:00

Table 5: Calibration result of Shika Dam Basin

COMPUTATION POINT	RMSE Stdev	Nash sutcliffe	PERCENT BIAS	R ²
JN-1	0.3	0.880	-17.69%	0.9824

Model validation

Validation was done by running the model with the respective optimized parameters for the watersheds with different input data set of 1st January to 31st December, 2020 and run just exactly as it was carried out in the calibration process. The output results during validation is shown in Figures 6 and 7 respectively. The results of validation model for RMSE Stdev, Nash sutcliffe (NSE), PBIAS, and R² were 0.2, 0.976, -16.05% and 0.8705 respectively. This according to Moriasi et al (2007) indicated that the model is classified as very good, which shows a strong relations between simulated and observed flow. Moreover, the results of the observed and simulated peak discharge are 228.6 m³/s and 216.2 m³/s and volume 34.88mm and 42.73mm for computed and observed, respectively. This shows that the computed peak discharge and

total volume are close to the observations with a very small error.

Figure 7 presented a validation graph of HEC-HMS simulation indicated a similar pattern of flow between the observed flow and simulated outflow. The results as obtained from the graph shows that there was low or zero flow between January to early July, 2020 while the peak flow discharge was found to be on 3rd August, 2020. This is due to rainfall precipitation which directly influenced the stream flow discharge within the period of June to October, 2020. Furthermore, as presented in the graph, the blue dotted line is higher than the black dotted line which shows that the observed flow is lower than the simulated outflow. This means that the flow was over-estimated, hence, the model cannot accurately predict the lowest flow discharge of the catchment.

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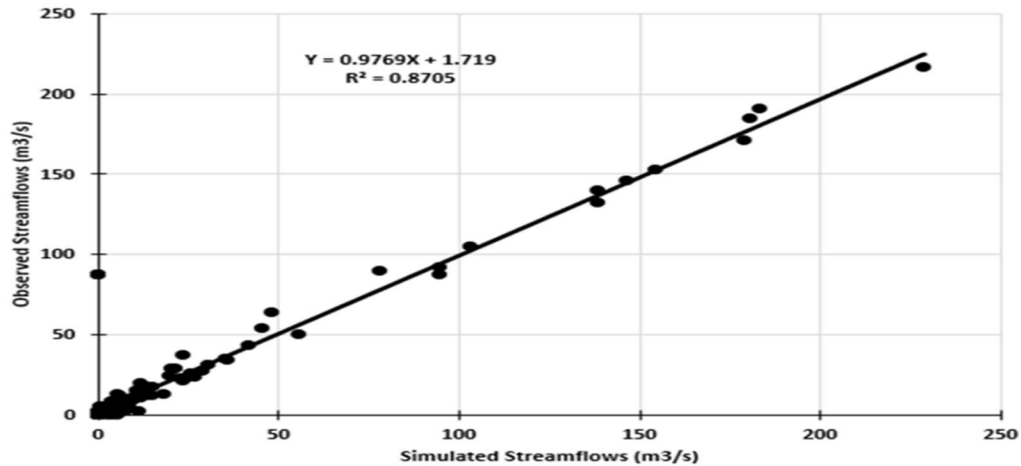


Figure 6: Observed and Simulated Streamflow during Validation Period

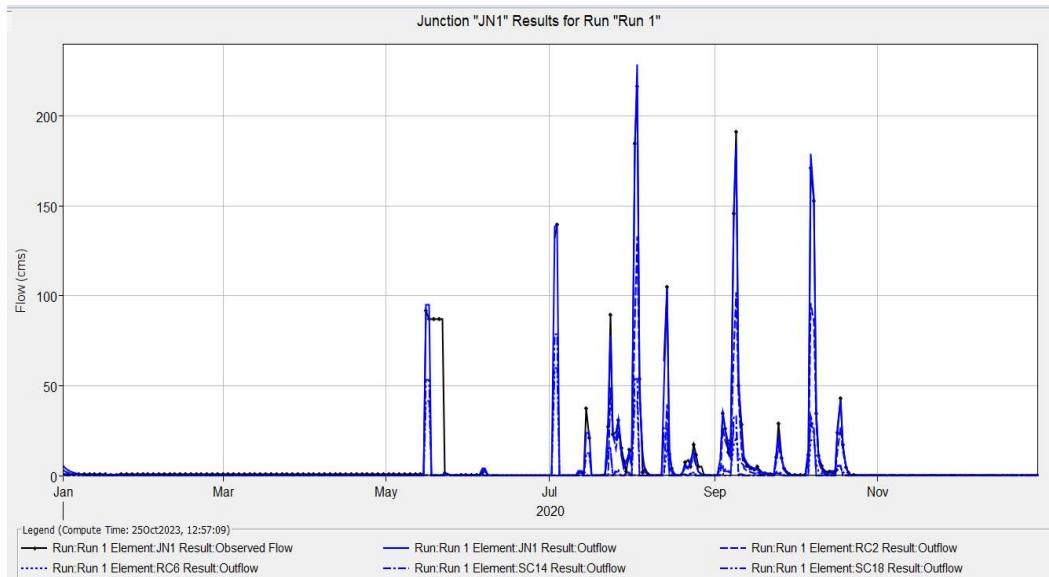


Figure 7: HEC-HMS Run Simulation of Zaria (Shika) Dam during Validation

CONCLUSION

In this study, the HEC-HMS model is evaluation for simulation of sediment in shika dam, Zaria-Nigeria. The performance of HEC-HMS model was assessed using different performance parameters both by graphical and visual interpretation. The performance results of the model calibration with optimization method for percentage of bias (PBIAS), Nash-Sutcliffe Efficiency (NSE), Coefficient Of Determination

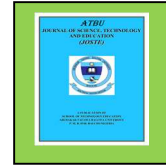
(R²) and Root Mean Square Error (RMSE) were -17.69%, 0.880, 0.9824 and 0.3 respectively which is classified as very good according to the performance evaluation criteria by Moriasi et al., (2007). However, the results of validation model for RMSE Stdev, Nash sutcliffe (NSE), PBIAS, and R² were 0.2, 0.976, -16.05% and 0.8705 respectively. This according to Moriasi et al (2007) indicated that the performance for qualitative ratings for the model is classified as

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very good which showing a strong relations between simulated and observed flow. Finally, based on the analysis obtained in this study, it can be concluded that the performance of the model is very good and suitable for investigation of Zaria (Shika) dam Sedimentation effects, and can be used for prediction of subsequent Hydro-Meteorological events in Nigeria's Watersheds, and most importantly is suitable for Water Conservation Management in Zaria and environs.

REFERENCES

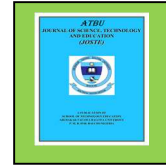
- Beven, K.J., 2001. Rainfall-runoff Modelling: the Primer. John Wiley & Sons, Lancaster, UK.
- Feldman, A.D., 2000. Hydrologic Modeling System HEC-HMS Technical Reference Manual, March 2000. Hydrologic Engineering Center, Davis, CA.
- Ismail, et al., 2021. Hydrological modelling for evaluating climate change impacts on streamflow regime in the bernam river basin malaysia. Ismail, et al., 2021. Loss methods in HEC-HMS model for streamflow projection under climate change: a review
- Ismail, H., Kamal, M. R., bin Abdullah, A. F., & bin Mohd, M. S. F. (2020a). Climate-Smart Agro-Hydrological Model for a Large Scale Rice Irrigation Scheme in Malaysia. *Applied Sciences*, 10(11), 3906.
- Ismail, H., Kamal, M. R., Hin, L. S., & Abdullah, A. F. (2020b). Performance of HEC-HMS and ArcSWAT Models for Assessing Climate Change Impacts on Streamflow at Bernam River Basin in Malaysia. *Pertanika Journal of Science & Technology*, 28(3).
- Ismail, H., Kamal, M. R., Jada, D. T., & Sai Hin, L. (2020c). Modelling Future Streamflow for Adaptive Water Allocation under Climate Change for the Tanjung Karang Rice Irrigation Scheme Malaysia. *Applied Sciences*, 10(14), 4885.
- J.U. Guduru et al. 2022. Rainfall-runoff modeling using HEC-HMS model for Meki river watershed, rift valley basin, Ethiopia
- Kamudyariwa, C., 2000. Seasonal Variation of Water Quality with Respect to Anthropogenic Activities along Mukuvisi River, Harare, Zimbabwe. MSc. Thesis. IHE, Delft, the Netherlands.
- Kudamnya, E. A., Schoeneich, K., Garba, M. L., 2013: Remaining Storage of the Zaria Impounded Reservoir and Rate of Erosion in Its Drainage Basin. American International Journal of Contemporary Research Vol. 3 No. 8; August 2013. www.aijcrnet.com.
- Liden, R., Harlin, J., Karisson, M., Rahmberg, M., 2001. Hydrological modelling of fine sediments in the Odzi River, Zimbabwe. *Water SA* 27, 303-314.
- Lucas, L., Janssen, F., Gerrit, C., Hurneman, 2002. Principles of Remote Sensing. In: ITC Educational Textbooks Series; 2, second ed.
- Maathuis, B.H.P., 2007. DEM Based Hydro-processing: Introduction to the Tools Developed, Tutorial with Exercises Version 1. Department of Water Resources, ITC, Enschede, The Netherlands.
- Maathuis, B.H.P., Wang, L., 2006. Digital elevation model based hydroprocessing. *Geocarto Int.* 21.
- Mawere, M., 2001. Land Application of Sewage: the Role of Crowborough Pasture Irrigation in the Reduction of Nutrient Loads to Marimba River. IHE Delft, the Netherlands, Delft.
- McEnroe, B.M., 2010. Guidelines for Continuous Simulation of Streamflow in Johnson County, Kansas, with HEC-HMS. Johnson County Public Works and Infrastructure Stormwater Management Program.
- Moretti, G., Montanari, A., 2008. Inferring the flood frequency distribution for an ungauged basin using a spatially

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- distributed rainfall-runoff model. *Hydrol. Earth Syst. Sci.* 12, 1141-1152.
- Nash, J.E., Sutcliffe, J.V., 1970. River flow forecasting through conceptual models. Part I: a discussion of principles. *J. Hydrol.* 10, 282-290.
- Randrianasolo, A., Ramos, M.H., AndrAassian, V., 2011. Hydrological ensemble ~forecasting at ungauged basins: using neighbour catchments for model setup and updating. *Adv. Geosci.* 29, 1-11.
- Sauer, V.B., Thomas, W.O., Stricker, V.B., Wilson, K.V., 1983. Flood Characteristics of Urban Watersheds in the United States. Water-supply Paper 2207. U.S. Geological Survey, Washington, DC.
- Schaefli, B., Harman, C.J., Sivapalan, M., Schymanski, S.J., 2011. HESS Opinions: hydrologic predictions in a changing environment: behavioral modeling. *Hydrol. Earth Syst. Sci.* 15, 635-646.
- Scharffenberg, B., 2004. Official HEC-HMS Introduction. US Army Corps of Engineers Hydrologic Engineering Center.
- Scharffenberg, W.A., Fleming, M.J., 2008. Hydrologic Modeling System HEC-HMS User's Manual. Hydrologic Engineering Center, Davis, CA..
- Snyder, F.F., 1938. Synthetic unit graphs. *Trans. Am. Geophys. Union* 19, 447-454.
- USACE, 2000. HEC-HMS Hydrologic Modeling System User's Manual. Hydrologic Engineering Center, Davis, CA.
- USACE, 2008. HEC-HMS Hydrologic Modeling System User's Manual. Hydrologic Engineering Center, Davis, CA.
- Wale, A., Rientjes, T.H.M., Gieske, A.S.M., Getachew, H.A., 2009. Ungauged catchment contributions to Lake Tana's water balance. *Hydrol. Process.* 23, 3682-3693.

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