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HYDROLOGICAL MODELLING OF KANGIMI DAM WATERSHED USING GIS AND SWAT MODEL

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Abstract: In recent years, hydrological models have been used in assessing complex hydrological processes occurring within a watershed. This study focused on application of physically based distributed hydrological model Soil and Water Assessment Tool (SWAT) interfaced with ARCGIS software over the Kangimi Dam sub-watershed, located in Kangimi river sub-basin of Kaduna basin, in Igabi Local Government Area, about 37km away from Kaduna metropolis, Kaduna State, Nigeria. The study aimed at calibrating and validating the model for streamflow simulation. The model was run for the period from 1979 to 2014 with a calibration period from 1983 to 1986 and a validation period from 1987 to 1990 which was period of discharge data. Calibration and validation of the model were achieved using the soil and water assessment tool-calibration uncertainty programs (SWAT-CUPs) with sequential uncertainty fitting (SUFI-2) algorithm. Based on recommended statistical coefficients, the model evaluation indicated a very good performance for both calibration and validation periods with (R2) and (NSE) to be 92% and 82%, for calibration, and 93% and 86%, for validation period respectively and good agreement between measured and simulated values of monthly scale discharge. The findings of this study can be useful in runoff simulation and to efficiently support water management policies in Kangimi Dam watershed.

Keywords: modelling, hydrology, watershed, SWAT, streamflow simulation

1. INTRODUCTION

Water is a vital element for survival of living organisms. It is an important factor for economic growth and boosting of agriculture and industry particularly in the viewpoint of rapidly growing population and urbanization. (Shimaa, 2015). Nigeria is faced with scarcity of freshwater or prone to contamination. To deal with water management problems, there is need for quantification and analysis of different elements of hydrologic processes taking place within the area of interest. Apparently, this analysis must be carried out on a watershed basis because all these processes are happening within individual micro watersheds (Shimaa, 2015). A management method that is technically sound is most appropriate, hence the need for hydrological models for water resources assessment and development. (Ndulue *et al.*, 2018)

Effective planning and management of water resource requires the use of watershed models for hydrological processes simulations. Hydrologic models offered a framework for making suitable decisions for sustainable management of soil and water resources in the watershed and have become an important tool for the study of hydrological processes. The application of a watershed model to simulate these processes plays a vital role in addressing a range of water resources and environmental and social issues (Omar, 2014).

The use of Geographic Information System (GIS) techniques has fostered and enhanced the elaborate use of watershed models globally. GIS is a practical tool for the effective management of large and complex database and to provide a digital representation of watershed characteristics used in hydrological modeling. . It has added confidence in the accuracy of modeling by determining watershed characteristics, developing more suitable approach toward the watershed conditions, improving the effectiveness of the modeling process and ultimately enhancing the estimation abilities of hydrological modeling, (Bhuyan *et al.*, 2003).

Several hydrological models have been developed to simulate rainfall-runoff processes at a watershed level. Knowledge of runoff simulation procedures is useful for water resources planning through prediction of the effects of management strategies on water resources. Modelling surface runoff forms a basis upon which policy makers, watershed planners/managers make appropriate decisions consistent with sustainable management of land and water resources in the watershed (Obiero et al., 2011). In view of this, the GIS interface provides the platform to streamline GIS processes tailored towards hydrologic modeling. Among the widely applied hydrological models for flow prediction in recent time is Soil and Water Assessment Tool (SWAT). SWAT is a river basin, or watershed, scale model which has the ability to simulate both the spatial heterogeneity and the physical processes occurring within smaller modeling units, known as hydrologic response units (HRU) for the sustainable planning and management of surface water resources of rivers. The selection of SWAT model was based on its clear advantage as a hydrological modelling tool that comprises computational efficiency, ability to simulates long term effects as a continuous model (Van Griensven, 2005), and capability to use readily available global datasets, availability of a reliable user and developer support has contributed to its acceptance as one of the most widely adopted and applied hydrological models globally (Gassman *et al.,* 2007). Gassman *et al.* (2007) gave an extensive review and application of the SWAT model across numerous watersheds worldwide: Van Griensven *et al.* (2005) reported a review of SWAT applications in the upper Nile basin. SWAT was also applied in countries like Egypt, Sudan, South-Sudan, Ethiopia, Eritrea, Uganda, Tanzania, Kenya, Burundi, Rwanda and DR Congo.

In a similar study, Adeogun *et al.*, (2014) modelled the hydrology of upstream watershed of Jebba reservoir in Nigeria. Ndulue *et al.,* (2018) applied SWAT model to the upper Ebonyi watershed to simulate streamflow and sediment yield. In this study, GIS based watershed model (ArcSWAT) was applied to Kangimi dam watershed to calibrate and validate the model for streamflow simulation of the watershed. The main objective of this study is therefore to study runoff simulation so as to efficiently support water management strategies in Kangimi Dam watershed. This objective is acomplished by using existing historical data with freely available global database, so as to effectively predict the hydrological processes with the SWAT model.

2. MATERIALS AND METHODS

— Description of Study Area

The Kangimi dam watershed is located in Northern part of Nigeria between latitude 10°46′ and longitude 7°25' and serves as a tributary of river Kaduna in Kaduna town in Igabi Local Government area of Kaduna state (Figure 1.). The dam was constructed in 1975 on the Kangimi river, about 3 km upstream of its confluence with the Kaduna river. The reservoir has a surface area of 692 ha and volume of 59 million m^3 and a mean depth of 17 m. The estimated mean retention time in the reservoir is 5–6 years. The Kangimi reservoir is known as an essential component of the bulk water supply scheme for Maraban Jos and some part of Kaduna outskirt; the water released from the reservoir to the communities is the cheapest source of fresh drinking water. The climate in the area is classified as tropical continental, with almost equal wet and dry seasons. The rainfall in the area occurs between May and October and the rest of the year is dry. Maximum daily temperatures lies between 30^0 to 40^0 C throughout the year, while minimum daily temperatures occasionally drop below 12^0 C. (Kemdirim, 2005).

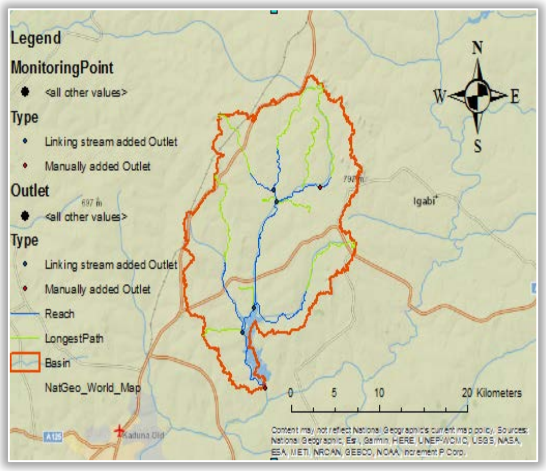

Figure 1: Geographic Map of the Study Area

— The SWAT Model

The SWAT was developed in the 1990s by the United States Department of Agriculture (USDA) (Arnold et al., 1998; Neitsch et al., 2002). It is a process based and spatially semi-distributed hydrological and water quality model designed to estimate and route water, sediments, and nutrient from individual sub-watersheds all through the main stream watersheds towards its outlet. These sub-watersheds are additionally divided into hydrological response units (HRUs) on the basis of their land cover, slope, and soil attributes.

SWAT model uses the principal water balance approach (i.e., Eq. 1) to calculate runoff volumes and peak flows (Arnold *et al.*, 1998) expressed as:

$$SWt = SW0 + \sum_{t=1}^{t}(Rday - Qsurf - Ea - Wseep - Qgw)i \qquad (1)$$

where SW$_0$ is initial soil water content and SWt is the soil water content on day t. All other measurements are taken in millimeters, and the time (t) is measured in days. The equation deducts all forms of water loss on any day i from precipitation for that day (Rday), including surface runoff (Qsurf, i), evapotranspiration (Ea, i), loss to vadose zone (wseep, i), and return flow (Qgw, i). By working with this equation, the model can predict changes in variables of interest like runoff and return flow. Runoff (Eq. 2) is derived from the USDA soil conservation service runoff curve number (CN) method (USDA 1972) as follows:

$$Qsurf = \frac{(Rday - 0.2S)^2}{(Rday - 0.8S)} \qquad (2)$$

where Qsurf is the daily surface runoff (mm), Rday is the rainfall depth for the day (mm), and S is the retention parameter (mm).

The retention parameter S and the prediction of lateral flow by SWAT model are defined in Eq. (3):

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \qquad (3)$$

where S = drainable volume of soil water per unit area of saturated thickness (mm/day); CN = curve number.

— Description of sequential uncertainty fitting (SUFI)-2 in SWATCUP

In SUFI-2, deviation between measured and simulated variables is defined as the uncertainty. The SUFI-2 sticks together uncertainty analysis along with calibration to obtain parameter uncertainties that ensure prediction uncertainties grouping the majority of the measured data, while developing minimum possible prediction uncertainty band. Input parameter uncertainty in SUFI-2 is demonstrated as homogeneous, i.e., uniform distribution, whereas model output uncertainty is measured at the 95% parameter prediction uncertainty (i.e., 95PPU). The P factor, which represents the percentage of underlying data in bracketed 95PPU, computed at 2.5% significance level confidence and the 97.5% significance level confidence intervals during output simulation, shows the quantity of uncertainty which is being captured, For discharge, a value of >0.7 or 0.75 is recommended to be adequate while the R-factor on the other hand is the ratio of the average width of the 95PPU band and the standard deviation of the measured variable. A value of <1.5, again depending on the situation, would be desirable for this index (Abbaspour *et al.*, 2004, 2007).

— Input data

Meteorological data including precipitation and temperature are the most essential inputs to hydrological models. One of the major problems encountered in the application of hydrologic models in developing countries is the lack of required data for model input (Adeogun *et al.* 2014). In order to overcome these challenges, historical data together with the National Centers for Environmental Prediction's Climate Forecast System Reanalysis (CFSR) daily weather data at 38 km resolution were used. Applications of CFSR have been presented by Saha *et al.*, (2010). The spatial data required for hydrological modeling in SWAT include digital elevation model (DEM), soil and land use land cover data. The SRTM DEM of 90m resolution (HTML: CGIARCSI) was obtained from the International Centre for Tropical Agriculture (CIAT). The soil map, was obtained mainly from the United Nation Food and Agriculture Organization (HTMAL: FAO-AGL, 2003) and extracted from harmonized digital soil map of the world (HWSD v1.1). Land-use data (West Africa Land Use Land Cover Time Series two-kilometer (2-km) resolution land use land cover (LULC) 2013) with 26 classes of land-use representation was obtained from USGS Earth Resources Observation and Science (EROS). Finally, the streamflow gauged data was collected from Kaduna State Water Board. A long term flow data were gauged at Ribako (located on 33390 2500 N, 73 180 1500 E) which is a very close control point Upstream the Kangimi Dam. The historic daily flow data were available for the period 1983–1990.

— Model simulation

Hydrological modelling of Kangimi Dam Watershed was executed using the ArcSWAT version of SWAT Model. After preparing data files and completing all model inputs based on procedure outlined in the SWAT model user documentation (Neitsch *et al.,* 2011). SWAT execution involves performing watershed delineation, HRU definition, sensitivity analysis, model calibration and validation. The model was executed using the Runoff Curve Number method for estimating surface runoff from precipitation, the Hargreaves method for estimating potential evapotranspiration generation, and the Variable-storage method to simulate channel water routing. The simulation is done for a period of 35 years with a warm up period of three years, from 1979 to 2014 which is the same period of availability of climate data.

— Model calibration and validation procedure.

The SWAT model was calibrated using the SUFI-2 optimization technique for the Kangimi basin using the daily observed data for the gauging station. Calibration period is taken to be 1983–1986, and validation period is taken as 1987–1990 along with three years warm-up period before calibration. Many studies emphasized on warm up period of 3 years for obtaining satisfactory results (Joh *et al.* 2011; Daggupati, 2015). In this study, the first step for the calibration and validation is the establishment of highly sensitive parameters for the watershed. The sensitivity analysis is so used to identify and rank the most responsive hydrological parameters that have significant impact on specific model output (Saltelli *et al.,* 2000).

— Model efficiency

To assess the performance of the model for the data obtained, a set of generally used goodness-of-fit indicators were calculated. In this study, SWAT model was evaluated using three quantitative statistics, namely the coefficient of determination (R^2), Nash-Sutcliffe model efficiency (NSE) and observations standard deviation ratio (RSR) and were given below as reported by (Krause *et al.*, 2005):

$$\mathrm{R2} = \left[\frac{\sum_{i=1}^{n}(Oi-\bar{O})(Si-\bar{S})}{\sqrt{\sum_{i=1}^{n}(Oi-\bar{O})^2}\sqrt{\sum_{i=1}^{n}(Si-\bar{S})^2}}\right] \tag{4}$$

It ranges from zero to 1.0 with higher values indicating less error variance, and values greater than 0.50 are considered acceptable (Santhi *et al.* 2001).

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{n}(Oi-Si)^2}{\sum_{i=1}^{n}(Oi-\overline{O})^2} \tag{5}$$

NSE ranges from negative infinity to 1 and 1.0 (1 inclusive), with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance. Generally, the model simulation is considered as satisfactory if NES > 0.5, (Moriasi *et al.,* 2007).

$$\mathrm{RSR} = \frac{\sqrt{\sum_{i=1}^{n}(Oi-Si)^2}}{\sqrt{\sum_{i=1}^{n}(Oi-\overline{O})^2}} \tag{6}$$

Oi and Si are the observed and simulated discharge values, respectively, $\bar{O}$ and ($\bar{S}$) are the mean of observed and simulated discharge values, and n is the total number of observed. A better assessment of model in the course of calibration and validation can be analyzed by computing P and R factors.

3. RESULTS AND DISCUSSION – PRELIMINARY RESULTS

— Delineated stream network and sub basins

The Kangimi dam watershed was delineated to 10 sub-basins, 39 hydrological response units (HRUs) and maximum and minimum elevation of 784m and 512m respectively as shown in Figure 2.

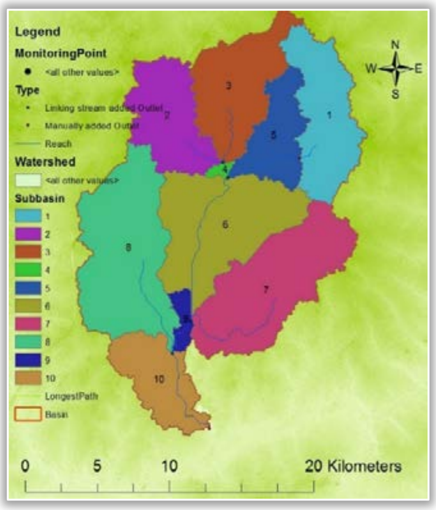

Figure 2: The DEM, Stream Network and Sub-basins numbered

— Delineated land use/cover

Seven (7) LULC classes were delineated from the watershed where agricultural land area has the highest percent coverage as showed in Figure 3.

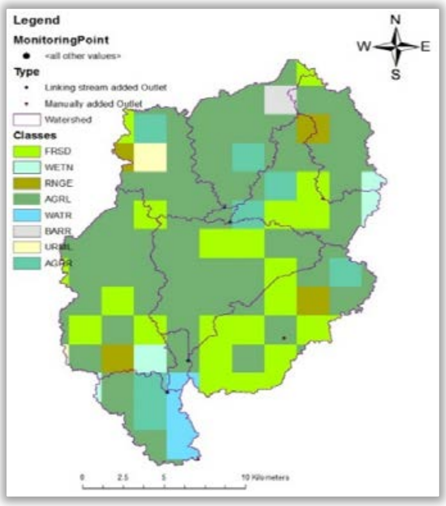

Figure 3: Delineated land use/cover Map

— Delineated Soil Map

For this study 3 soil types were determined after collecting soil samples from different locations within the study area from two different layers (0 - 30 cm and 30 - 100 cm depth) and analyzed to validate the model soil parameters as showed in Figure 4.

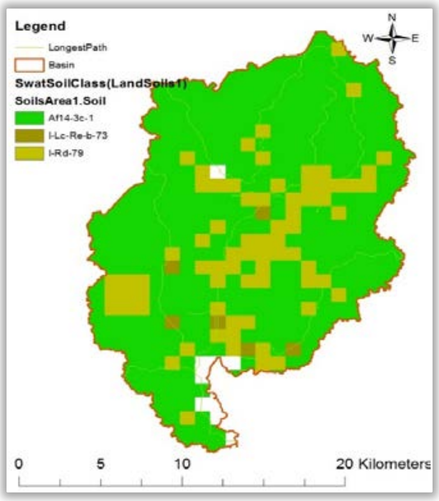

Figure 4: Delineated Soil Map

— Model Calibration and Validation

Model calibration and validation are vital for simulation process, which are used to assess model prediction results. This is to reduce the uncertainty associated with the model prediction. Streamflow calibration and validation were based on the observed flow data collected by Kaduna State Water Board at Ribako gauge station upstream the Kangimi Dam on Kangimi river. The available measurements were used for comparison with the predicted results in order to test the SWAT simulation efficiency. Calibration took place monthly where outflow data existed from 1983 to 1986 and then the parameters were validated from 1987 to 1990. After achieving a representative runoff data, the same value of calibrated hydrological parameters was used for validation. The SUFI2 algorithm within SWAT-CUP software was used for sensitivity analysis (One at a time sensitivity analysis) and calibrations by realizing 500 simulations for the 5 most sensitive parameters. The parameters found to be most sensitive are curve number (CN2), Base flow alpha factor (ALPHA_BF.gw), soil evaporation compensation factor (ESCO), threshold water depth aquifer (GWQMN) and soil available water capacity (SOL_AWC). These parameters were adjusted to bring simulated values close to the observed values as reported by Fadil *et al.*, (2011), Abbaspour *et al.,* (2007).

— Model Performance

The statistical evaluation showed a very good match between the monthly observed and simulated river discharge as presented in Table 1. The values of Coefficient of Determination (R^2) for both calibration and validation recognize the accuracy of the results as shown in Figure 5 and Figure 6. The value R^2 test stands 0.92 and 0.93 for calibration and validation respectively. It indicates that model results produced for the flow are very good for both periods. According to NS method, the model results of 0.82 for calibration and 0.86 for validation are very satisfactory as compared to similar studies.

Many studies with the SWAT related R^2 and NS values ranged from 0.4 to 0.9 and 0.3 to 0.9 respectively, depending on the drainage area of the basin, the time interval of the simulation and the available database. Ndulue et al., (2018) obtained R^2 and NS values of (0.53 and 0.74) and (0.61 and 0.59) in the calibration and validation of SWAT, respectively, for the Hydrological modelling of upper Ebonyi watershed using the SWAT model, using a time series of data to simulate the model. Adeogun *et al.,* (2014) obtained R^2 and NS values of (0.76 and 0.71) and (0.72 and 0.78) in the calibration and validation of SWAT, respectively for the GIS-based hydrological modelling of upstream watershed of Jebba reservoir in Nigeria using SWAT model.

Table 1. Statistical evaluation of simulated versus observed annual stream flow data

Coefficient	Calibration Period (1993-1996)		Validation period (1996-1990)	
	Obs. Flow	Sim. Flow	Obs. Flow	Sim. Flow
	m^3/s	m^3/s	m^3/s	m^3/s
Mean	1.46	1.13	1.39	1.12
R2	0.92		0.93	
NSE	0.82		0.86	
RSR	0.77		0.77	
PBIAS	23.0		19.0	

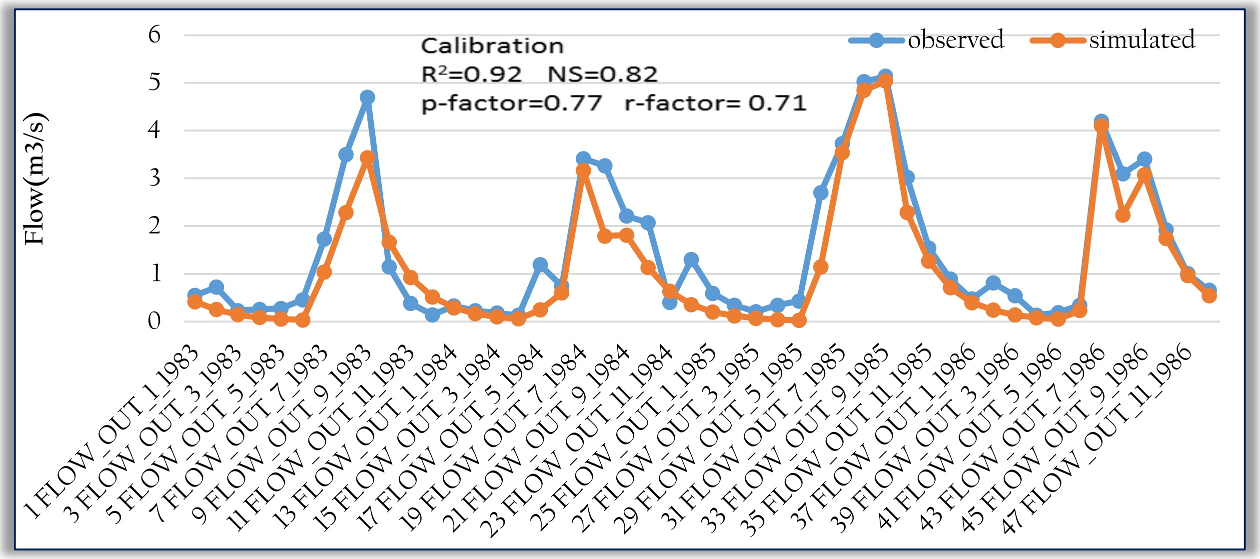

Figure 5: Comparison of observed and simulated streamflow for R2, NS, p-factor and r-factor statistics during the calibration period

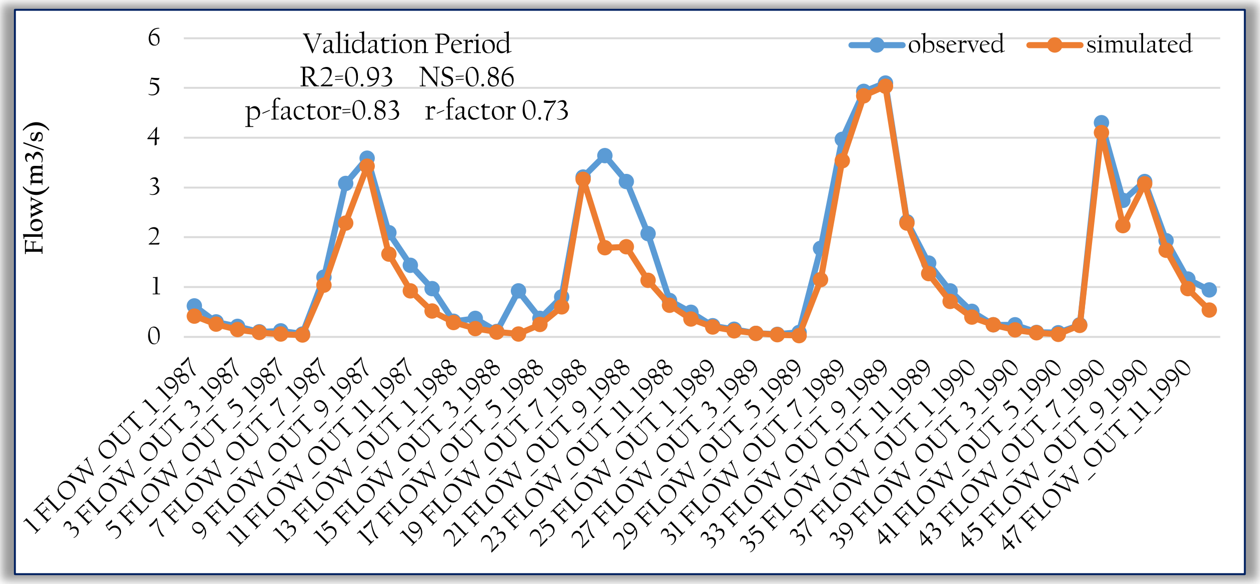

Figure 6: Comparison of observed and simulated streamflow for R2, NS, p-factor and r-factor statistics during the Validation period

Shimaa, (2015) obtained R^2 and NS values of (0.93 and 0.80) and (0.85 and 0.75) in the calibration and validation of SWAT, respectively for the hydrological modeling of the Simly Dam watershed (Pakistan) using GIS and SWAT model. Therefore, these suggest strong agreement between the simulated and observed stream flow during this period, based on the performance criteria stated above.

The simulation underpredict the peak values of flow experienced in the month of July, August and September as shown in figure 5. It is clear that if more reliable precipitation and temperature data sets of the meteorological stations with good spatial coverage of the study area are available, the results of the model could be equally improved with excellent accuracy. The underprediction of flow during peak events by the SWAT model has been reported in many studies, Jayakrishnan *et al.*, (2005) Gassman *et al.*, (2007) and Fadil *et al.*, (2011)

4. CONCLUSION AND RECOMMENDATION

Watershed models have become a main tool in addressing a wide spectrum of water resources and environmental problems. The present study comprises the application of hydrological model to simulate the hydrological response of

Kangimi dam watershed. The hydrological model selected for modeling stream flows in the watershed is the ArcSWAT interface implemented in the ArcGIS software, soil and water assessment tool (SWAT). The SWAT model has been well-documented as an effective water resources management tool.

The program SUFI-2 in SWAT-CUP package was used for calibration/uncertainty analysis, validation, and sensitivity analysis. The calibration and validation of the model produced good simulation results.

The efficiency of the model has been tested by coefficient of determination, Nash Sutcliffe Efficiency (NSE) in addition to another two recommended statistical coefficients: Percent Bias and RSR-observation standard deviation ratio. On monthly basis, the Coefficient of Determination and Nash and Sutcliffe Efficiency (NSE) were found to be 92% and 82%, for calibration and 93% and 86% for validation respectively, which indicate very high predictive ability of the model.

The model can be used successfully to predict the volume inflow to Kangimi Dam when gauging stations are installed at each subbasin for both climatological and hydrological data collections, so as to facilitate the storage and efficient water management.

References

[1] Abbaspour K. C., M. Vejdani, and S. Haghighat. (2007). SWATCUP calibration and uncertainty programs for SWAT. In Proc. Intl. Congress on Modelling and Simulation (MODSIM'07), 1603-1609. L. Oxley and D. Kulasiri, eds. Melbourne, Australia: Modelling and Simulation Society of Australia and New Zealand.
[2] Adeogun, A.G., Sule, B.F., Salami, A.W. and Okeola, O.G. (2014). 'GIS-based hydrological modeling using SWAT: case study of upstream watershed of Jebba reservoir in Nigeria',Nigerian Journal of Technology, Vol. 33, No. 3, pp.351–358.
[3] Arnold J.G, Srinivasan R., Muttiah R.S., Williams J.R., (1998). Large area hydrologic modeling and assessment – Part 1: Model development, J. Am. Water Resour. Assoc. 34 (1) 73–89.
[4] Bhuyan S.J., Koelliker J.K., Marzen L.J., Harrington J.R., An integrated approach for water quality assessment of Kansas watershed, Environ. Model. Softw. 18 (2003) 473–484.
[5] CGIAR SRTM 90m Digital Elevation Data http://srtm.csi.cgiar.org/, Accessed on 4th July, 2018
[6] Daggupati P, Pai N, Ale S Douglas-Mankin KR, Zeckoski R, Jeong J, Parajuli PB, Saraswat D, Youssef MA (2015). Recommended calibration and validation strategy for hydrologic and water quality models.Trans ASABE 58(6):1705–1719.
[7] Fadil A., Rhinane H., Kaoukaya A., Kharchaf Y., and Bachir O.A. (2011). "Hydrologic Modeling of the Bouregreg Watershed (Morocco) Using GIS and SWAT Model" Journal of Geographic Information System vol 3, 2011, pp279-289.
[8] Gassman P.W., Reyes M.R., C.H. Green, J.G. Arnold, (2007). The soil and water assessment tool: historical development, applications and future research directions, Trans. ASABE 50 (4) (2007) 1211–1250.
[9] Gassman P.W., Reyes M.R., Green C.H., Arnold JG, (2007). The soil and water assessment tool: historical development, applications and future research directions, Trans. ASABE 50 (4) (2007) 1211–1250.
[10] Harmonized World Soil Database (HWSD). Food and Agri-culture Organization of the United Nations, Rome www.fao.org/nr/water/docs/harm-worldsoil soil-dbv7cv.Pdf accessed on July 6, 2018
[11] Jayakrishnan R., Srinivasan R., Santhi C., Arnold J.G., (2005). Advances in the application of the SWAT model for water resources management, Hydrol. Process. 19 (3) (2005) 749–762
[12] Joh HK, Lee JW, Park MJ, Shin HJ, Yi JE, Kim GS, Srinivasan R, Kim SJ (2011). Assessing climate change impact on hydrological components of a small forest watershed through SWAT calibration of evapotranspiration and soil moisture. Trans ASABE 54(5):1773–1781.
[13] Kemdirim, E.C. (2005). 'Studies on the hydrochemistry of Kangimi reservoir, Kaduna State, Nigeria', African Journal of Ecology, Afr. J. Ecol., 43, 7–13
[14] Krause, P., D. P. Boyle, and F. Base. (2005). Comparison of different efficiency criteria for hydrological model assessment. Adv. Geosci. 5: 89-97.
[15] Moriasi D., Arnold J.G., Van Liew M.W., Bingner R.L., Harmel R.D., Veith T.L., (2007) Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, Trans ASABE 50 (3) 885–900.
[16] Ndulue, E.L., Ezenne, G.I., Mbajiorgu, C.C., Ogwo, V. and Ogbu, K.N. (2018) 'Hydrological modelling of upper Ebonyi watershed using the SWAT model', Int. J. Hydrology Science and Technology, Vol. 8, No. 2, pp.120–133
[17] Neitsch SL, Arnold JG, Kiniry JR, Srinivasan R & Williams JR (2002). *Soil and water assessment tool user's manual. Version 2000.* GSWRL Report 02-02. Temple, Texas: Grassland, Soil & Water Research Laboratory
[18] Neitsch SL, Arnold JG, Kiniry JR, Williams JR (2011). Soil and water assessment tool theoretical documentation version 2009. Texas Water Resources Institute.
[19] Obiero, J.P., Hassan, M.A., Lawrence O. and Gumbe, M. (2011) 'Modelling of streamflow of a catchment in Kenya', Journal of Water Resource and Protection, Vol. 3, No. 9, pp.667–677
[20] Omar, M., 2014. Space-time variation of hydrological processes and water resources in Rwanda. Phd Dissertation, UNESCO-IHE Institute for water education Delft, Netherland.
[21] Saha S., Moorthi S., Pan H.-L., Wu X., Wang J., Nadiga S., Tripp (2010), The NCEP Climate Forecast System Reanalysis, Bulletin of the American Meteorological Society, 1015-1057
[22] Saltelli A., Scott E.M., Chan K., Marian S., (2000) Sensitivity Analysis, John Wiley & Sons Ltd., Chichester,
[23] Santhi C., Arnold J.G., Williams J.R., Dugas W.A., Srinivasan R., Hauck L.M., (2001). Validation of the SWAT model on a large river basin with point and non-point sources, J. Am. Water Resour. Assoc. 37 (5) (2001) 1169–1188.
[24] Shimaa, M.G., 2015. Hydrological modeling of Simly Dam watershed (Pakistan) Using GIS and SWAT Model. Alexandria Engineering Journal (2015) 154. 585-594.
[25] USGS Earth Resources Observation and Science (EROS) https://eros.usgs.gov/westafrica. Accessed on 6th July, 2018.
[26] Van Griensven A, (2005). Sensitivity, Auto-calibration, Uncertainty and Model Evaluation in SWAT, UNESCO-IHE, 2005, p. 48

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