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Data driven parameter estimation and Application of two Storage Based Runoff models on Oshin Catchment using Mod16 Evapotranspiration datasets

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Abstract

This research aims to apply two storage-based rainfall-runoff models which have been proven and used in other catchments/watersheds, such as the Australian Water Balance Model and the Sacramento storage-based Runoff Model, to the Oshin catchment area of Kwara State, Nigera. This is to determine the applicability of the storage-based runoff models which were developed in watersheds of other countries on a Nigerian watershed. Previous researches focused more on physically-based models, but none has focused on an optimization of the parameter datasets making a comparative evaluation of the runoff parameters lacking. This paper presents for the first time, the parameter optimization of Australian Water Balance Model and SACRAMENTO runoff parameters and a comparative evaluation of the efficiencies of the European-developed storage-based runoff models in runoff estimation on the Oshin Watershed and it sensitivity analysis. The SACRAMENTO model outperformed the AWBM model with a NASH Sutcliffe Criterion of 0.753 during calibration and a Nash Sutcliffe of 0.742 during validation, while the AWBM had a Nash Sutcliffe of 0.517 during calibration and 0.423 during validation. The AWBM model had two parameters that were sensitive during optimization using pattern search algorithms (BIF and Kbase). During optimization trials, the Sacramento had none of its parameters sensitive. Therefore, the applicability of both the rainfall-runoff models were confirmed, with the SACRAMENTO as the most suitable for the catchment.

Key Words: Australian Water Balance Model, Runoff, SACRAMENTO, Oshin water shed, parameter optimization

INTRODUCTION

Storm flooding in urban areas has terrible impacts on civilizations because it results in lost of lives and infrastructural damage, as well as larger-scale interruptions to economic performance (Tierolf et al., 2021; Torti, 2012; Chen et al., 2020). Considering the current global situation of a changing climate and its potential effects on the intensity and pattern of rainfall events, it is expected to have more frequent, flood scenarios in the future. Due to the increase in urbanization and land-use changes, unplanned urbanization and inadequate drainage

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systems are the main causes of flooding, and developing countries are more likely to experience its negative impacts (Nkwunonwo et al., 2020).

Adverse hydrological conditions serve as threats in different ways to societies, communities, and ecosystems. However, hydrological models developed can be applied in such scenarios to simulate extreme events. A difference in the structures of the hydrological models can help in the understanding of the spread of extreme runoff event. The runoff model is a very important Tool for use in the monitoring of water resources and control (Yining et al., 2021). Rainfall and runoff modeling is used to simulate life and death situations related to floods, land use, erosion, pollution, climate change, and food (Ewen et al., 2021).

METHODOLOGY

Study Area

The River Oshin takes its source from a mountain located in the area of Ila-Orangu, flowing in a northward direction into the Niger River. The river measures 170 km in extent. The Oshin watershed is located in the Guinea savanna zone of Nigeria where it remains one of the major tributaries to the Niger River in the Guinea Region.

The upper part of the Oshin watershed is situated at latitudes 8 00 'and 8 26' 8' N and longitudes 4 45' and 5 00' E (Figure1). The length is about 56km. The river is a fourth-order stream that flows for approximately 70 kilometers within the upper watershed. In addition, the average monthly rainfall in December and November is 2.0mm. for January to March, 16.0mm, and 230mm for April to October.

The soil order of the soils in the area as classified by US Soil Taxonomy is Oxisols.

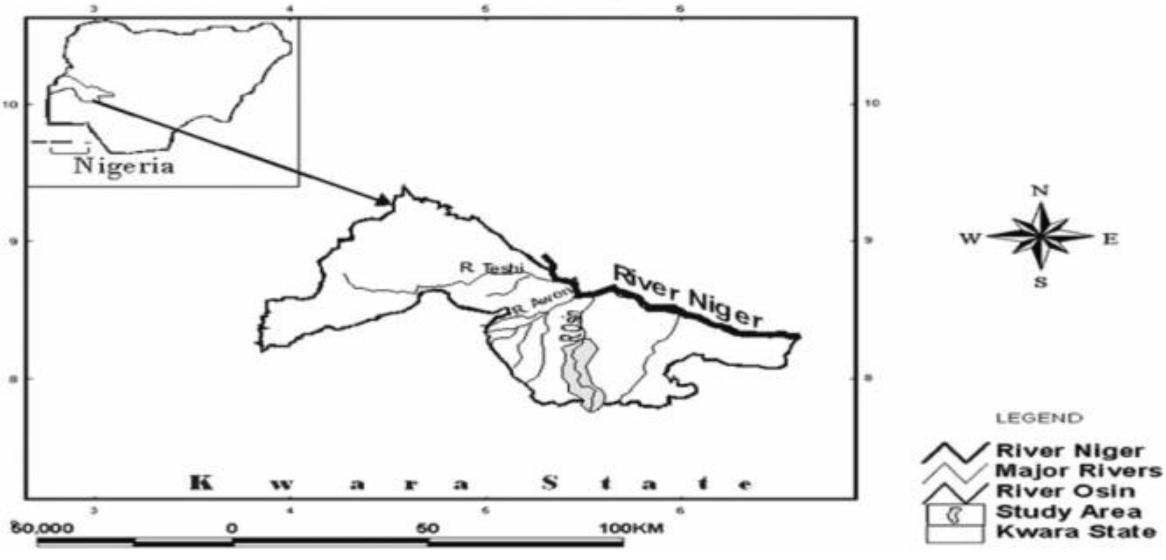

Figure 1: Study area map of Oshin, Source: Digitized from Dada(2006: 12)

Australian Water Balance Surface Storage Runoff Model

The Australian Water Balance Model makes use of surface storage concept to analyse and simulate partial areas of runoff. These surface storage used are three in number. The water balance of each store is calculated separately from the rest. At each time step, rainfall is added to each of the three surface moisture stores, and evapotranspiration is subtracted from each store, yielding the balance equation storen = storen + rain-evap (n = 1 to 3).

Sacramento Surface Storage Runoff Model

The Sacramento Model has five stores: The volume of water held in the soil matrix by surface tension is represented by tension water stores. Only evapotranspiration can remove water from the tension water stores. Water can move through the soil vertically and laterally to other stores and be discharged as inter-flow (upper zone) or base-flow (lower zone) in the case of free water stores (lower zone).

Data Collection and processing

Model Setup: The Rainfall-Runoff model was developed to perform rainfall-runoff modeling using the AWBM and SACRAMENTO models. The catchment area measures 2118.7km2, and the input data for precipitation, observed data, and evapotranspiration for the eight years from year 2001 to 2008 were converted to SWAT document format**.** The file format (PCP file format; this was achieved by editing an already available PCP file with the notebook Editor program) in order to be made available for importation into the Rainfall Runoff Library. This was achieved by editing an already existing PCP file using Notepad, overwriting each file with the exact file of the meteorological variables. Each file was saved with names to represent the meteorological variables in it.

Hydro-logical, temporal and meteorological data: For calibration and validation, the hydrological datasets of the catchment will be required. The meteorological and rainfall datasets are the minimal inputs for the hydrological models, and these have been obtained from the river basin development in charge of the river network.

Calculation of potential Evapotranspiration: the potential evapotranspiration used, was obtained by using MODIS USGS satellite Potential evapotranspiration datasets for each locality, the longitude and latitude of Oshin watershed was inserted and the potential evapotranspiration data for a period of twenty years was generated, this was then prepared and cleaned using Microsoft Excel. AAppEEARS (Application for Extracting and Exploring Analysis Ready Samples) provides a faster way to access and transform geospatial datasets by leveraging spatial, band and spatial parameters. The datasets which were obtained as ET_500m and PET_500M were resampled from an mm/8days into mm/day.

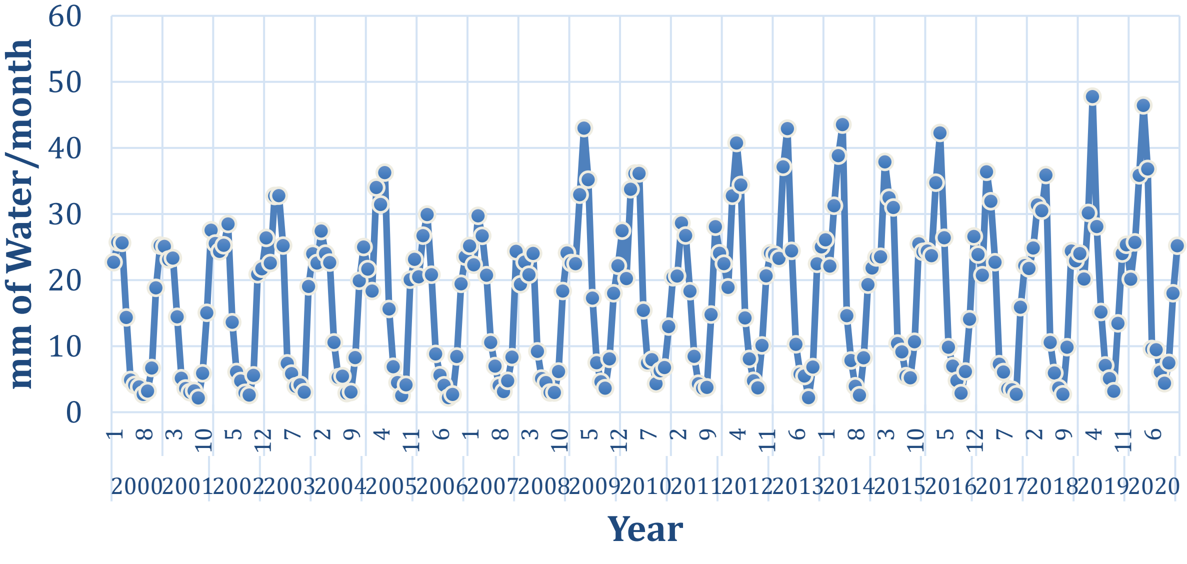

Figure 2: Time series chart showing mm of water evaporated per month in oshin watershed

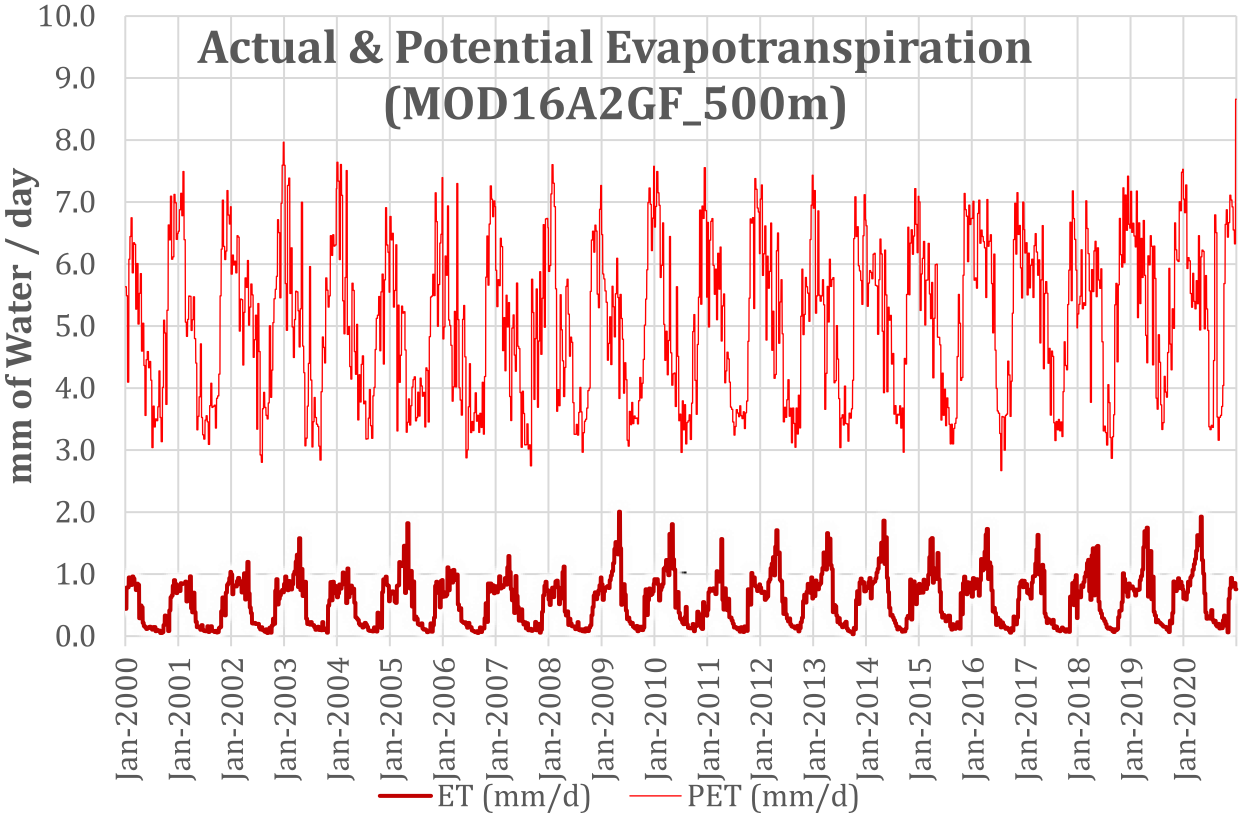

Figure 3: Variations in Actual and potential evapotranspiration from year 2000 to 2020

The analysis of the evapotranspiration datasets showed that evapotranspiration has been highest from mid-2019 to 2020. It also reveals a consistent upward trend increase each year over the watershed. This implies increasing drought. The datasets reveal that ET is highest in April, with an ET and PET of 6.8.

RESULTS

The Australian Water Balance Model.

The graph below depicts the best fit analyzed over the calibration period, while the charts attached show the comparison of observed and simulated discharge during the Australian Water Balancing Model validation period.

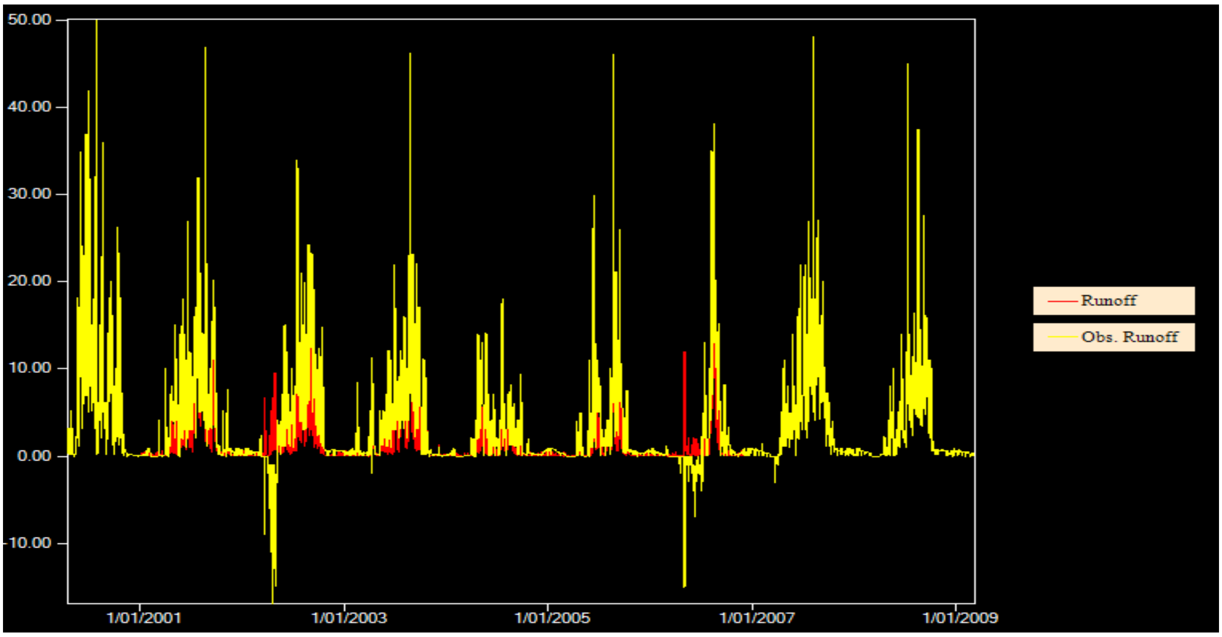

Figure 4: Graph of observed discharge values versus simulated discharge values

The correlation as represented in the regression line graph showed that the Nash Sutcliffe of 0.517 and 0.423 was achieved after the model was formed

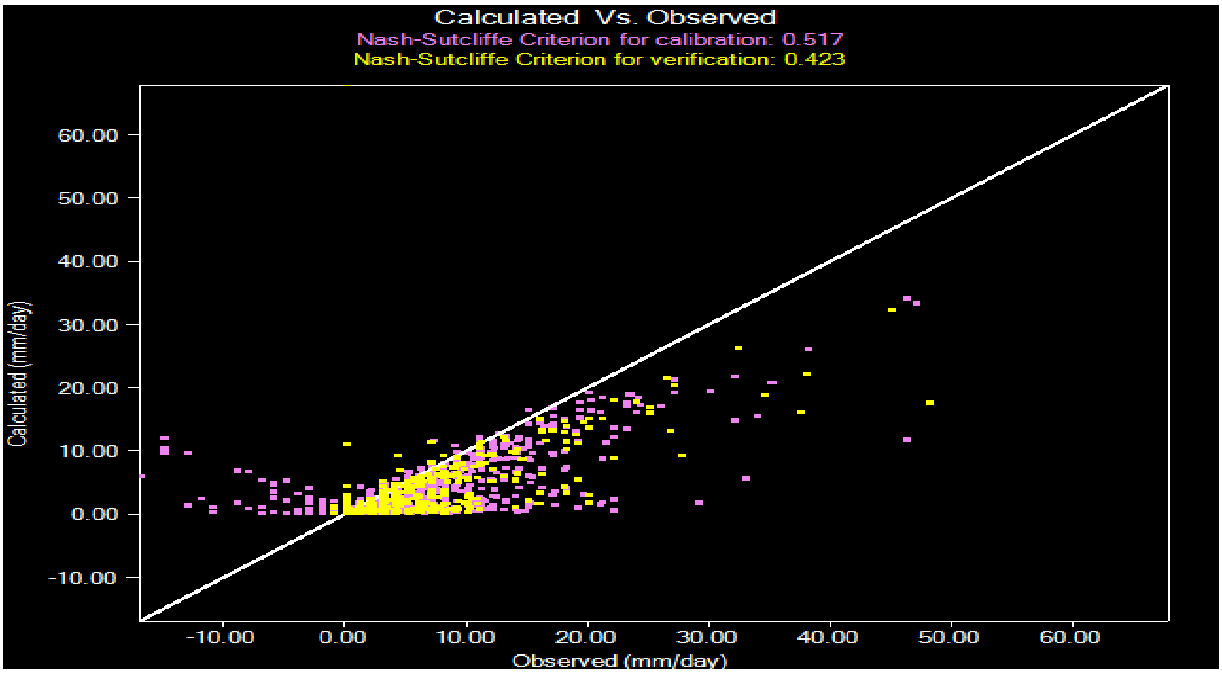

Figure 5: Graph of Nash-Sutcliffe criterion for the period of Validation and calibration.

The performance of the model was evaluated using the following evaluation criteria: coefficient of determination (R^2), Nash Sutcliffe efficiency index (EI), and Root mean square error (RMSE), as shown in table 2 below. The parameters were then optimized to get the best parameter sets. The optimized datasets are depicted below. This yielded a high R^2 coefficient for both calibration and validation periods as shown in table 2 below.

Table 1: Evaluation of the AWBM Model Performance

Performance criteria	Calibration	Validation
R^2	0.767	0.705
ET	0.5151	0.402

The optimized parameter value were in higher limits of their range for K_{base} and within lower values for other parameters , this shows that the proportion of moisture remaining per time step is higher, as shown in table 3 below.

Table 2: Parameters of AWBM model optimized

Parameter	Optimized parameter values	Range of the parameters
A_1	0.134	0.000 – 1.000
A_2	0.433	0.000 – 1.000
BIF	0.267	0.000 – 1.000
C_1	0	0 – 50
C_2	0	0 – 200
C_3	0	0 – 500
K_{base}	0.784	0.000 – 1.000
K_{surf}	0.078	0.000 – 1.000

After further optimization and sensitivity trials, K_{base} and BIF parameters were the only sensitive parameters, whilst the rest remained insensitive, as shown in the table below.

Table 3: Sensitivity Analysis of AWBM

Model Parameter	Sensitivity Analysis
A_1	Non Sensitive
A_2	Non sensitive
BIF	sensitive
C_1	Nonsensitive
C_2	Nonsensitive
C_3	Nonsensitive
K_{base}	sensitive
K_{surf}	Nonsensitive

Sacramento Model.

The optimized parameters were found using the genetic algorithm. The graph shown in figure below shows a summary of the best match output during the period of calibration, and the charts attached show comparative descriptions of simulated and observed flow.

discharges during the Sacramento model's validation

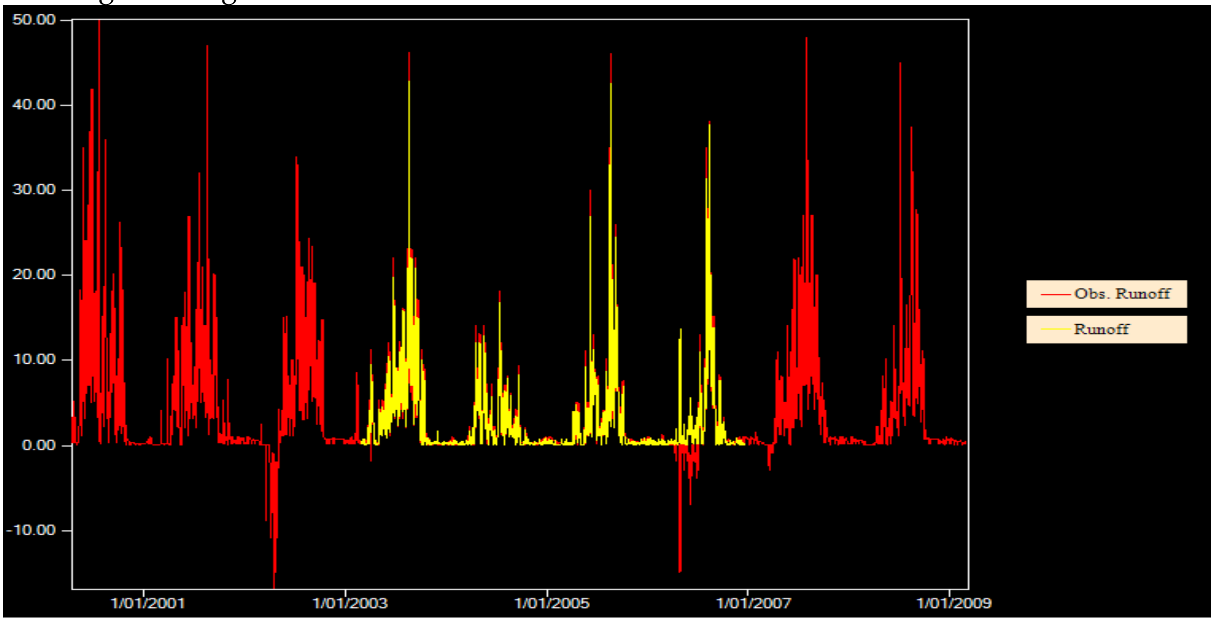

Figure 6: Graph of observed discharge values versus simulated discharge values

The Figure below shows the regression plot of the Nash Sutcliffe criterion for both the calibration and validation periods, this reveals a higher Nash Sutcliffe during calibration periods than during the validation period.

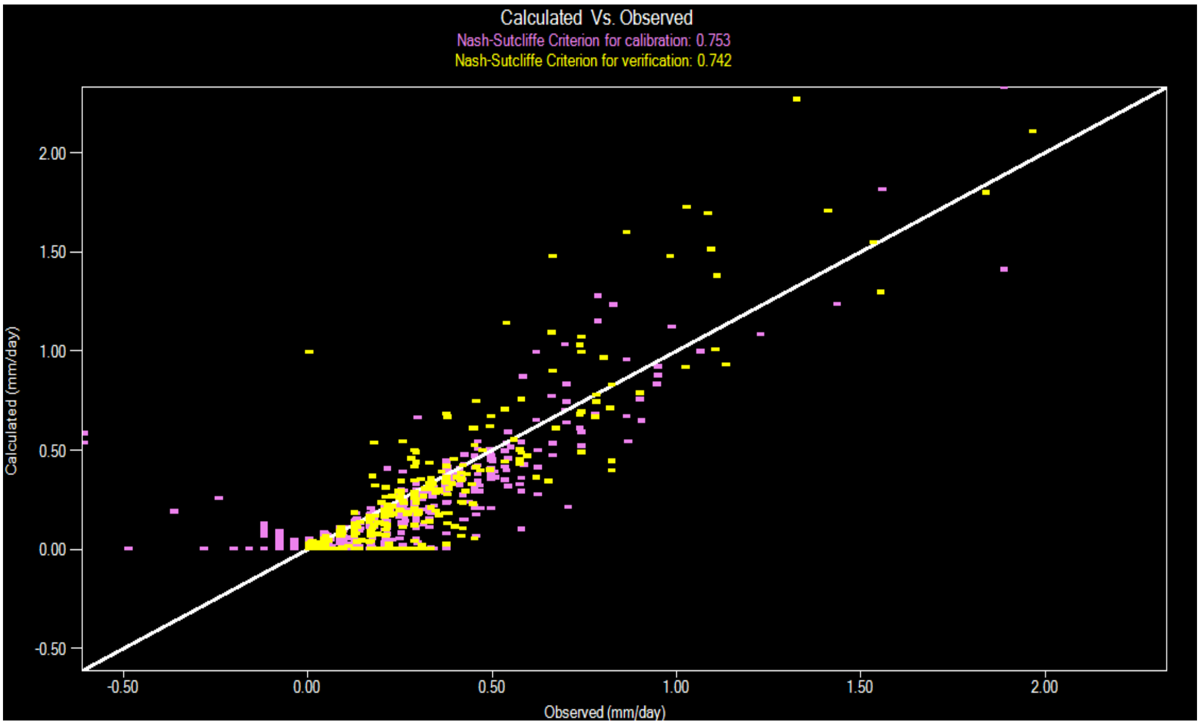

Figure 7: graph of Nash Sutcliffe criterion for calibration and validation period

The model's performance was assessed using the following criteria: the Nash-Sutcliffe efficiency index (EI), coefficient of determination (R2), and root mean square error (RMSE).the table below provides a summary of the best match obtained during calibration.

Table 4: Performance evaluation of the Sacramento Model

Performance criteria	Calibration	Validation
(R^2)	0.878	0.908
ET	0.753	0.742

Sensitivity analysis shows Rserv, Sarva and Ssout parameters to be true, this reveals that the fraction of lower zone free water unavailable for transpiration is sensitive, also the decimal fraction representing the portion of the basin normally covered by streams, lakes and vegetation that can deplete stream flow evapotranspiration as sensitive.

Comparisons between Simulated Runoff from AWBM, SACRAMENTO and Observer Discharge

The graph of simulated discharge vs observed for each of the model was compared on a single graph sheet with data of Observed discharge. it showed Sacramento model to have high peaks than AWBM model, it also shows that Sacramento were able to predict peaks in the observed discharge data , but predicted higher values, on the other hand AWBM were able to predict moderate level of peaks as compared to the observed discharge.

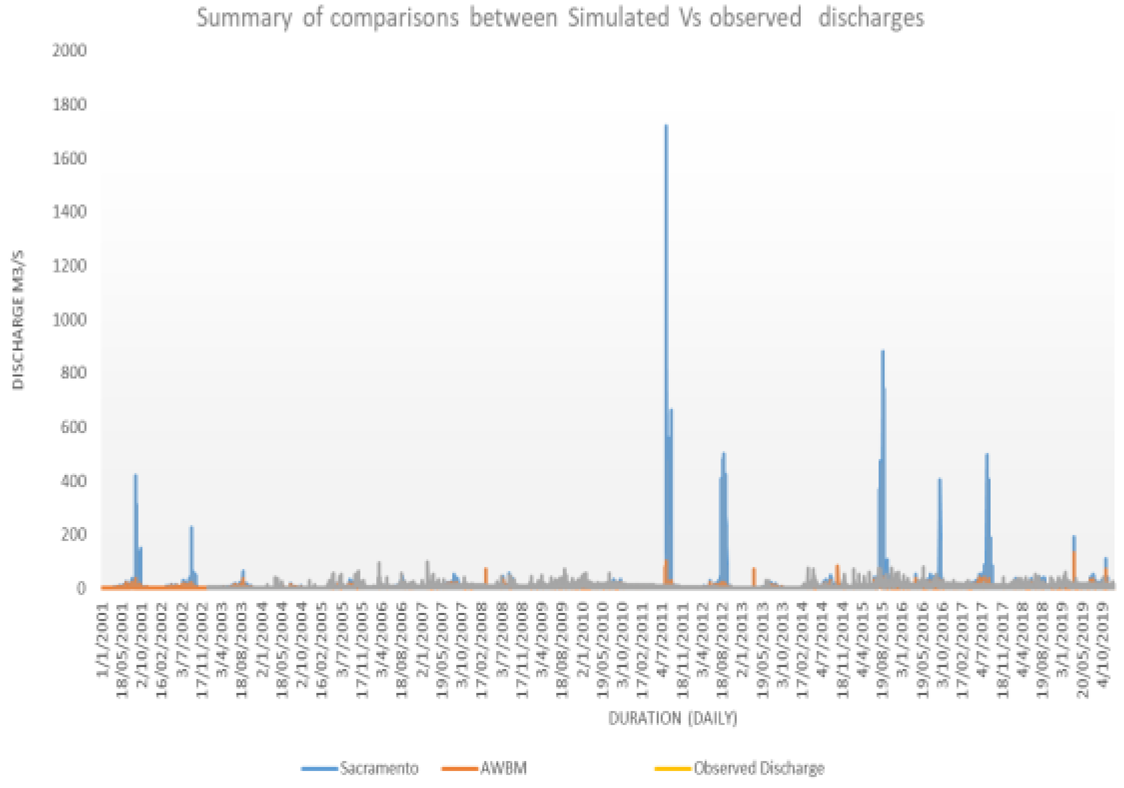

Figure 8: Comparisons SACRAMENTO and AWBM simulated discharge vs Observed Discharge

Although the highest peaks from the Sacramento model occurred late 2011, the difference in results between the predicted results and observed result, proves that results of the Sacramento are overly exaggerated during extreme events, on the other hand AWBM model is within tolerable ranges from observed discharge during extreme events as seen in 2011, 2015 and 2001.

CONCLUSION

The AWBM Runoff Model produced a gave a high calibration ET of 0.767 during calibration and ET of 0.705 during validation, which was outperformed by the Sacramento. This shows that the Sacramento model fits best in modelling the runoff characteristics of the Oshin watershed, and use in other close catchments would be encouraged. This reveals that the Sacramento model is more applicable and suitable in the guinea catchment compared to the AWBM, but results in overestimation of discharge peaks, while the AWBM results to moderate estimation of peaks.

REFERENCES

Balvanshi, A. and Tiwari, H.L., (2015). Rainfall runoff estimation using RRL toolkit. *International Journal of Engineering Research & Technology*, 4(5): 595-599.

Chen, A., Giese, M. and Chen, D., (2020). Flood impact on Mainland Southeast Asia between 1985 and 2018—the role of tropical cyclones. *Journal of flood risk management,* 13(2): 12598.

Chouhan, D., Tiwari, H.L. and Galkate, R.V., (2016). Rainfall runoff simulation of Shipra river basin using AWBM RRL toolkit.

Ewen, J. and O'Donnell, G.M., (2021). If a Rainfall-Runoff Model was a Hydrologist. Hydrology and Earth System Sciences Discussions, pp.1-25.

Kangsabanik, S. and Murmu, S., (2017), May. Rainfall-runoff modelling of Ajay river catchment using SWAT model. In IOP Conference Series: Earth and Environmental Science (Vol. 67, No. 1, p. 012033). IOP Publishing.

Li, Y., (2021), May. Performance evaluation of Tanh and AWBM rainfall-runoff models. In IOP Conference Series: Earth and Environmental Science (Vol. 768, No. 1, p. 012048). IOP Publishing.

Nkwunonwo, U.C., (2020). Flood Risk Analysis for Critical Infrastructure Protection: Issues and Opportunities in Less Developed Societies. In Issues on Risk Analysis for Critical Infrastructure Protection. IntechOpen.

Odhiambo, K.O., Ong'or, B.T.I. and Kanda, E.K., (2022). Assessment of rainwater harvesting potential of Rachuonyo North Sub-Catchment in Kenya using the Australian water balance model. *AQUA—Water Infrastructure, Ecosystems and Society*, 71(2):345-354.

Tierolf, L., de Moel, H. and van Vliet, J., (2021). Modeling urban development and its exposure to river flood risk in Southeast Asia. *Computers, Environment and Urban Systems,* 87:101620.

Torti, J., (2012). Floods in Southeast Asia: A health priority. *Journal of global health*, 2(2).

Van Kempen, G., Van Der Wiel, K. and Melsen, L.A., (2021). The impact of hydrological model structure on the simulation of extreme runoff events. *Natural Hazards and Earth System Sciences*, 21(3): 961-976.