

# Evaluation of the Impact of Climate Change on Streamflow Using SWAT Model

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The Soil and Water Assessment Tool (SWAT) model was applied in this study to simulate stream-flow in the Oyun River Basin. The model was calibrated and validated using monthly stream-flow data for the basin. Model performance was satisfactory for calibration and validation with a coefficient of determination ( $R^2$ ) of 0.69 and 0.88, respectively. Climate change impact on Oyun River was assessed by driving the SWAT model with climate parameters obtained from two global climate models (HadGEM2-ES and BCC-CCSM1-1M) based on RCP 2.6 for 2050 – 2059 and 2080 – 2089 periods. With respect to a baseline period of 2000 – 2009, HadGEM2-ES predicted a 4.62% decrease in total stream-flow while the BCC-CCSM1-1M predicted stream-flow increase by 6.18% for the 2050 – 2059 period. However, both HadGEM2-ES and BCC-CCSM1-1M predicted stream-flow to increase by 18.92% and 11.25% respectively for the 2080 period. The HadGEM2-ES model showed consistency in relating future rainfall predictions with future discharge trends for the periods under study. Model results show the need for adaptive measures to mitigate climate change impacts on the water resource system.

**Keywords:** SWAT model; climate change; stream-flow; HadGEM2-ES; BCC-CCSM1-1M

## I. INTRODUCTION

Availability of water resources is important for economic and social development of any nation. Water-related activities such as agriculture, hydropower generation, water transportation, inland fisheries and water supply provide revenue and employment, which drives economic/national growth (Kankam-Yeboah *et al.*, 2013). Changes in climate alter runoff by affecting rainfall and temperature, which will significantly have implications on water resources (Pan *et al.*, 2017). The hydrologic response of a watershed to changes in climate is a relevant discussion for sustainable water resources development, management and planning.

Climate change impacts on stream-flow can be evaluated either by driving hydrologic models using different climate scenarios concerning historical observations or by coupling climate model and by hydrologic model. Over the years, global

climate models (GCMs) have proven to be successful in reproducing observed climate variables for use in hydrologic models (Goyal *et al.*, 2012). Many studies have focused on using hydrologic models to establish a relationship between climate parameters and watershed hydrology (Legesse *et al.*, 2003; Qi *et al.*, 2009; Sead *et al.*, 2010; Mango *et al.*, 2011; Khoi and Suetsugi, 2014; Zuo *et al.*, 2016; Lin and Jin, 2017; Yira *et al.*, 2017; Yan *et al.*, 2019). The report by the Intergovernmental Panel on Climate Change (IPCC, 2007) predicts a temperature rise of about 3 – 4°C for the West Africa region towards the end of the 21<sup>st</sup> century. In Nigeria, studies by Okafor and Ogbu (2018), Okafor *et al.*, (2017), Idowu *et al.*, (2011), and Enete and Amusa (2010) have shown that climate variability is significantly affecting watershed hydrology with implications on human well-being. However, the lack of hydro-meteorological data in Nigeria has greatly affected research

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efforts towards this end and hence the reliance on remotely sensed data for climate impact studies on watershed hydrology. Water from the Oyun River is critical for the region's economy. It sustains the agricultural, aquaculture, recreational and hydropower generation activities in the basin (Manta *et al.*, 2010). However, the threat of a changing climate poses far-reaching consequence for this resource, thereby complicating its future development and management. This research, therefore aimed at evaluating the effects of future changes in future climate on the discharge of Oyun River using climate projections from two GCMs.

## II. MATERIALS AND METHOD

### A. Theory of the SWAT Model

This model is a physically-based, distributed and continuous-time model used for rainfall-runoff modelling at the watershed scale (Arnold *et al.*, 1998). It comprises of many components - hydrology, soil erosion, crop growth and management modules. The SWAT model can be interfaced with different geographical information system (GIS) software, which presents a user-friendly window for storing, processing and analysing heterogeneous input parameters. During model setup, the watershed is discretized into sub-basins through which flows are routed to watershed outlet. The model is computationally efficient and simulates the water balance at the hydrologic response unit (HRU) level, which is a homogeneous combination of slope, soil and land-use. The sub-basins and HRUs are determined by the user by setting the cell size within the given range. Stream-flow is routed from HRU to sub-basin to the watershed outlet and is based on the water balance model (Neitsch *et al.*, 2011).

$$SW_i = SW + \sum_{i=1}^i (R_i - Q_i - ET_i - P_i - QR_i) \quad (1)$$

where,  $SW$  = soil water content;  $i$  = time (day);  $t$  = simulation period (day);  $R$  = rainfall (mm);  $Q$  = runoff (mm);  $ET$  = evapotranspiration (mm);  $P$  = percolation (mm); and  $QR$  = return flow (MM).

### B. Study Area

The Oyun River Basin is approximately 610 km<sup>2</sup> and is in Ilorin, Kwara State, Nigeria. The inhabitants in this basin are largely farmers and cultivate corn, vegetables, cassava, rice, and rear farm animals. The region lies within the sub-humid climatic zone with a mean elevation of 251 m above mean sea level and a flat landscape characterized with scattered farming settlements. Major land uses within this watershed include cropland, shrubland, grassland, built-up, forest and water body. The region experiences the bi-modal peak of the rainy season (April and September), with a mean annual rainfall of 1700 mm, mean monthly maximum 31°C and minimum temperature of 29°C (Manta *et al.*, 2010). The Oyun River originates from an elevation of 465m and flows northeast for about 80 km before joining the Asa River (Mustafa and Yusuf, 2012). This flows further to discharge into River Niger upstream of Jebba hydroelectric dam. The Oyun River serves as the principal source of water supply to the University of Ilorin, Nigeria and neighbouring towns.

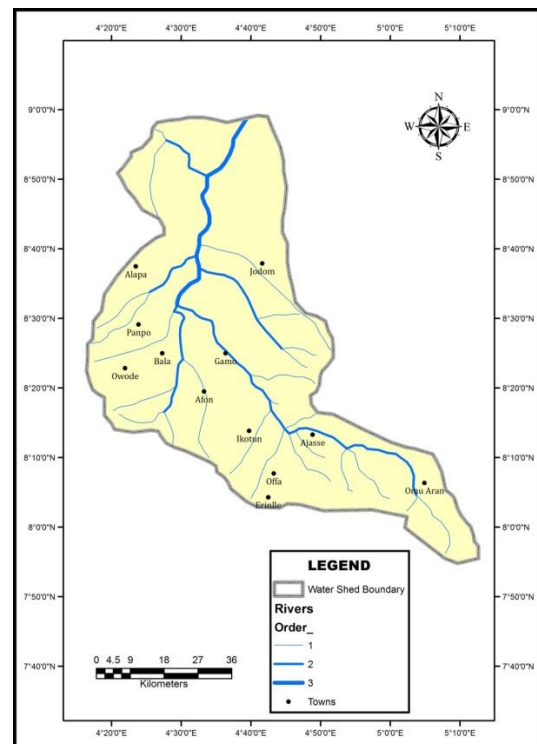


Figure 1. Oyun River Watershed, Kwara State, Nigeria

### C. Model Input Data

SWAT requires major input such as spatial datasets of elevation (DEM), climate and land use/cover and soil maps. A DEM of 90 m resolution (USGS 2006) was derived from the United State Geological Survey (USGS) Shuttle Radar Topography Mission (SRTM) website and pre-processed using the MapWindow GIS tool. Land use data of the study locations were obtained from the USGS data archive. 30 m resolution Landsat image data was processed and vectorized using the GIS tool. The land cover classification system of the Food and Agricultural Organization was modified to suit the land cover classes in the management component of the SWAT model for this study. Soil data were obtained from the Harmonized World Soil Database (HWSD) at a spatial resolution of 1km. Climate data of daily relative humidity, wind speed, rainfall, temperature, and solar radiation for the watershed were obtained from the Nigerian Meteorological Agency (NIMET).

### D. Climate Trend Analysis

In the past, statistical methods have been widely applied in hydro-meteorological, water quality, environmental monitoring and climate studies (Oguntunde *et al.*, 2011; Onyutha *et al.*, 2015; Diop *et al.*, 2017). The non-parametric test did not rely on the skewness of data or make any assumption on its underlying distribution and was used in this study. The Mann-Kendall test (Kendall, 1975) is used primarily for analysing increasing or decreasing trends over time and is stated as:

$$Z = \begin{cases} \frac{s-1}{\sqrt{VAR(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{s-1}{\sqrt{VAR(S)}} & \text{if } S < 0 \end{cases} \quad (2)$$

$$S = \sum_{k=1}^{n-1} \sum_{e=f+1}^n \text{sign}(x_e - x_f) \quad (3)$$

$$\text{sign}(x_j - x_k) = \begin{cases} x_e - x_f = 1 & \text{if } x_e - x_f > 0 \\ x_e - x_f = 0 & \text{if } x_e - x_f = 0 \\ x_e - x_f = -1 & \text{if } x_e - x_f < 0 \end{cases} \quad (4)$$

$$VAR(S) = \frac{1}{18} \left[ \frac{n(n-1)(2n-5)}{\sum_{p=1}^g t_p(t_p-1)(2t_p+5)} \right] \quad (5)$$

where,  $S$  = Mann-Kendall test value,  $X_e$  and  $X_f$  = data values sequentially;  $g$  = total number of tied data;  $t$  = total number of

data points in the  $g$ th group. The  $H_0$  (null hypothesis) is rejected if  $-Z_{1-\alpha/2} \geq Z \geq Z_{1-\alpha/2}$ , where  $\alpha$  is the significant level.

Positive values of  $Z$  signify increasing trend while negative values of  $Z$  value decreasing trend. Sen's non-parametric model is very robust and gives a more realistic slope of trend (Gocic and Trajkovic, 2013; Tabari *et al.*, 2015). The ( $Q_i$ ) slope, for all data points, is computed as:

$$Q_i = \frac{x_u - x_v}{u - v} \text{ for } i = 1, 2, \dots, N \quad (6)$$

where  $Q_i$  is slope estimator,  $x_u$  and  $x_v$  are values at time  $u$  and  $v$  ( $u > v$ ).

### E. SWAT Model Setup

The DEM of the watershed was delineated into seventeen sub-basins and thirty-seven HRUs based on a threshold (5%) for soil, land use and slope. Two years (2003 – 2004) of monthly stream-flow records measured at the watershed outlet, was used for calibration using the SWAT Calibration and Uncertainty Program (SWATCUP) tool (Abbaspour, 2015) and supplemented with manual method. The model validation was performed using monthly stream-flow data for 2004 – 2005. Model performance for both validation and calibration periods were determined with the coefficient of determination ( $R^2$ ) as stated in Equation 2. Satisfactory results are obtained when  $R^2 > 0.5$  (Moriasi *et al.*, 2007).

$$R^2 = \frac{\left[ \sum (\hat{x}_1 - \bar{x})(x_i - \bar{x}) \right]^2}{\sum (\hat{x}_1 - \bar{x})^2 \sum (x_i - \bar{x})^2} \quad (7)$$

where,  $\bar{x}$  = mean of simulated;  $\bar{x}$  = mean of observed values;  $\hat{x}_1$  = simulated values;  $x_i$  = observed values.

### F. Climate Change Projections

Climate records for two global climate models (Table 1) with Representative Concentration Pathways (RCP) of 2.6 from the 5<sup>th</sup> phase of the Coupled Model Inter-comparison Project (CMIP5) were used in this study.

Table 1. Climate Change Scenarios

GCMs	Institute	Emission scenarios	2050 Timeline	2080 Timeline
BCC-CSM1.1M	Beijing Climate Centre, China	RCP 2.6	2050 – 2059	2080 – 2089
HadGEM2-ES	Met. Office, Hadley Centre, UK	RCP 2.6	2050 – 2059	2080 – 2089

*HadGEM2-ES* = Hadley Global Environment Model 2 – Earth System; *BCC-CSM1.1M* = Beijing Climate Centre Climate System Model (V. 1.1)

MarkSimGCM weather generator model which works on the principle of a third-order Markov chain process was used to produce future climate data for the 2050 and 2080 time periods while assuming an equivalent CO<sub>2</sub>~450 ppm and radiative forcing of 2.6 W/m<sup>2</sup> (Van *et al.*, 2011). The expected demographic scenarios assumed for these periods are a global population above 9 billion and high global economic growth. Projected climate variables for these periods and baseline records (2000 – 2009) were used to drive the hydrologic component of the SWAT model as described by Trotochaud *et al.* (2016).

### III. RESULTS AND DISCUSSION

#### A. Analysis of Climate Trend Variations

Table 2 summarizes trends in relative humidity, wind speed, minimum and maximum temperature, precipitation and solar radiation in the Oyun River watershed from 1980–2013.

Table 2. Mann-Kendall Test Statistics for Annual Climate Parameters

Parameter	Initial year	Final Year	N	Z	slope
Precipitation (mm)	1980	2013	34	-2.40	-10.40
Max. Temperature (°C)	1980	2013	34	2.34	0.034
Min. Temperature (°C)	1980	2013	34	2.13	0.016
Relative Humidity (%)	1980	2013	34	-1.48	-0.001

Solar Radiation (MJ/m <sup>2</sup> /day)	1980	2013	34	3.91	0.042
Wind speed (m/s)	1980	2013	34	-0.68	-0.001

The result shown in Table 1 signifies that that minimum temperature, maximum temperature and solar radiation solar showed a positive trend. In contrast, rainfall, wind speed and relative humidity showed a negative trend for the period considered. These results showed a similar trend to studies by Oguntunde *et al.* (2011) and Abiodun *et al.* (2011) but differed in magnitude.

#### B. Model Calibration and Validation

Model characteristics sensitive to runoff were obtained from Schuol and Abbaspour (2006) and used for the calibration process to get the best fit between observed and simulated stream-flow. Ranking of sensitive parameters is listed in Table 3.

Table 3. Ranking of Parameter Values (Schuol and Abbaspour, 2006)

Parameters	Definitions	Range
CN2	Runoff CN	62.17 – 71.17
ESCO	Soil evaporation factor	0.31 – 0.59
SOL-AWC	Saturated hydraulic conductivity	0.15 – 0.17
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	67.48 – 127.73
SOL_Z	Depth of soil surface from the bottom layer (mm)	56.23 – 67.33
ALPHA_BF	Baseflow alpha factor (days)	0.66 – 1.03
EPCO	Plant uptake factor	0.16 – 0.41
GW_DELAY	Groundwater delay	58.30 – 174.99
GW_REVAP	Groundwater 'revap' factor	0.14 – 0.24

A comparison of simulated and observed stream-flow at monthly time steps showed a good fit for both validation and calibration periods. Statistical analysis showed that the results are satisfactorily for calibration and validation periods with R<sup>2</sup>

> 0.6, as shown in Fig. 2 and 3, respectively. The statistical model performance is also shown in Table 4.

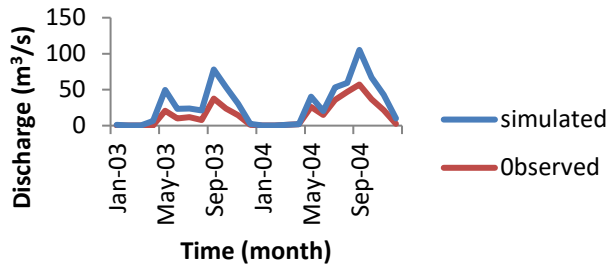


Figure 2. Calibration Plots

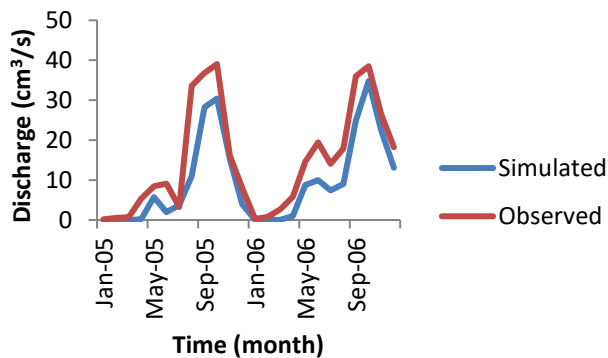


Figure 3. Validation Plot

Table 4. Model Statistical Performance

Characteristics	Period	Coeff. of Determination (R <sup>2</sup> )
Calibration	2003 – 2004	0.69
Validation	2005 – 2006	0.88

Evaluation of the average monthly observed and simulated stream-flow for calibration period and validation period show that SWAT under-predicted stream-flow by about 14% and 35% for both periods respectively. This may be attributed to the poor spatial representation of climate parameter, especially rainfall for the watershed during the period of discharge measurements. Lack of weather data necessitated the use of only one weather station, which was even located outside the study area for this study. Besides, the model result could be as a result of under-prediction of baseflow in the Oyun River basin. Kankam-Yeboah *et al.* (2013) observed the same trend in their study and reported that the SWAT model does not handle baseflow simulation well.

### C. Climate Projections

A comparative study between historical and downscaled climate data show that temperature increased for all models in the future. As shown in Table 5, the average minimum and maximum temperature increase ranged from 2.89 – 9.10% in the future for this basin. This supports the result of Yira *et al.* (2017). In Table 5, it can be shown that the total mean monthly rainfall decreased by 7.17 % and 11.10% for HadGEM2ES and BCCCSM1-1M respectively for the 2050 – 2059 period but increased by 7.19% and 9.4% for HadGEM2ES and BCCCSM1-1M respectively for the 2080 – 2089 period.

Table 5. Historical and Future Climate Data

MON	Maximum Temperature					Minimum Temperature					Rainfall				
	HIS	Had 2050	BCC 2050	Had 2080	BCC 2080	HIS	Had 2050	BCC 2050	Had 2080	BCC 2080	HIS	Had 2050	BCC 2050	Had 2080	BCC 2080
JAN	32.6	34.0	33.9	34.1	33.5	18.7	20.5	20.5	20.2	20.3	102.3	93.8	140.0	75.6	110.7
FEB	33.2	35.0	34.1	35.0	34.4	19.2	21.5	20.2	21.7	20.5	104.8	106.3	164.3	157.6	149.7
MAR	34.0	35.7	35.6	35.5	35.1	21.8	23.7	23.0	23.8	23.0	775.2	627.1	463.2	519.7	687.7
APR	33.4	35.2	35.0	35.3	34.5	22.1	24.1	23.6	24.1	23.4	1132.1	859.8	1033.0	833.6	1023.0
MAY	31.9	33.7	33.3	33.7	32.5	21.3	23.2	22.7	23.2	22.5	1841.1	1795.2	1653.0	1870.5	1991
JUN	29.7	31.5	30.6	31.5	30.1	21.6	23.4	22.6	23.4	22.4	1725.2	1778.8	1617.1	1736.9	1667
JUL	27.2	28.5	28.6	28.4	28.5	19.8	21.6	20.9	21.5	20.7	1738.4	1598.6	1410	1939.3	1287
AUG	27.4	28.5	28.5	28.5	28.3	20.1	21.8	21.2	21.7	21.1	1373.2	1433.9	1214.0	1690.3	1647
SEPT	28.3	29.4	29.5	29.4	29.1	20.3	21.9	21.4	21.9	21.1	2997.9	2262.2	2675.5	2034.6	2035

OCT	30.0	31.2	31.4	31.2	31.3	20.6	22.2	21.8	22.1	21.5	2076.1	2342.2	1907.5	2070.4	1777
NOV	32.3	33.7	33.3	33.8	33.0	19.8	21.7	21.2	21.5	21.0	348.4	308.9	320.8	278.8	325.2
DEC	33.0	34.1	34.4	34.2	33.6	18.7	20.8	20.4	20.1	20.2	70.6	54.1	101.8	51.20	241.8
AVE	31.1	32.6	32.3	32.5	32.0	20.3	22.2	21.6	22.1	21.5	14285.3	13260.9	12700.2	15313.8	15628
% change		+4.8	+4.0	+4.7	+2.9		+9.1	+6.3	+8.6	+5.6		-7.17	-11.1	+7.2	+9.4

Had 2050 and 2080 means HadGEM2-ES for 2050 and 2080 periods respectively; BCC 2050 and 2080 means BCC-CSM1-1M for 2050 and 2080 periods respectively; (+) indicates increase while (-) indicates decrease.

#### D. Climate Change Impact on Streamflow

The influence of changes in climate on discharge is presented in Table 6. Relating the baseline period (2000 – 2009) to the 2050 – 2059 period, HadGEM2-ES predicted that the total stream-flow decreased by 4.62% while BCC-CSM1 showed that stream-flow increased by 6.18%. However, both models simulated stream-flow to increase in the 2080 – 2089 period. Stream-flow results for the 2050 period were consistent with rainfall projection for the HadGEM2-ES model for the same period. However, the BCC-CSM1-1 model result shows a decreasing rainfall trend but projected an increase in stream-flow for the 2050 period. For the 2080 period, both GCMs showed an increasing rainfall trend with a corresponding projected increase in stream-flow.

Generally, the lack of agreement between the models concerning the projected stream-flow for the 2050 period creates uncertainty on the Oyun River discharge for the middle of the 21<sup>st</sup> century. Yira *et al.* (2017) reported that such mixed stream-flow signals for future periods are prevalent in GCM-enabled applications in the West African Region. This result could also be because of the high uncertainties associated with GCM outputs. Bias correction of climate parameters or averaging GCMs result could improve the accuracy of projected hydrologic dynamics of the basin. Since stream-flow is very sensitive to rainfall, this study has shown that changes in rainfall projections will have varying impacts on stream-flow, making its consideration crucial in climate change studies, especially for West African regions.

Table 6. Future Simulated Impacts of Climate Change on Streamflow

Scenario	Streamflow	% change in streamflow
Baseline	2633.3	-
BCC-CSM1-1M (2050 period)	2796.03	6.18
HadGEM2-ES (2050 period)	2511.72	- 4.62
BCC-CSM1-1M (2080 period)	3131.64	18.92
HadGEM2-ES (2080 period)	2929.62	11.25

#### IV. CONCLUSION

The impact of climate change on the river flow of the Oyun River watershed was assessed using the SWAT model. Model calibration and validation were simulated using monthly river discharge data for the basin. The model performed satisfactorily based on results of the coefficient of determination which was higher than 0.6 for both calibration and validation periods. Downscaled climate data from GCMs were further used to study future impacts on stream-flow. Results from HadGEM2-ES and BCC-CSM1-1 showed a decrease and increase in stream-flow respectively for the 2050 – 2059 periods while both GCMs showed an increasing runoff trend for the 2080 period. Lack of agreement between both GCMs for the 2050 period creates high uncertainty in projected stream-flow change signals and underlines the need for a larger ensemble of projections and utilizing improved climate projections for climate impact assessments in the West African region. The outcome of this research can be a decision support tool to policymakers in developing adaptive measures to

mitigate the effect of varying climatic parameters on hydrologic systems in the sub-Saharan region.

## V. ACKNOWLEDGEMENT

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