

A STUDY ON THE APPLICABILITY OF A SWAT MODEL IN PREDICTING THE WATER YIELD AND WATER BALANCE OF THE UPPER OUÉMÉ CATCHMENT IN THE REPUBLIC OF BENIN

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Abstract

This study investigates the applicability of a Soil and Water Assessment Tool (SWAT) model in predictions of the water yields and water balance of the Upper Oueme catchment in the northern part of the Republic of Benin. Meteorological and hydrological data for a period of 20 years were collected from the Meteorological Agency of Benin and the National Directorate of Water respectively. Spatial data such as a Digital Elevation Model and land use and soil maps were also extracted from suitable databases. Geographic information system (GIS) software was applied in combination with SWAT to process the spatial data and simulate the streamflow record. A good correlation between the simulated and observed data during the calibration and validation was found, using statistical measures such as the Nash-Sutcliffe Efficiency ($NSE > 0.65\%$), the standard deviation ratio ($RSR < 0.6$), percent bias ($\pm 10\% \leq PBIAS \leq \pm 15\%$), and the coefficient of determination ($R^2 = 0.78$). An estimated potential water yield of 18,671.61mm in the catchment over the period of the simulation suggests that subsistence agriculture is sustainable in the area. The model is suitable for estimating the water yield and water balance in the catchment.

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Key words

- Catchment
- SWAT model.
- GIS,
- Water Yield,
- Water Balance.

1 INTRODUCTION

The problem of the scarcity and poor quality of water is prevalent in many developing nations of the world. This, in some cases, has been attributed to the overutilization and mismanagement of limited freshwater resources (Olofintoye et al., 2013; Ayanshola et al., 2016). To effectively resolve water mismanagement issues to ensure the sustainability of freshwater at both the watershed and basin levels, reliable estimates of the water yield and balance is a prerequisite (Ayanshola et al., 2018). The water balance in a catchment is influenced by parameters such as the climate, land use, soil use, and physical properties defined by the morphology. Understanding the hydrological response of a watershed to variations in these parameters is necessary in assessing the water yield and availability within a catchment over a period of time (Tracy and Scott, 2013).

Agricultural activities and urbanization have been identified as major contributors to extensive changes in land and soil use. These changes often lead to the degradation of land, which, more often than not, is detrimental to the sustainability of the environment (Portnova and Safriel, 2004). For instance, the deforestation of virgin land for agricultural or urban uses may impact soil integrity, the assemblage of native species, and nutrient fluxes. This may affect the hydrological regime of the watershed by altering the rates of interception, infiltration, evapotranspiration and groundwater recharge, which often result in changes in the timing and amount of the river flow (Smakhtin, 2001). Contrary opinions (Chandler, 2006), however, suggest that afforestation, especially the establishment of plantations in subtropical regions, has resulted in increased transpiration over an area with a consequential reduction in the groundwater recharge and base flow rates. This can also affect the hydrological regime

of a watershed. Further studies (Chandler, 2006; Bonnell et al., 2010) suggest, however, that the removal of a vegetal cover may result in an increased base flow if the soil is left undisturbed or may result in a reduction in base flow if the deforestation is followed by land use practices such as urbanization, which can compact the soil. Hence, extensive changes in land use as a result of agricultural activities or urbanization necessitate an investigation of the water balance and yield of a watershed.

An extended period of drought experienced in the northern parts of the Republic of Benin in the 1970s resulted in the degradation and depletion of croplands in the region. A massive migration of farmers from the region led them to resettle in the less-populated southern areas of the upper Oueme catchment (GLOWA-IMPETUS, 2005). These migrant farmers occupied croplands in what is now referred to as “cropland colonization” in that area. Massive changes in land use occurred as a result of the removal of vegetation cover when the farmers searched for new farmlands and urban areas to develop and resettle in. Lawin et al., (2019) reports a substantial conversion of the woodlands, gallery forests, forests and savannas into agricultural land in the area between 1975 and 2013. Agriculture occupied 7.1% of the catchment area in 1975 but 31.4% in 2013. These changes have resulted in increased direct runoff and erosion. Furthermore, the pressure on natural and freshwater resources in the region has been further exacerbated by a high demographic growth rate of about 3% per annum and, in recent times, the impact of climate change. Thus, it is pertinent to investigate the water balance and yield in the region to reduce the vulnerability and ensure the sustainability of its freshwater resources. This aim aligns with the sustainable development goal (SDG) No. 6 of the United Nations (UN, 2021).

According to Stehr et al. (2008), the study of water resources at the river catchment level has been widely adopted as a better alternative for managing and assessing freshwater resources. Various hydrological models that incorporate an understanding of hydrological components and their spatial and temporal variability have been applied for the efficient planning and management of water resources. In particular, researchers have adopted simulation software in modeling hydrological processes in the region of the study area. For instance, Lawin et al., (2019) investigated the impacts of climate change on the Ouémé River discharge at the Bonou outlet (1971 to 2050) using four global climate models (GCM). The Hydrological Modeling System from the Hydrological Engineering Center (HEC-HMS), which is a semi-distributed model, was used to simulate the runoff. The model showed an ability to simulate runoff while taking into account changes in the land use and cover. An increasing trend in discharges was forecasted over the study period. Biao (2019), applied a lumped conceptual hydrological model based on the least action principle (HyMoLAP), which was designed to minimize uncertainties in rainfall-runoff process modeling, to assess the impacts of climate change on river discharge dynamics in the Bétérrou and Bonou sub-catchments in the Oueme River basin. The model's uncertainty projections indicated that the entire discharge distribution had shifted towards extreme events. HyMoLAP was found suitable for modelling river discharges in the basin. The water balance of the interactions between the soil, biosphere, and atmosphere over the upper Ouémé River basin was evaluated by Getirana et al. (2014) using a Land Surface Model (LSM). It was determined that a LSM is not appropriate for estimating river discharges in that region. Further studies based on field measurements were recommended to improve

the performance of the model. A study on the application of the LISFLOOD hydrological model in estimating future discharges in the Ouémé river basin at the Bétérrou outlet is reported in Emmanuel et al., (2018), while the application of a time-dependent generalized extreme value (GEV) model in estimating the annual maximum discharge at five gauging stations in the Ouémé River Basin may be found in Hounkpe et al., (2015).

The Soil and Water Assessment Tool (SWAT) developed by Texas Agricultural and Mechanical University (TAMUSWAT, 2021) is a physically-based model, which employs a water balance equation for the simulation of the hydrological processes within a watershed. A major example of the applications of SWAT took place within a hydrological unit model that was used to support the United States Department of Agriculture (USDA) analyses of the Resources Conservation Act Assessment of 1997. This system was employed to simulate the hydrology and losses from pollutants within each of the 2,149 United States Geological Survey (USGS) 8-digit Hydrological Cataloging Units (Arnold *et al.*, 1999; Gassman *et al.*, 2007). Olusanya et al. (2021) investigated the applicability of SWAT in the Oueme River Basin using remotely sensed data due to the unavailability of observed data. The model satisfactorily simulated the streamflow; however, the effectiveness of the satellite data remains unclear in some areas. Other applications of SWAT have also been reported in the literature (Stehr et al. 2008; Tracy and Scott, 2013; Ayanshola et al., 2018).

This study further investigates the applicability of SWAT in the upper Oueme catchment. The aim of the research is to calibrate a SWAT model using a manual optimization method (Moriassi et al., 2007) and to use the calibrated model to estimate the water yield and water balance of the catchment. The remaining part of the paper is sectioned as follows: Section 2 presents a brief description of the study area; section 3 describes the methodology adopted in the study; while section 4 presents the results and discussion. The conclusion is presented in section 5.

2 DESCRIPTION OF THE STUDY AREA

The River Oueme, which is also called the Weme river, is the largest river in the Republic of Benin, West Africa. The river, which is about 510 kilometers long, is sourced in the Atakora Mountains at an elevation of about 465 meters above sea level and flows through several agro-ecological zones to discharge into the Atlantic Ocean at the Gulf of Guinea in Cotonou at an average rate of 170 cubic meters per second. The catchment of the river is situated between latitudes 6°30'N and 10°00'N and longitudes 0°52'E and 3°05'E. Its largest tributaries are the Okpara River on the left flank and the Zou River on the right. The Oueme River catchment represents the largest river basin in the country, with an area of about 46,990 square kilometers. The Oueme River Basin is composed of two main sub-basins, i.e., the Upper Oueme Catchment in the Dahomeyen Pédic plain and the Lower Oueme Catchment situated on the coastal sediments. The region is in the tropical savanna climate zone according to the Köppen climate classification. The annual average rainfall ranges from 900 mm to 1,200 mm, while the average annual temperature ranged between 25°C to 30°C within the period from 1998 to 2017. The largest portion of the basin area, i.e., about 89%, is located in Benin; 10% is situated in the western part of Nigeria, while 1% lies on the eastern fringe of Togo (Bossa, 2012).

The upper Oueme River basin is a sub-basin in the Oueme River catchment. It has a drainage area of 14,400 square kilometers. The sub-basin is located in the Sudan climate zone and is characterized by a single rainy season with an average rainfall of 1150 mm/year. The bulk of the rainfall occurs during the monsoon period between April and October. The average runoff is about 150 mm/year (Getirana et al., 2014). The geomorphology of the catchment is characterized by a flat, undulating pediplain relief with altitudes from 227 to 616 meters above sea level. The geology of the study area is mainly characterized by a Precambrian basement, which predominantly consists of complex granulites and gneisses. The dominant soil type is Luvisols and reflects stable geological conditions. The texture of the various soil types encountered is mainly composed of loam, clay, clay-loam, sandy-loam and sandy-clay-loam (Lawin et al., 2019). The land cover in the watershed is 80.7 % forest, 18.9 % croplands, and 0.3 % urban. The major crops grown in the catchment are corn, cassava, yams, and sorghum (Olusanya et al., 2021). Fig. 1 shows the study area.

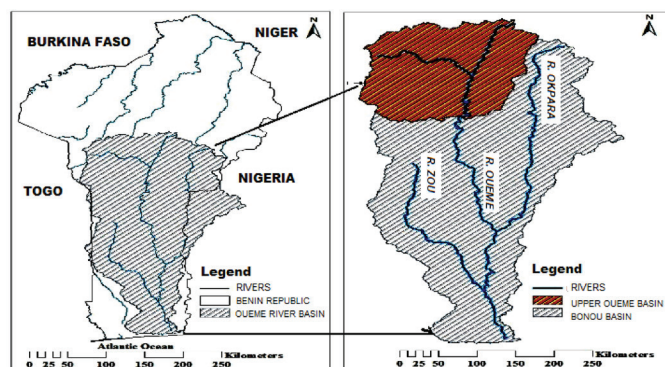


Fig. 1 Location of the Oueme River catchment area.
(Adapted: www.mapwindow.com)

3 MATERIALS AND METHOD

3.1 Methodological framework

A hybrid framework was adopted in this study. Adeyemo and Olofintoye (2012) reported the success of several applications of hybrid models in resolving water management problems. The authors also noted that the development of hybrid systems, which blend existing models into a coherent solution framework that provides useful tools to aid in critical water management decisions, has been found propitious. Therefore, the application of hybrid models in the solution of water resources problems is encouraged (Olofintoye et al., 2016).

The hybrid framework applied in this study involves the combination of a Geographic Information System (GIS) software and SWAT. The GIS interface used was Map-window. This interface was chosen based on its ease of use and reported capability to effectively simulate the hydrology of a catchment with a high degree of accuracy when used in combination with a suitable plug-in (Tetsoane, 2013). Documentation on the software may be found at MapWin (2021). A plug-in that facilitates the incorporation of SWAT in the Map-window software environment is Map-window SWAT (MWSWAT). Documentation on the plug-in is available at TAMUSWAT (2021). In the workflow of the study,

MWSWAT takes spatial data sets as the input and processes them in conjunction with the Map-window preprocessor to delineate the watershed and demarcate the Hydrological Response Units (HRUs) within the watershed. The HRUs and weather data are further processed by the SWAT engine to simulate the streamflow. During the calibration and validation, the simulated streamflow is compared with the observed streamflow, and the model parameters are adjusted until an acceptable calibration is achieved. The calibrated model is then used to estimate the water balance and yield of the catchment. This workflow is depicted in Fig. 2.

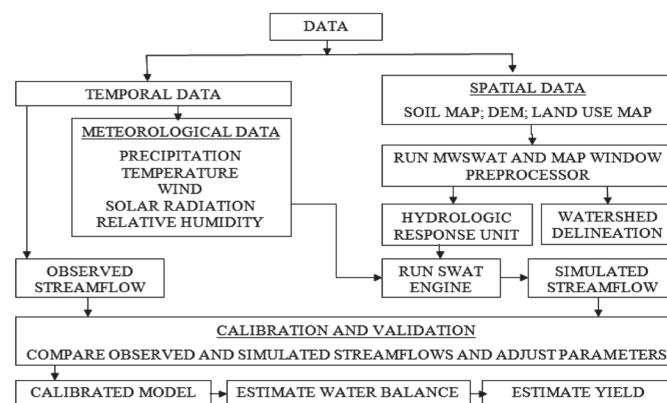


Fig. 2 Methodological workflow diagram of the modeling process

3.2 Data collection

The types of data required for the study are spatial and temporal data. The spatial data are topographical, i.e., a Digital Elevation Model (DEM) and soil and land use maps. These were employed to delineate the catchment area, demarcate the HRUs, and show the type of soil and land use/cover respectively. The watershed area is 14,236.73km² at a mean elevation of 355.09m with a slope of 0.99. The temporal data used are meteorological and streamflow data. The meteorological data include the daily precipitation, temperature, solar radiation, wind speed, and relative humidity. These were used in conjunction with the HRUs as an input to the SWAT engine to determine the hydrological response (simulated streamflow) of the catchment. Where there are gaps in the dataset, a weather generator embedded in SWAT (developed by Schuol and Abbaspour, 2007) was used to estimate the missing data. The streamflow data was acquired for the calibration and validation of the model.

The spatial data maps of the study area are presented in Fig. 3. Fig. 3a presents a 90 x 90 m resolution topographical data extracted from the Shuttle Radar Topography Mission (SRTM) website (<http://srtm.csi.cgiar.org/>). The site archives digital elevation data for major parts of the world. These archives have been preprocessed to fill data voids and to facilitate its ease of use by a wide range of potential users. This was done in an effort to encourage the applications of geospatial science methods for sustainable development and resource conservation in the developing world. The DEM provides the basis for watershed delineation into sub-basins. Also, topographic parameters such as the terrain slope, channel slope, and reach length are evaluated using the DEM. The land use maps (Figs. 3b and 3c) for the area were extracted from the Global Land Cover Characterization (GLCC) database (<http://edcns17.cr.usgs.gov/glcc/glcc.html>). This database is maintained by the United States Geological

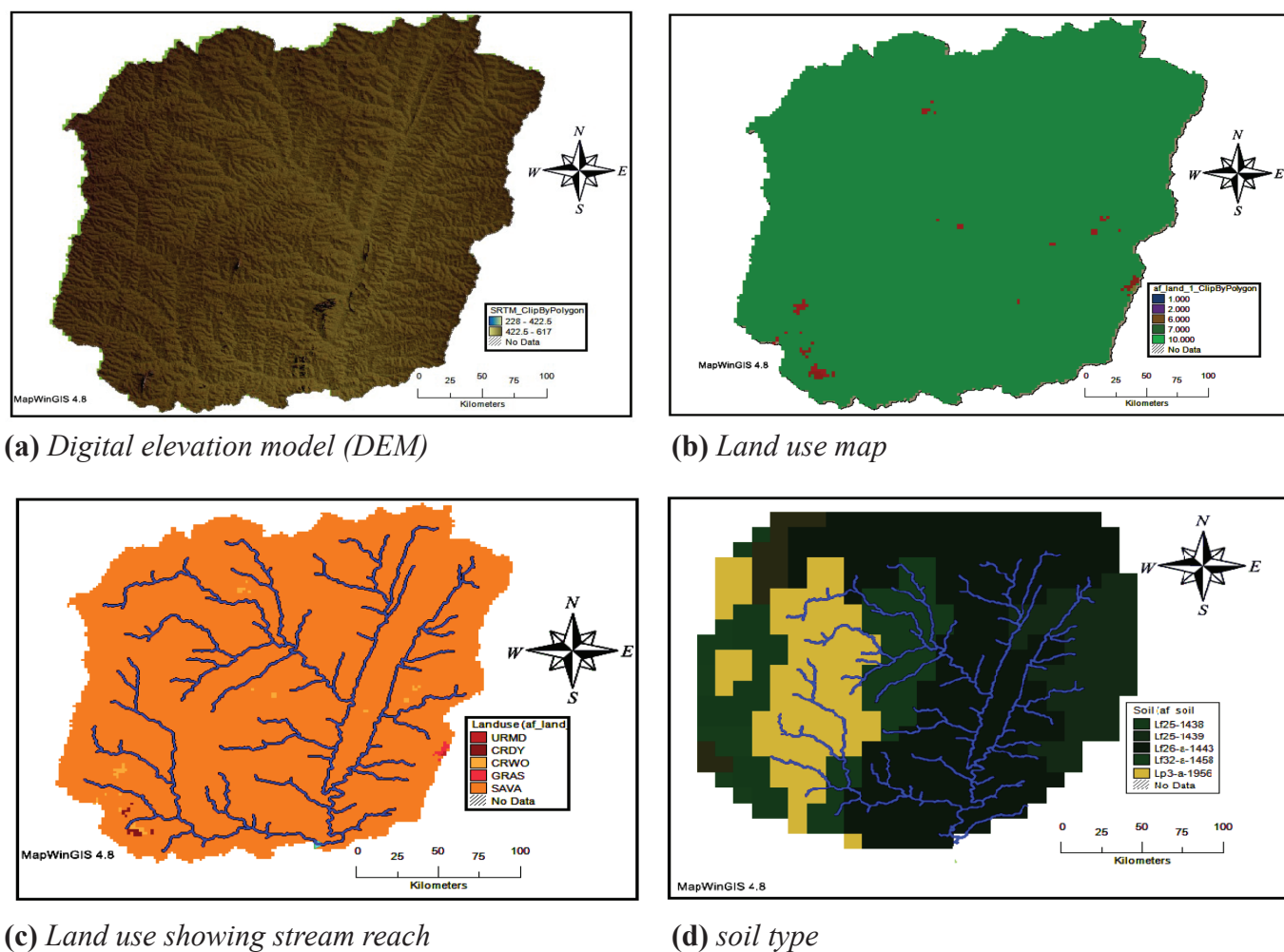


Fig. 3 Spatial data maps of the Upper Ouémé River Catchment.

Tab. 1 The land use distribution in the study area

S/N	SWAT Code	Description	Area(ha)	%Watershed
1	SAVA	Savannah	894687.98	60.5
2	CRWO	Cropland/Woodland	492448.10	33.3
3	GRAS	Grass Land	26618.81	1.8
4	URMD	Urban and Built-Up Land	14788.23	1.0
5	CRDY	Dry Land, Cropland, and Pasture	50279.98	3.4

Survey. The GLCC has a spatial resolution of 1 Km and 24 classes of land use representations, which provided the basis for estimating the vegetation cover in the watershed. Tab. 1 shows the land use distribution in detail. The soil map for the study area (Fig. 3d) was obtained from the Harmonized Digital Soil Map of the World (HWSM). These maps were produced by the Food and Agriculture Organization of the United Nations and were completed in January 2003. The database provides data for 16,000 different soil mapping units containing two layers (depths of 0 - 30 cm and 30 - 100 cm). Tab. 2 shows the soil distribution in the study area.

Tab. 2 The soil type distribution in the study area

S/N	SWAT Code	Description	Area(ha)	%Watershed
1	Lf26-a-1443	Sandy-Clay-Loam	743897.0	49.69
2	Lf25-1438	Sandy-Clay-Loam	237453.8	15.86
3	Lp3-a-1956	Sandy-Clay-Loam	336304.1	22.46
4	Lf25-1439	Sandy-Clay-Loam	156459.4	10.45
5	Lf32-a-1458	Sandy-Clay-Loam	208.77	0.01

The meteorological data were obtained from the Benin Meteo Agency for the Parakou weather station, which is located at 2.60° N, 9.35°E. The monthly streamflow data from the stream gauging station located at Bétérou for the years 2003–2009 was collected from the National Directorate of Water (DG-Eau) of Benin. This was used for the calibration of the model. Tab. 3 presents the data used in this study, while Tab. 4 presents the monthly averages of the variables at the Parakou weather station.

Tab. 3 Model input for the upper Ouémé river catchment area.

S/N	Data type	Description	Resolution	Source
1	Topography	Digital Elevation Model	90×90 m	Radar Topographical Mission Shuttle
2	Land Use Map	Land Use Classification	1 km	Global Land Cover Classification, Satellite Raster
3	Soil Map	Soil Type and Texture	10 km	Digital Soil Map of the World
4	Weather	Daily Precipitation, Temperature, Relative Humidity, Wind Speed, Solar Radiation	Daily	Benin Meteo Agency
5	Streamflow	Monthly stream flow	Monthly	National Directorate of Water

Tab. 4 Monthly averages of the variables at the Parakou weather station (1998 – 2017)

Variable	J	F	M	A	M	J	J	A	S	O	N	D
Precipitation (mm)	3.3	9.5	34.2	77.5	134.1	168.1	176.4	206.5	216.2	107.3	8.7	2.1
Solar Rad/day (h)	8.1	8.2	7.5	7.7	7.3	6.4	4.8	3.8	5	6.8	8.3	8.5
T max (°C)	38.2	39.4	39.9	39.3	36.9	34.3	32.9	32.2	33.0	34.7	36.6	37.0
T min (°C)	17.1	19.4	21.2	20.8	20.3	19.6	19.9	19.8	19.5	20	19.1	17.0
RH max (%)	89.8	90.1	90.1	95.3	96.6	97.2	97.4	97.7	98.0	97.4	96.7	92.0
RH min (%)	8.2	7.9	11.4	23.2	37.0	46.6	51.8	55.3	52.4	35.4	14.4	9.8
Wind sp (m/s)	2.2	2.1	2.3	2.5	2.3	2.1	2.0	1.9	1.7	1.8	1.9	2.2

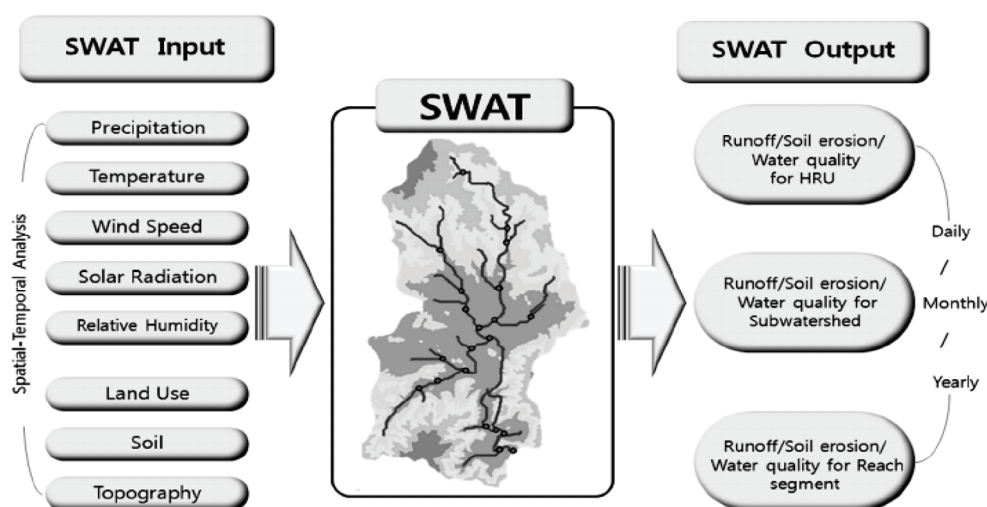
3.3 Configuration of the model for the hydrological simulation

SWAT is a semi physically-based model, which can model a number of sub-basins based on a given digital elevation model map instead of using regression equations to describe the input-output relationship. The model simulates surface and subsurface processes by accounting for vadose processes. Runoff volume is calculated using the Curve Number (CN) Method, and the sediment yield is calculated using a modified universal soil loss equation. The routing is done using the variable storage method or the Muskingum method. Extensive details of the model may be found in the literature (Neitsch et al., 2011; Arnold et al., 2012; TAMUSWAT, 2021). Fig 4 gives an overview of the SWAT model.

Configuring the model for a hydrological simulation involves adjusting the relevant settings in the software's interface. The settings to be adjusted may include the period of simulation, the location of the spatial and weather database files, and the methods of computing hydrological variables (which may be optimized). In this study, the simulation period was from January 1, 1998, to December 31, 2017 (20 years). A total of 147 sub-basins were created and further divided into 174 HRUs.

3.4 Calibration and validation of the model

SWAT provides different methods for estimating hydrological variables. For example, the Priestley, Penman-Monteith or

**Fig. 4** Overview of the SWAT model (Heo et al., 2008)

Tab. 5 Performance ratings for the recommended statistics for calibrating the monthly time step (Moriassi et al., 2007)

Performance Rating	PBIAS (%)	RSR	NSE
Very good	$PBIAS < \pm 10$	$0.00 \leq RSR \leq 0.50$	$0.75 < NSE \leq 1.00$
Good	$\pm 10 \leq PBIAS < \pm 15$	$0.50 \leq RSR \leq 0.60$	$0.65 < NSE \leq 0.75$
Satisfactory	$\pm 15 \leq PBIAS < \pm 25$	$0.60 \leq RSR \leq 0.70$	$0.50 < NSE \leq 0.65$
Unsatisfactory	$PBIAS \geq \pm 25$	$RSR > 0.70$	$NSE \leq 0.50$

Tab. 6 Optimization of the model parameters

SWAT Code (Parameter)	Description	Method	SWAT-Value	Decision Variable range
IPET	Potential Evapotranspiration	Priestley	0	0 - 2
		Penman/Monteith	1	
		Hargreaves	2	
IEVENT	Run off	Curve Number	0	0 - 1
		Green/Ampt	1	
IRTE	Routing	Variable	0	0 - 1
		Muskingum	1	

Hargreaves methods are available for estimating potential evapotranspiration; the Curve Number or Green and Ampt methods are available for estimating surface runoff; while the Variable or Muskingum methods are available for channel water routing. These were used as parameters in calibrating the model. The Actual Evaporation is computed as a function of the Potential Evaporation by the SWAT model internally.

Manually calibrating a physically-based process model involves iteratively adjusting the parameters of the model until the discrepancy between the model output (simulated data) and the observed (measured) data is at a minimum, or until a test statistic, which is evaluated based on this discrepancy, falls within an acceptable range (Moriassi et al., 2007). However, caution must be exercised to ensure that the range of values employed for the parameters during calibration is plausible. This is necessary to ensure the applicability of the calibrated model afterwards when assessing the impacts of changing scenarios in the management options (Stehr et al., 2008). Moriassi et al. (2007) suggests the use of three statistics in evaluating the model's performance; i.e., the standard deviation ratio (RSR), the Nash–Sutcliffe efficiency (NSE), and the percent bias (PBIAS). These may be employed as objective functions in optimizing the model. These statistics and the coefficient of determination (R^2) were employed to evaluate the model's performance in this study. The rating for the performance of the model, which was calibrated on a monthly time-step and based on these statistics, is presented in Tab. 5.

Since the aim of this study is to demonstrate the applicability of SWAT in the basin, a manual calibration approach (Moriassi et al., 2007) was adopted. A constraint satisfaction combinatorial optimization problem, in which the parameters for computing the variables are adjusted until the NSE and PBIAS falls within a very good or good range, was adopted. The optimization model parameters are given in Tab. 6.

The SWAT model was calibrated for the upper Oueme river watershed using the observed streamflow at the Beterou gauging station. Streamflow data from January, 2003, to December, 2005, was used as the calibration set, while data from January, 2006, to December, 2009, was used as the validation set. The simulation in SWAT was based on a daily time-step; therefore, the simulated

daily streamflows were aggregated to monthly flows to enforce the calibration in the monthly time-step.

4 RESULTS AND DISCUSSION

4.1 SWAT parameters settings

The settings determined from the calibration are as follows: the Run-off Curve Number (CN) method was employed to estimate the surface runoff from precipitation (IEVENT=0); the Penman-Monteith method was selected for estimating the potential evapotranspiration (IPET=1), while the variable storage method was chosen to simulate the channel water routing (IRTE=0).

4.2 Evaluation of the model's performance

The computed values of the test statistics used for the model's evaluation are presented in Tab. 7 for both the calibration and validation datasets. Fig. 5 presents a pictorial view of how well the simulated data fits the observed data during the calibration and validation.

An inspection of Fig. 5 shows a good fit between the simulated and observed streamflow data. Also, the NSE values are greater than 0.65; the values of RSR are greater than or equal to 0.5; while the PBIAS values lie in the range $\pm 10\% \leq PBIAS < \pm 15\%$, for both the calibration and validation periods. This indicates the good performance of the model (See row 2 of Tab. 5).

The fit here is not as close as that reported by Emmanuel et al., (2018) using the LISFLOOD model (NSE=0.92 for calibration

Tab. 7 Values of the performance statistics for the calibration and validation data sets.

Test Statistics	Data Set Calibration	Validation
NSE	0.66	0.75
RSR	0.58	0.50
PBIAS	-14.00%	-11.90%
R^2	0.78	0.78

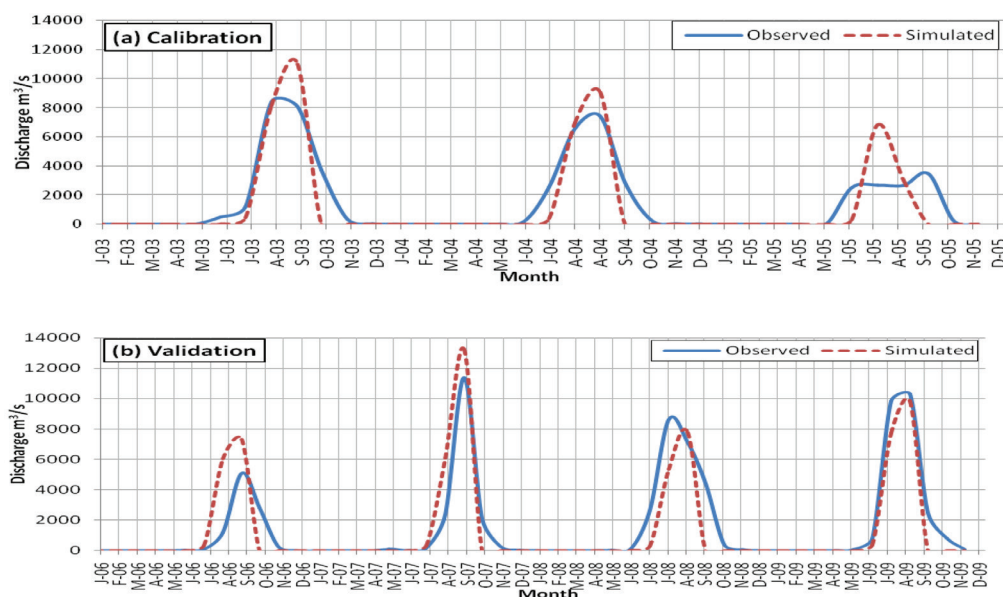


Fig. 5 Fit of observed and simulated monthly streamflow for the (a) calibration and (b) validation periods.

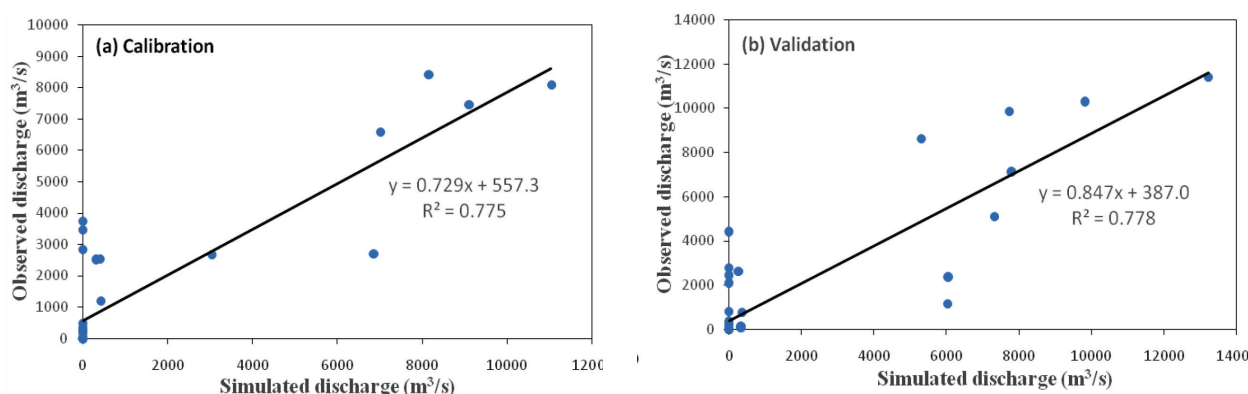


Fig. 6 Correlation between the observed and simulated monthly discharge for the (a) calibration and (b) validation periods.

and $NSE=0.95$ for validation). This may be due to differences in the periods employed for the model's calibration and the differences in the types and number of model parameters and other possible random variables. Since both studies employed the manual calibration approach, the performance of one model over the other may not be established until rigorous statistical tests are performed. This is beyond the scope of this study. However, the better performance during validation than during calibration that was observed in the study is also the case in the present study.

A study by Getirana et al. (2014) in the study area also produced $NSE=0.9$ for both the calibration and validation. However, the ISBA model employed was optimized using a multi-objective complex evolution global optimization algorithm. The values of NSE in this study suggest a closer fit than the study by Olusanya et al. (2001), who calibrated a SWAT model using remotely sensed data in the region and obtained $NSE=0.55$ during calibration and $NSE=0.51$ during validation. The results however were satisfactory.

Negative values of the PBIAS may be obtained in cases where a model overestimates the observed data. However, the errors in the estimates in this study are negligible as the value of the statistics lies in the range of a good fit (Tab. 5). Furthermore, the regression analyses of the observed versus the simulated data (Fig. 6) for the calibration and validation periods show good

relationships between the dataset as indicated by the R^2 values of approximately 0.78 in both cases.

The manual approach adopted in this study may constitute a serious limitation. Overall, the model developed in this study compares well with models that have been applied in the area. The aim of this study is to demonstrate the applicability of the model in the area and not involve a rigorous comparison of the model's performance. Since the performance of the calibrated model falls in a good range, the model is therefore adopted for the remaining part of this study.

4.3 Application of the results

Following the successful calibration and validation of SWAT, the model was applied to estimate the water balance components of the river basin and subsequently the water yield.

4.3.1 Estimation of the water balance

The estimation of the Upper Oueme River catchment water balance components was done on an annual basis for 20 years

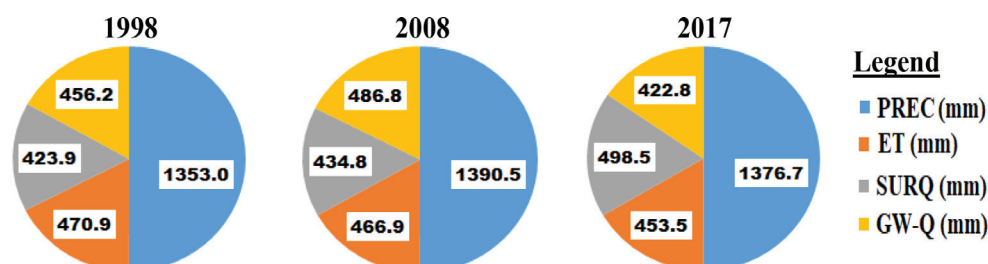


Fig. 7 Pie charts showing the water balance in (a) 1998, (b) 2008 and (c) 2017

(1998 to 2017). The main components of the water balance in the river basin are: the total amount of precipitation (PREC) in the basin in a year, the actual evapotranspiration (ET) from the basin, and the net amount of water that appears as streamflow out of the basin (the water yield). The SWAT simulation outputs (measured in mm) are: (ET), surface runoff (SURQ), groundwater flow (GW-Q) and lateral flow (LAT-Q). Pie charts showing the water balance for the years 1998 (the beginning of the simulation period), 2008 (a year around the middle of the simulation period), and 2017 (the end of the simulation period) are presented in Fig. 7 a–c respectively.

It was observed that the lateral flow contributions to the river flow were negligible in all the cases and is therefore not a component in the pie charts. Lateral flows are usually high where an impervious layer is close to the surface and the slope of the area is high (Reddy, 2014). The contrary, however, exists in the study area. The loose nature of the soil (see Tab. 2) combined with the gentle slope of the area (less than 3%) reduces the potential for lateral flows. Also, farming activities in the area have further loosened the top soil.

In 1998, approximately 35% of the precipitation within the basin was lost through ET, while about 31% and 34% were converted into surface runoff and base flow respectively. Around 34%, 31% and 35% of the rainfall, respectively, appeared as ET, SUR-Q, and GW-Q in 2008, while about 33%, 36% and 31% of the precipitation, respectively, appeared as ET, SUR-Q and GW-Q in 2017.

In order to facilitate a comparison of the water balance obtained in this study with an earlier study in the basin (Getirana et al., 2014), the water balance over a period of 4 years (2005–2008) was estimated. In this study, approximately 41% of the precipitation within the basin is lost through ET, while about

27% and 32% are converted into surface runoff and the base flow respectively. The values here are different from those obtained in the earlier study, which reported 72%, 5% and 23% respectively for ET, SUR-Q and GW-Q. It should be noted, however, that the water balance in the earlier study was estimated over 5 stations, while the water balance in this study employs a single station. Moreover, the authors reported that the LSM method employed in estimating the water balance in the study is not an appropriate approximation for the river discharges in the tropical region. Therefore, the calibrated SWAT model in this study is adopted for further evaluations. However, the high rate of evapotranspiration observed in the earlier study is also noted herein. This high rate of ET in the basin may be attributed to the significant vegetal cover (see Tab. 1), the high temperatures and the high volumes of water available at the root zone due to high percolation as indicated by the large volume of the groundwater flow. While the potential surface runoff in the Upper Oueme River watershed may not be particularly high, the high volume of sub-surface water (about 34%) suggests that the development of sub-surface water is a viable alternative source of water resources for the inhabitants of the study area.

4.3.2 Estimation of the water yield

The water yield potential of a basin is one of the important parameters that need to be estimated for efficient water management. Knowledge of this data may assist managers in planning and predicting the possibilities of water shortages in the future. In SWAT modeling, the water yield may be considered as the total amount of water leaving the HRUs and entering the main stream channel during the time step (Adeogun et al., 2014).

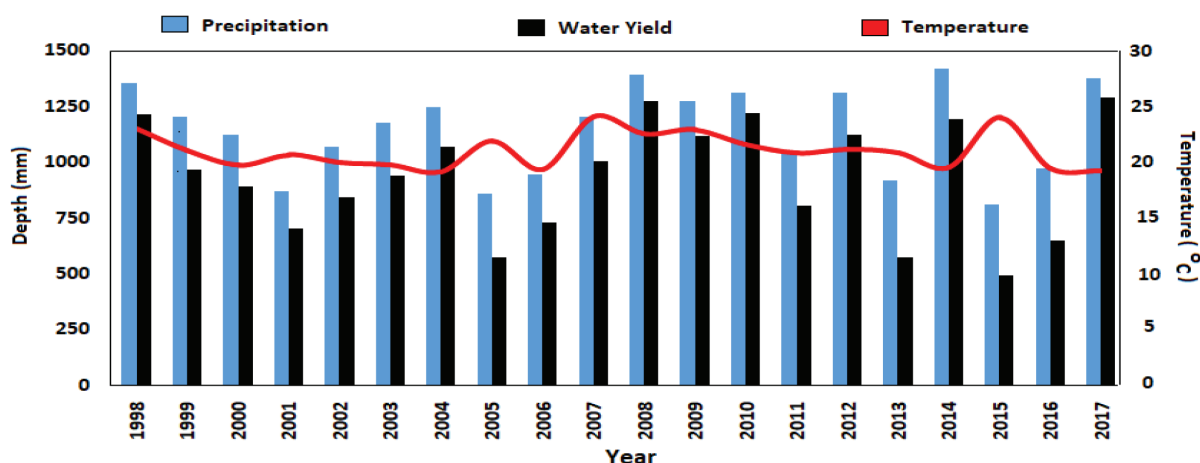


Fig. 8 Plot of the Annual Water Yield from 1998 – 2017

The contributions of each sub-basin in the watershed to the water yield during the period of the simulation were examined using the calibrated SWAT model. A cumulative amount of 18,671.61 mm of water was estimated as the potential water yield of the basin over the period of the simulation (1998–2017). This suggests that subsistence agriculture is sustainable in the area.

The distribution of the annual water yield in the basin was also investigated. A plot showing variations in the water yield over the simulation period is presented in Fig. 8. It was observed that the maximum yield (1,289.1 mm) occurred in 2017, while the minimum (492.7 mm) occurred in 2015. It may be inferred that 2015 was a dry year with a low precipitation record in the catchment.

5 CONCLUSION

This study investigated the applicability of SWAT in estimating the water balance and yield by simulating the hydrological processes and responses within a river basin. The model was calibrated and validated using the monthly streamflow data from the Beterou River gauging station and subsequently

employed to estimate the water balance and yield of the Upper Oueme River Basin. A close fit between the simulated and observed streamflow data during the calibration and validation suggests a good model performance. This was further established by the values of the standard test statistics ($NSE > 0.65$, $RSR \leq 0.5$, $\pm 10\% \leq PBIAS \leq \pm 15\%$ and $R^2 > 0.75$) lying within good acceptable ranges. Overall, the model was able to predict the water balance and yield in the study area satisfactorily. The results showed that once the SWAT hydrological model is effectively calibrated, it can be a useful tool for accurate hydrological predictions to aid in management decisions.

The surface runoff potential of the catchment was moderate; however, substantial sub-surface water components suggest that sub-surface water development is viable as an alternative potential water resource for the basin. Although the surface runoff is moderate, Emmanuel et al., (2018) has noted that the Oueme River at the Beterou outlet will experience increased discharges for all the time horizons until 2050 and for all the combined climate and land use change scenarios. This information on the future of water resources in the basin is an invitation to water resource managers to plan for design and mitigation strategies to cope with the negative effects of increased discharges.

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