AIMS Geosciences

AIMS Geosciences, 7(3): 338–354.
DOI: 10.3934/geosci.2021021
Received: 19 June 2021
Accepted: 12 August 2021
Published: 16 August 2021

http://www.aimspress.com/journal/geosciences

Research article

Hydrological response to land use and land cover changes in a tropical West African catchment (Couffo, Benin)

Quentin Fiacre Togbévi* and Luc Ollivier Sintondji

Laboratory of Hydraulics and Water Management, National Water Institute, University of Abomey-Calavi, Benin

* **Correspondence:** Email: f.togbevi@gmail.com; Tel: +233541571132.

Abstract: This study evaluated the impact of land use and land cover changes on the water balance of the Couffo catchment (Benin) using the Soil and Water Assessment Tool (SWAT). To that end, soil, land uses, hydro-meteorological data including rainfall, temperatures (maximum and minimum), wind speed, solar radiation, relative humidity and discharge data were used as main inputs. To assess the impact of land uses on the catchment water balance, three different land uses (2000, 2006 and 2011) were used. Results showed that from 2000 to 2011, croplands and fallows increased by 34% while the shrub and grass savannahs decreased respectively by 34 and 24%. In addition, agroforestry and gallery forest decreased by 63% and 58% respectively while a rapid increase in settlement. The study outcome suggested that the SWAT provided satisfactory results for discharge with R^2, NSE, KGE and absolute percent of bias (absPBIAS) ranged between (0.7–0.9), (0.6–0.9). (0.6–0.9) and (5.3–34) respectively. Moreover, the evaluation of land use and land cover changes on the catchment water balance resulted in an increase in annual surface water and water yield, while the groundwater and actual evapotranspiration (ETa) have decreased. Findings of this study may be a great contribution to water resource management in the Couffo catchment. This may contribute to better allocate water for the actual catchment population demand without dampening those of the future generation.

Keywords: hydrological modelling; land use and land cover; SWAT; water balance; Couffo catchment; Benin

1. Introduction

West African countries, and particularly Benin, face a large discrepancy between the renewable water supply and the availability of water for household, agriculture and industrial purposes. This situation is a result of many constraints. The physical constraints emanate from the annual shift between wet and dry seasons and the socio-economic and institutional constraints arise from inadequate infrastructures leading to insufficient use of the available freshwater [1].

Rapid population growth along with agricultural intensification causes significant land use change in many West African catchments [2–5]. However, climate and land use changes already have a considerable impact on the hydrological cycle over West African countries [6–8]. These issues include the increase in population growth, the increasing demand of land for production, settlement, and agriculture to cover the food needs of this growing population [9]. The observed changes in land use and land cover (LULC) may have devastating impacts on water balance in the catchment. Indeed, several studies have shown that changes in LULC due to the increase of anthropogenic activities (e.g., agriculture, urbanization, overgrazing) are one of the main factors of change in water balance [10–13].

To determine the impacts of such changes in the hydrology of the catchment, simulating the different components of the water budget has gained much importance. In fact, for more than a decade, the quantification of the effect of LULC changes on hydrology has been considered as an area of interest for many hydrologists. Thus, several modelling approaches have been applied in tropical catchments. These approaches include the study of Leemhuis et al. [14] Indonesia's catchment, the study of Andersen et al. [15] on the Senegal river basin and the study in Terou catchment (Benin) [1,16]. In that respect, the number of modelling exercises has increased rapidly, with studies undertaken in the Oueme sub-catchments (Benin) [5,17–19] and in the White Volta basin [4,6,20,21] and in Dano catchment [3] as well as in the Couffo catchment (Benin) [22] and in Ghana, particularly in the Bonsa catchment [2] and Owabi catchment [23].

For example, Hosseini et al. [24] have evaluated the effects of land use change impacts on water balance in Taleghan catchment in Iran and reported an increase in surface runoff while groundwater and interflow decreased. In a tropical catchment of central Uganda, Gabiri et al. [25] assessed the impact of land use management on water resources using the SWAT2012 and the SWATgrid models. Their results indicated a strong relationship between land use conservation options and with a decrease in surface runoff, annual discharge and water yield while the opposite observation was shown with the continuous exploitation option. In addition, Aduah et al. [2] who investigated the impacts of land use change on the hydrology of the lowland rainforest catchment in Ghana achieved the conclusion that streamflow increased up to 37% due to a decrease in forests of about 39%. Added to that, a decrease in surface runoff and groundwater with savanna and grassland in Volta basin was observed [4]. In Dano catchment (Burkina Faso), a study of Yira et al. [3] using WaSiM model, showed an increase in total discharge (up to 17%) with a decrease in evapotranspiration (−5%) due to land use changes. In Benin, limited studies focused on LULC change on the catchments' hydrology. For example, Cornelissen et al. [1] have used different four hydrological (Water balance and Simulation Model, SWAT, UHP-HRU and GR4J) models to evaluate the impact of land use and climate changes on the discharge of West African catchments. All these models have simulated an increase in surface runoff due to land use change. For example, Bormann [12] found that land use is one of the main environmental changes that affected long-term water balance in Oueme basin (Benin).

In recent years, different methodologies have also been used in Benin in attempting to better understanding the hydrological process occurring within catchments [1,5,26–28]. Table 1 summarizes relevant studies of LULC impacts on hydrology in tropical regions.

To achieve effective and sustainable use of land and water resources, many comprehensive tools are used. Since field data collection is costly and time-consuming, many modelling approaches have been developed to assess the land and water interactions and to quantify the potential effects of LULC change on the catchment hydrology process. This may, therefore, contributes to providing forecasts for the future. One of the comprehensive hydrological models for this exercise is the SWAT model developed by Arnold et al. [29], which is used for this study. Some studies in Benin have used SWAT model in assessing LULC change on water balance [1,5,26,30]. Although the previous attempted to assess the relationship between land use dynamics and water balance, few of them have considered the related impact of LULC changes on water balance. The objective of this research is to evaluate the performance of the hydrological model SWAT for the Couffo catchment in simulating the water balance at the catchment outlet in view of evaluating the impact of land use changes.

2. Materials and methods

2.1. Study area

The Couffo catchment (Figure 1) is located between the latitudes 7°0′ North to 14°50′ North and longitudes 1°30′ East to 1°3′ East, and covers an area of 1664.4 km^2. Rainfall is characterized by two seasons: a dry season from November to March and the rainy one from April to October with a peak flow of rainfall in July-August. The annual rainfall average ranges between 1200–1300 mm from 1959 to 2018 and the mean annual temperature is about 31°C. The catchment is drained by the Couffo river with a length of 190 km. The vegetation of the catchment includes agricultural land, savannah and wetland with *ferralsols*, *gleysols*, *lixisols* and *vertisols* as main soil types.

Table 1. Summary of relevant studies of land use impacts on hydrology in tropical regions.

Authors	Study area/Study size	Data/model used	Key results
Gietz *et al.* [31]	3 catchments, Benin/3–16 km^2	Field measurements of soil hydraulic properties, gauge data, SIMULAT-H	(1) Good model performance achieved using discharge and soil moisture (2) Land use proved to be a major factor in runoff generation process
Yira et al. [3]	Dano catchment, Burkina Faso/195 km^2	SRTM 90 m, LANDSAT and RapidEye derived maps, gauge data (Climate, discharge, soil moisture, groundwater), National climate dataset, field measurements of soil hydraulic properties/ WaSiM	(1) Annual decrease in savanna area up to 2% since 1990 (2) 5% increase in discharge was due to LULC change
Cornelissen et al. [1]	Terou catchment, Benin/2344 km^2	Gauge data, Landsat data, SRTM 90 m, /WaSiM, SWAT, UHP-HRU, GR4J	(1) All models achieved good performance (2) Increase in discharge due to the increase of agricultural land
3- Sintondji et al. [22]	Couffo catchment, Benin/1657.67 km^2	Gauge data, Landsat data, SRTM 90 m, /SWAT	(3) Decline in natural vegetation due to expansion of agriculture (4) Loss of rainfall through evapotranspiration
Diekkruger et al. [19]	Oueme catchment, Benin/from local to large scale	Field measurements of infiltration rate, gauge data, SRTM 90 m/SIMULAT-H, UHP-HRU, SWAT	(1) Good model performance achieved (2) High correlation between LULC and runoff coefficient
Awotwi et al. [4]	White Volta basin/Burkina Faso and Ghana	Landsat data, gauge data, SRTM 90 m/SWAT	(1) Decrease in savanna due to increase in in agricultural activities (2) Surface runoff and groundwater decreased with savanna and grassland conversion to cropland
Aduah et al. [2]	Bonsa catchment. Ghana/1482 km^2	Landsat data, gauge data, ACRU model	(1) Increase in streamflow up to 37% due to the decrease in evergreen and forest and increase in settlement and mining areas
Osei et al. [23]	Owabi catchment, Ghana/69 km^2	Landsat data, gauge data, SRTM 30 m/SWAT	(1) Forest and topography have major role in water loss (2) Evaporation and surface runoff were the dominant processes
Hosseini et al. [24]	Teleghan catchment, Iran/800.5 km^2	Landsat data, gauge data, STRM 85 m/SWAT	(1) Model achieved good performance (2) Increase in surface runoff (up tot 7.3%) and decrease in lateral flow and groundwater (11.3 and 11% respectively) due to change in LULC

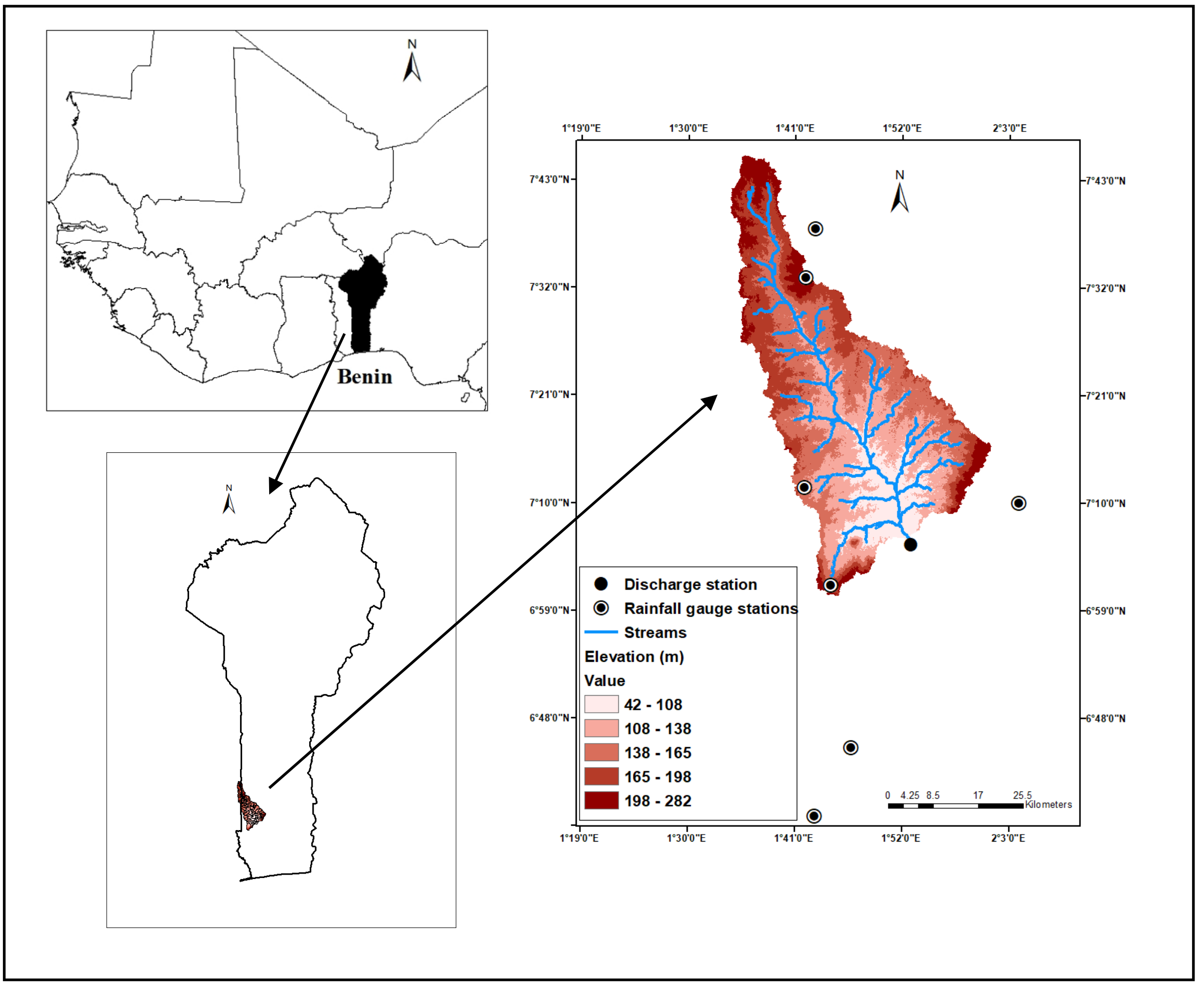


Figure 1. The Couffo catchment at Lanta outlet.

2.2. *Land use and land cover assessment*

LULC dynamics were analysed using Landsat images from Landsat ETM+ (Enhanced Thematic Mapper). The images were downloaded from the United States Geological Survey (USGS) data centre (https://earthexplorer.usgs.gov/). Three years (2000, 2006, 2011) were considered. The images were at 30 m spatial resolution and were acquired approximately at the beginning of the dry season (November-December). The choice of this period was due to the advantage of low cloud cover during the dry season and possible maximum photosynthetic activity. In addition, the contrast between the natural environment and the croplands can be more distinguished at the beginning of the dry season [32]. The ground truth survey was carried out within the watershed in the same season. The Global Positioning System (GPS) was used for training identification across the watershed. Thus, 90 points within the different land use classes were used for training and 60 points for image validation. The various homogenous units from the different images were identified and geo-rectified to the projected coordinates system (UTM WGS 84 Zone 31 North) of the study area. The coloured compositions were created by combining channels 4 for the infrared, 3 for the red and 2 for the green. After checking the normal distribution of the images, the maximum likelihood algorithm was used for supervised classification of the images. This method of classification was used because the study area was well known. The determination of the number of image classes was based on the supervised classification and the data collection from the field. The confusion matrix of each image was generated in order to determine the accuracy of the classification. The kappa coefficient was adopted to measure the degree of agreement. It is commonly used to assess the differences between different LULC maps. All image processing including geometric, radiometric and atmospheric corrections through a raster calculation tool were done using Envi version 5.0. ArcGIS version 10.2 was used to produce LULC maps for the different images.

2.3. Description of SWAT model

The SWAT model is a continuous, long-term and semi-distributed model that simulates surface flow, soil erosion, sediment loadings and the movement of nutrients through catchments [29]. The model uses the Digital Elevation Model (DEM), soil and land use data as main inputs. SWAT subdivides the catchment into sub-basins based on the DEM. After that, the model delineates the hydrological response units (HRU) which have unique combinations of slope, land use and soil types for each sub-basin [33]. In addition, the surface runoff, nutrient cycle, plant growth and management practices, and soil water content are simulated for each HRU. SWAT also requires daily climate data (rainfall, relative humidity, solar radiation, wind speed, and maximum and minimum temperatures from gauging stations. Among the methods used to estimate evapotranspiration, the one of Penman-Monteith is applied for evaporation estimation and to establish the water balance of each HRU.

SWAT uses Equation (1) to simulate the hydrological cycle [34].

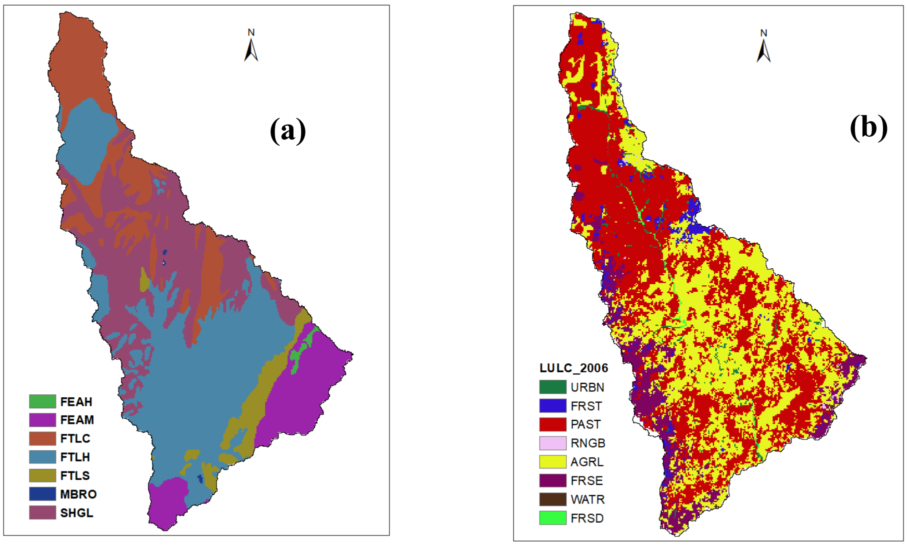
$$SW_f = SW + \sum_{i=0}^{t} \left[R_{day} - \left(Q_{surf} + ET + W + Q_{ground} \right) \right] \tag{1}$$

where SW_f is the daily final soil water content (mm); SW is the daily initial soil water content (mm); R_{day} is the daily rainfall (mm); Q_{surf} is the daily surface runoff (mm); ET is the daily evapotranspiration (mm); W is the daily percolation (mm) and Q_{ground} is the daily groundwater flow (mm) and t is the time (day).

2.3.1. Data sources

Hydrological modelling requires high-quality hydro-meteorological and hydrological data [35]. The lack of streamflow data was a major limitation of this study for model calibration and validation. Table 2 shows the type and source of applied datasets used in this study. Figure 2 shows the soil map and the LULC of the Couffo catchment. Eight dominant LULC categories and seven soil types were observed within the catchment (Figure 2).

The SWAT v2012 downloaded from (http://swat.tamu.edu/software/) and ArcGIS version 10.2 were used for this study. After the model run, a total area of 1664.4 km^2 catchment boundary was delineated, with 97 subbasins and 325 HRUs.



Soils		Land uses	
FEAH	Ferrasol	URBN	Settlement
FEAM	Lixisol	FRST	Gallery forest
FTLC	Luvisol	PAST	Savanna
FTLH	Vertisol	RNGB	Plantation
FTLS	Plinthosol	AGRL	Cropland
MBRO	Alisol	FRSE	Agroforestry
SHGL	Gleysol	WATR	Water bodies
		FRSD	Degraded forest

Figure 2. Soil map of Couffo catchment (a); Year 2006 LULC of Couffo catchment (b).

Daily rainfall was obtained from seven rain gauge stations, and wind speed, relative humidity, solar radiation and maximum and minimum temperature were obtained from the synoptic station of Bohicon (2003–2011).

Table 2. Applied datasets and required inputs for SWAT model.

Dataset	Resolution/scale	Required parameters	Source
Topography (DEM)	30m × 30m	Slope, sub-basins, channel, aspect, etc.	www.earthexplorer.usgs.gov
Soil map	1:25000	BD, Ksat, etc.	SOTER database (INRAB, Benin)
Land use maps	5–250 m	Soil units	https://earthexplorer.usgs.gov/
Land use characteristics	–	LAI, albedo, root depth, land use classes, etc.	Literature
Meteorological data	Daily (2003–2011)	Rainfall, temperature, relative humidity, solar radiation, wind speed	Benin Meteorological Agency
Discharge	Daily (2000–2011)	Discharge	Benin Water Agency

2.3.2. SWAT model calibration, validation and uncertainty analysis

Several parameters influence the catchment processes, leading thus to a large number of uncertainties related to the hydrological model outputs. The calibration is a process of adjusting a range of model parameters until the model outputs match closely as possible the behavior of the observation [43] based on defined objective functions. This procedure also includes the reduction of uncertainty. Among various techniques developed by researchers, the Sequential Uncertainty Fitting version 2 (SUFI-2) was used for this study to account for different types of uncertainties arising from the model parameters, conceptualization, and observed data [36,44–45]. SUFI-2 is selected due to its ability to estimate both parameter and uncertainties in hydrological models [36]. A total of 17 parameters were chosen during the calibration process. Table 3 shows the objective functions used in evaluating the overall model performance along with their required satisfactory thresholds following Moriasi et al. [37]) and Abbaspour [36].

The sensitivity analysis was done using the Global sensitivity test using the t-test, p-value and *p* and *r* factors as well for uncertainty analysis at 95% prediction uncertainty (95PPU).

Table 3. Model performance indices and their optimal thresholds for discharge (following Moriasi et al. [37]) and Abbaspour [36]).

Objective function	Threshold
p-factor	≥0.70
r-factor	Closer to 0
t-stat	Larger absolute value
p-value	≤0.50
R^2	≥0.50
NSE	≥0.50
KGE	≥0.50
PBIAS	±25%

The p-factor indicates the percentage of the measured data that is captured by the 95PPU. The best performance is achieved when p-factor is equal to 1. For the r-factor which shows the calibration quality, better performance is achieved with a value of 0, implying the correct fit between the measured and observed streamflow or discharge [38]. Other model performance indices used in this study included the Kling Gupta Efficiency (KGE), the percentage of bias (PBIAS) and the Pearson product-moment-correlation coefficient (R^2) [38].

To evaluate the effect of LULC on the blue water (BW) and green water (GW), the meteorological data for the entire simulation period and the soil datasets are being kept constant and the model was run using the land use maps separately. The following equations 2 and 3 below have been used to assess BW and GW:

$$BW = Q + deepAq \tag{2}$$

$$GW = ET_a + \Delta S \tag{3}$$

where BW and GW are respectively the blue water and green water resource, Q is the total runoff, *deepAq* is the deep aquifer recharge, ET_a is the actual evapotranspiration and ΔS is the soil moisture storage.

3. Results

3.1. Land use and land cover analysis

The overall accuracy assessment indicated a good classification. The Kappa index was 0.7 and the overall accuracy for the referenced image of 2011 was 0.8.

From the land use of 2000 and 2011, savannah and croplands were the most dominant LULC in the Couffo catchment (Table 4). In 2000, croplands and fallow areas occupied 50% of the total area while savannah occupied 30%. In 2011, croplands and fallow areas occupied around 70% of the total area (with an increase of 34% compared to 2000) while savannah areas decreased by about 26%.

Table 4. Land use and land cover of 2000 and 2011 with the percentage change (area in km^2).

LULC	Area 2000	Area 2011	% Change
Shrub savannah	121	80	−34
Gallery forest	106	45	−58
Grass savannah	408	312	−24
Agroforestry	158	59	−63
Croplands and fallows	850	1136	34
Bare-land	2	1	−48
Water bodies	10	12	19
Settlements	9	20	133

3.2. Streamflow of the catchment

For calibration analysis, 17 parameters that affect surface runoff and baseflow have been selected [38]. The selected parameters were chosen from the literature to reflect as much as possible the hydrological processes occurring in the catchment. The sensitivity analysis test showed that ten of the selected parameters regulated the outlet discharge in the catchment (Table 5). These included the curve number (CN2), the baseflow alpha factor (ALPHA_BF), the soil available water storage capacity (SOL_AWC), time required for water leaving the bottom of the root zone to reach the shallow aquifer (GW_DELAY), the minimum water level for baseflow generation (GWQMN), the deep aquifer percolation coefficient (RCHRG_DP), the groundwater "revaporation" coefficient (GW_REVAP), the Manning's "n" value for the main channel (CH_N2), the threshold water level in the shallow aquifer for "revaporation" to occur (REVAPMN) and the soil evaporation compensation factor (ESCO). Besides, ESCO and CN2 were found to be the most sensitive as reported by other studies in neighbouring catchments [4,22–23].

Table 5. Most sensitive parameters during streamflow simulation.

Parameters	Calibrated values	Fitted values	p-value	Rank
ESCO	[0; 1.5]	0.9	0.01	1
CN2	[−10; 55]	3	0.01	2
CH_N2	[0; 0.2]	0.1	0.09	3
SOL_AWC	[0.3; 1]	0.5	0.10	4
GW_REVAP	[0.5; 2]	0.1	0.17	5
GWQMN	[0; 8]	1.8	0.22	6
REVAPMN	[0; 5]	4.8	0.22	7
ALPHA_BF	[0.05; 0.7]	0.2	0.24	8
RCHRG_DP	[0; 0.5]	0.4	0.34	9
GW_DELAY	[0; 20]	17.9	0.43	10

3.3. SWAT model performance (calibration and validation)

The SWAT model was calibrated for five years (2003–2007) and validated for four years (2008–2011) with three years as warm-up period. The performance of the model was based on the statistical indices obtained during the simulation. The statistical indices included the Pearson product-moment-correlation-coefficient (R^2), the Nash-Sutcliffe model Efficiency (NSE), the Kling Gupta Efficiency (KGE) and the percentage of bias (PBIAS). *absPBIAS* refers to the absolute value of the PBIAS metric. During the calibration and validation, there was a consistency of the models' simulated discharge with the seasonal discharge and the rainfall pattern. Moreover, the SWAT model performance was satisfactory as shown by Table 6.

The water balance components for each LULC are presented in Table 7. The simulation outputs for different LULC during the calibration and validation processes are shown in figure 3. One can observe that the model treated the rainy months as dry periods where the amount of rainfall was lower (as well as for the discharge flow) and therefore overestimated the discharge. This situation is observable during July and August.

The model uncertainty is the inability of the SWAT model to incorporate some important processes that occur in the catchment. However, for this study, the model bracketed about 40–60% of the observed data as indicated by the 95PPU. Furthermore, the coefficient of correlation between simulated and observed discharges showed a strong agreement (Figure 4).

Table 6. Model performance metrics for the different land uses.

	2000		2006		2011	
	Calibration	Validation	Calibration	Validation	Calibration	Validation
R^2	0.9	0.8	0.7	0.8	0.7	0.7
NSE	0.9	0.8	0.6	0.8	0.7	0.6
KGE	0.9	0.9	0.7	0.9	0.7	0.6
absPBIAS (%)	5.9	5.3	15.2	9.4	21	34
p-factor	0.5	0.5	0.4	0.5	0.4	0.5
r-factor	0.6	0.7	0.9	0.6	0.5	0.4

Table 7. Water balance components during the calibration and validation processes.

Water balance components (mm)	Year 2000	Year 2006	Year 2011
Rainfall	1239.8	1239.8	1239.8
Surface runoff	355	356.1	366
Lateral flow	4.94	4.96	4.89
Groundwater flow	143.9	148.9	140.8
Deep aquifer recharge	9.65	9.67	9.4
Total flow/water yield	513.4	519.6	524.1
Actual Evapotranspiration	687.3	681.2	676.7
Potential evapotranspiration	2040.4	2037.2	2033.1

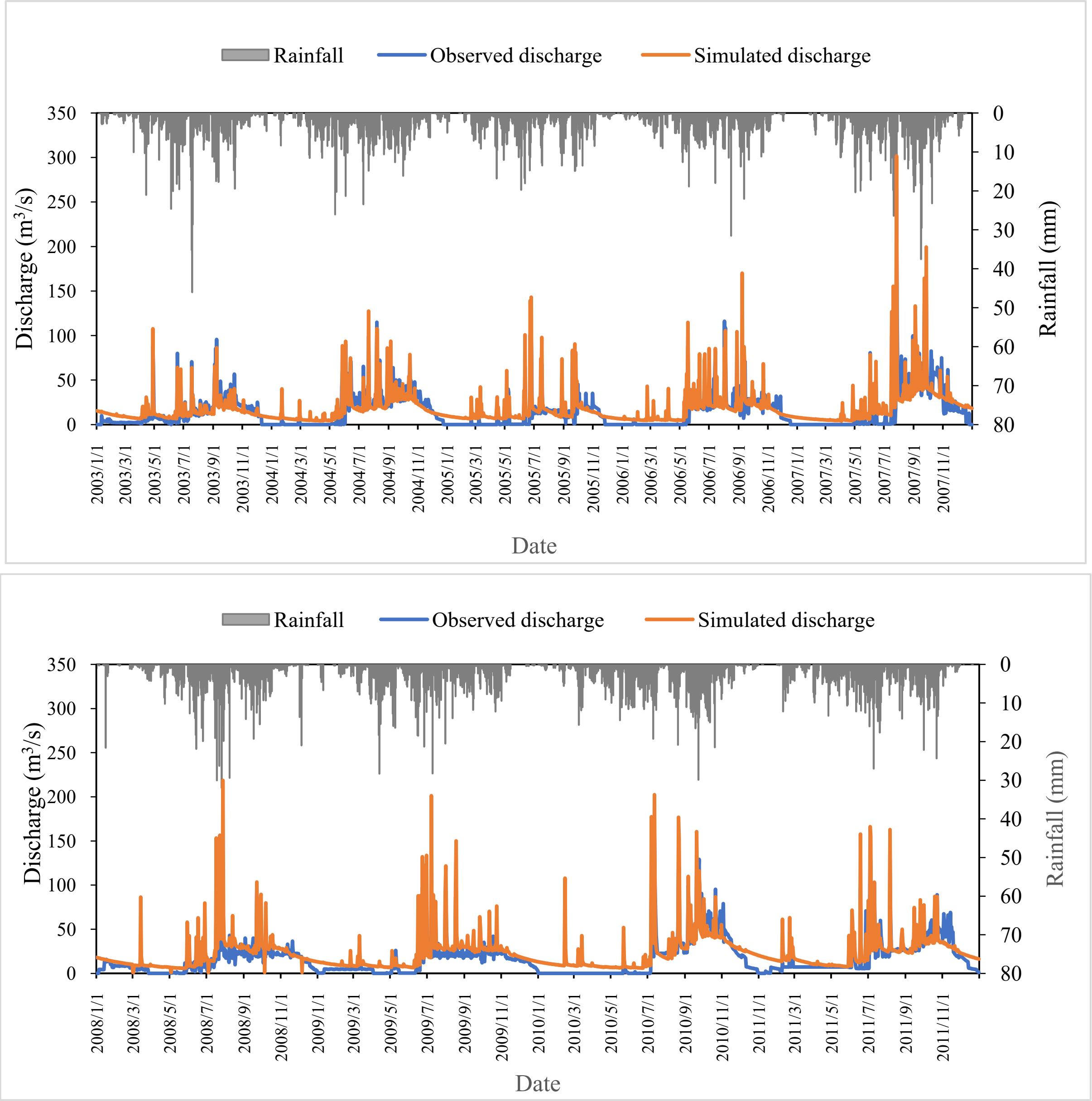


Figure 3. Simulated and observed discharges during calibration (top) and validation (down) periods.

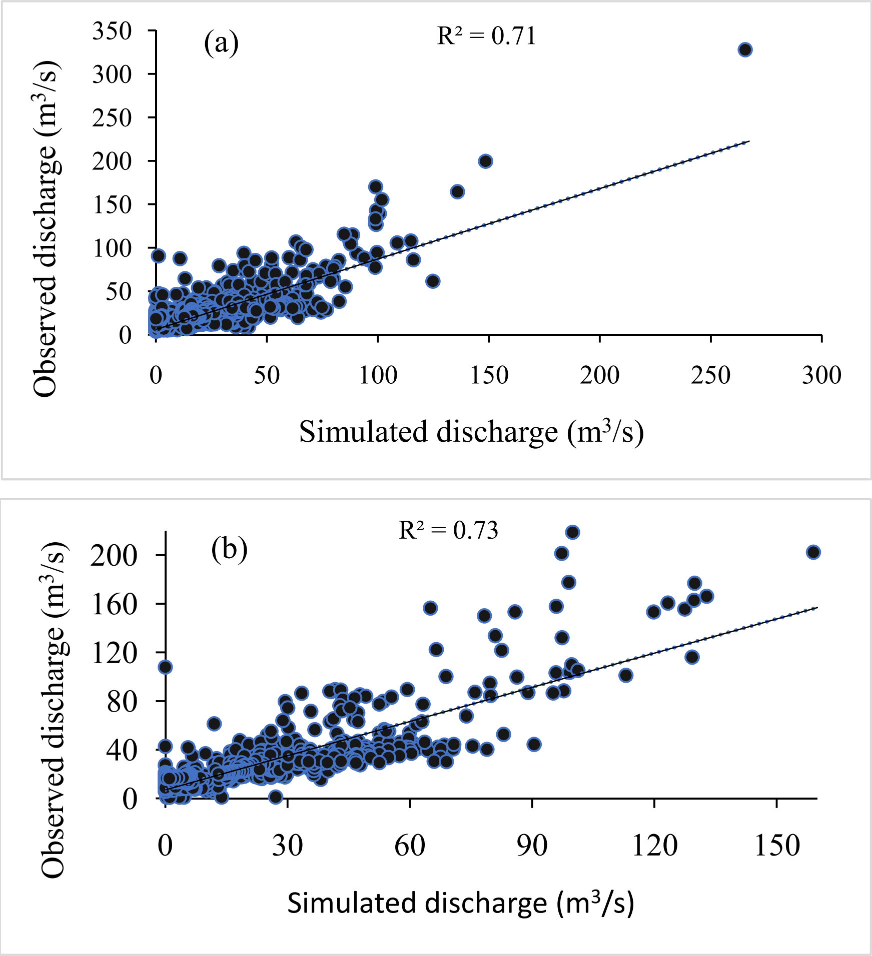


Figure 4. Relationship between the calibrated (a) and validated (b) models.

3.4. Effect of land use on green water

The observed daily meteorological and soil data were kept constant, the model was run for 2000 and 2011 LULC separately and the two hydrographs were compared. LULC characteristics during these periods have considerable influence on the spatial distribution of the annual evapotranspiration. Agricultural lands are found to have the highest ETa followed by the savannah areas (Table 8). Moreover, comparing the results of LULC of 2000 and of 2011, the mean annual ETa of the latter is larger than the one of the former by 10.6 mm (Table 8).

Table 8. Statistics of water balance components for 2000 LULC and 2011 LULC.

	Surface runoff		Groundwater		Eta	
	Value	% Change	Value	% Change	Value	% Change
Observed						
Year 2000	355		143.9		687.3	
Year 2006	356	+1	148.8	+4	681.2	−1
Year 2011	366	+3	140.7	−2	676.7	−2

3.5. Effect of LULC on blue water

The effect of LULC on blue water is reflected through the amount of surface runoff and groundwater. However, in the Couffo catchment, the savannah and forest areas are converted to cropland, both surface runoff and groundwater decreased accordingly during the simulation period (2000–2011). The shrub savannah, grass savannah and gallery forest decreased by 41, 96 and 61 km^2 respectively, and cropland and fallow areas increased by 286 km^2 (Table 4), surface runoff increased from 355 to 366 mm, with a little decrease in groundwater from 143.9 to 140.7 mm during the simulation period (Table 7).

4. Discussion

4.1. Land use and land cover analysis

Agriculture constitutes the main activity of the Couffo catchment. This implies the needs and the increase in croplands [39]. Moreover, the results of this study indicated an increase in croplands that may be due to the high demand of land for agriculture purposes leading consequently to a decrease in savannah areas. Besides, the decreased in forest may be related to the population demand for firewoods and charcoals [22]. This conversion of Savannah and forest areas to croplands induced some changes in the hydrological process in the catchment as well as in the water quality.

4.2. Discharge simulation

The inability of the model to capture at least 70% of the observed data could be related to uncertainties in the input dataset [23]. These errors are the systematic errors associated with the measurement instruments. For example, rain gauges are known to have errors ranging from 5–6 % and 5% respectively for their systematic error magnitudes and random error magnitude [40]. In addition, there are limited rain gauges in the Couffo catchment and the temperature, solar radiation, wind speed and relative humidity were derived from the nearest synoptic station (Natitingou) that was near the catchment. Thus, this synoptic station and the neighbouring rain gauge data used for gap filling may induced their individual errors in the Couffo climate dataset. In addition, the discharge measurement at the catchment outlet is likely to spread errors during computations and instrumentation and quality control which may lead to possible outliers in the final dataset.

The results of the discharge in the Couffo catchment showed good results as indicated by the goodness of fit statistics and the trends of the simulated and observed discharge over the considered period. The performance of the model in simulating the catchment discharge is indicated by p-factor and r-factor ranging between 0.4 and 0.5, and between 0.4 and 0.9, which demonstrated that almost 50% of the measured is captured by the 95PPU and the calibration quality was around 60%. The other model performances indices (R^2, NSE, KGE and absPBIAS) ranged between 0.6 and 0.9 for R^2, NSE, KGE and between 5 and 34% for absPBIAS. These indices indicated the good performance of the model in simulating the catchment discharge. This performance is also depicted in the pattern of the discharge graphs during the calibration and validation periods. Similar results were achieved in neighbouring catchments such as Amoussou [41] in Mono-Aheme-Couffo catchment; Sintondji et al. [42] in Okpara catchment and Cornelissen et al. [1] in Oueme catchment.

4.3. Effect of LULC on green water and blue water

The difference in ETa could be caused by the changes observed between different LULC. For example, the increase in cropland areas is a result of decreasing in savannah. Thus, the change in LULC induced changes in mean ETa observed between the considered periods. In addition, the change in ETa may also be a result of the differences in the leaf area index and stomatal resistance of the different LULC that control the evapotranspiration. Yira et al. [3] found in Dano catchment, that the decrease in evapotranspiration was related to the change in LULC, therefore, the change observed in LULC in Couffo catchment may be one of the main factors leading to the change in ETa.

These differences in blue water can be related to the results of LULC changes, which may be caused by various activities such as agriculture, which is the dominant one in the study area. This corroborates the findings of Awotwi et al. [4] in White Volta basin and Yira et al. [3] in Dano catchment where the decrease in savannah led to an increase in the catchment discharge.

5. Conclusions

This study assessed the impacts of LULC changes on the water balance components of the Couffo catchment. The SWAT model was applied with different LULC maps. The hydrological response to LULC changes indicated that different LULC changes have effects on water yield, discharge flow, blue and green waters. Regarding the LULC changes, croplands increased by 34 % while the savannah (shrub and grass), agroforestry and forest areas decreased between 24 and 60 % from 2000 to 2011. In the same period, surface water has increased by 11 mm while groundwater and ETa have decreased by 3.2 mm and 10.6 mm, respectively. The outcomes of this study can be used as a baseline in quantifying the impacts of projected LULC and climate changes on the catchment hydrology. This study showed an important water availability of such agricultural catchment. Hence, some adaptive measures including tree planting, soil and water conservation techniques are recommended for a sustainable use of catchment water resources. Although the outputs of this study underscore the importance of good land management practices, there are certain uncertainties related to this modelling exercise. Among such uncertainties, those associated with the discharge gauge measurement, missing data in discharge flow and input data (e.g., climate data) may induce errors in the final outputs of the model, including uncertainties related to the model parameterization. Thus, satellite data may be preferred to limit some uncertainties and missing values related to measured data, particularly in poorly gauged West African catchments including the Couffo catchment.

Conflict of interest

The authors declare no conflict of interest.

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