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CLIMATE CHANGE AND WATER RESOURCES: APPLICATION OF THE SWAT MODEL TO THE SOUTH-EAST AGNÉBY WATERSHED OF IVORY COAST

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ABSTRACT: The aim of this study is to highlight the combined effects of climate change and anthropization on surface waters in the Agnéby watershed. The global hydrological balances produced by the SWAT model show that in the year 2050, precipitation will record a deficit of 1.87%, while actual evapotranspiration will be 2.80% higher. Groundwater recharge and runoff will be in deficit by 2.5% and 9.77% respectively, and stock variation will be in deficit by 36.62% compared with the reference period. For 2080, precipitation, groundwater recharge and runoff will be in deficit by 1.23%, 1.5% and 10.23% respectively. Actual evapotranspiration will show an excess of 3.37%, and the change in stock relative to the reference period will also show a deficit of 20.42%. The hydrological consequence of this state of affairs is the depletion of surface water resources over the years in the Agnéby watershed due to anthropogenic activities. The predominance of evapotranspiration can be explained by the fact that the area will be covered by large-scale farming operations. These could also be explained by the fact that the area will be less favorable to surface runoff than to infiltration.

KEYWORDS: Climate change, Water resource, Agnéby catchment, SWAT model, Ivory Coast.

1 INTRODUCTION

Human-induced climate change is causing dangerous and widespread disruption to nature and affecting the lives of billions of people around the world, despite efforts to reduce the risks. The populations and ecosystems least able to cope are the hardest hit, say scientists in the latest report from the Intergovernmental Panel on Climate Change [8]. Over the second half of the last century, water supplies declined in most of West Africa's main river basins. The reasons for this decline are a complex combination of climate change, land use and population growth. Studies based solely on climate projections therefore suggest that river flows could fall by a further 20-40% by 2050 [22].

In Côte d'Ivoire, the impacts of climate change are being studied as part of a wider programme on water resources. Similarly, studies carried out in certain catchment areas have also shown a decline in surface and groundwater resources [20]. The results show a decrease in rainfall [23]. [14] have characterised an increase in temperatures in studies carried out throughout Côte d'Ivoire.

The Agnéby catchment in south-eastern Ivory Coast has not been spared the effects of climate change. Work carried out on the runoff regime and anthropogenic activities has highlighted changes in the catchment's hydrological behaviour. Its rainfall regime has fallen by around 10% [13]. Depending on rainfall, runoff in the catchment has recorded a hydrometric deficit of almost 46% [10]. Between 1988 and 2020, degraded and dense forests under human control fell from 19.12% to 24.2% and 64.35% to 11.6% respectively, and by 2050 and 2080 they will have fallen from 24.2% to 11.4% and 11.6% to 6% respectively [12]. Agriculture remains a predominant sector of the national economy, employing 2/3 of the working population. Given that water resources are a vital component of development and that shortages are likely to be frequent in the region, it is important to act on adaptation to climate change for sustainable development. Several physical hydrological models that take into account the multifactorial relationships between natural conditions and hydrological functions have been developed to simulate hydrological processes at the catchment scale. These include MODFLOW [16], TOPMODEL [3], SHE [1] and MODCOU [15]. Of these, SWAT has proved to be the most effective in reproducing the hydrological function of catchments on various occasions [19]. This work is being carried out in a context of pressure on water resources due to the combined influences of climate change and land-use dynamics on the sustainability of water resources by 2050 and 2080. Specifically, we are going to highlight the potential impacts of anthropisation and the terms of the catchment's water balance.

2 Presentation Of The Study Area

The study area is located in West Africa, in the south-east forest of Ivory Coast. The catchment area studied is that of the Agnéby (Fig. 1). The Agnéby catchment lies between latitudes 33000 N and 429000 N and between longitudes 6300000 W and 750000 W. It covers an area of 8640 km^2. The basin borders the Bandama river to the west and the Comoé and Mé rivers to the east. The basin has a mild transitional equatorial climate, with cumulative rainfall of 1784 mm.yr^{-1}. The vegetation consists mainly of dense evergreen forest. The relief of the basin is characterised by altitudes ranging from 8 to 100 m on one side and 100 to 300 m on the other. The geology of the basin is based on Precambrian formations: arkosic schists north of Bongouanou and south of Agboville, mica-schists and granites in the central part. Its soil structure is divided into two types: ferralitic soils, both weakly and strongly denatured, found in the north and centre of the basin, and a complex of hydromorphic soils that have evolved little over small areas. Two rain gauge stations and one hydrometric station located in the area were selected for their data quality.

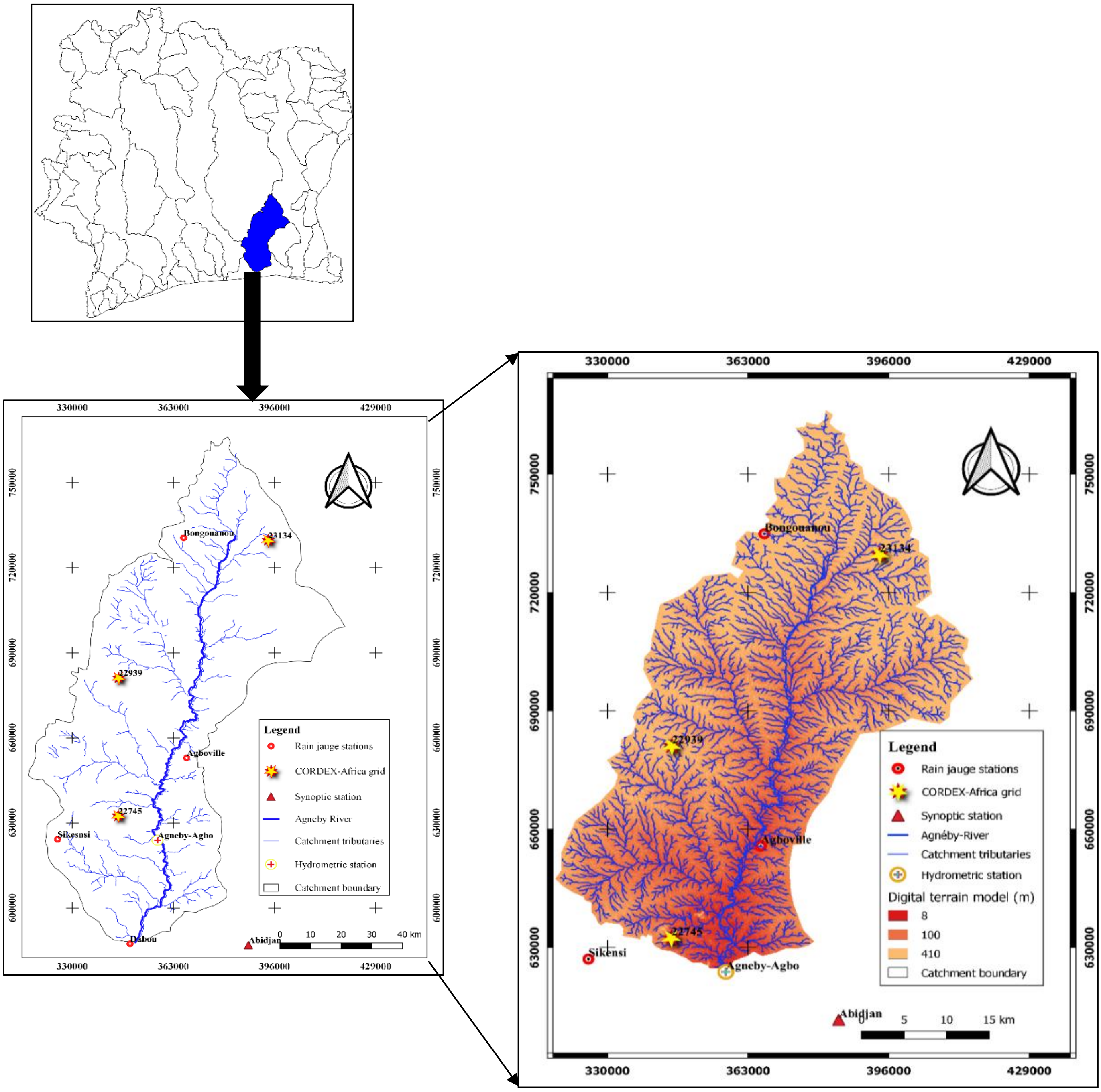

Fig. 1. Location of the Agnéby catchment area

3 Data And Methods

3.1 Data

The rainfall and daily temperature data collected come from the Operating and Development Company airport, aeronautical and meteorological. Flow rates were obtained from the Directorate General of Human and Hydraulic Infrastructures (DGHHI). These data had no gaps and were of good quality for use. The data for the regional climate models (RCMs) used were obtained from the CORDEX-Africa programme and consisted of rainfall and temperature variables, with a daily time step and a resolution of 50 km. These data were biased, and we corrected the biases before processing.

For the implementation of the SWAT model the daily precipitation and temperature data collected were used. As for the data on relative humidity, solar radiation and wind, the model's climate stations were used over the period 2004-2015 for the reference period. The 2020 land use maps were added to these data, and the study area was extracted from the world soil map produced by the [7] at a scale of 1: 5000000, which is recognised by the model. In the context of climate change for the 2050 and 2080 horizons, meteorological data has also been simulated for the periods 2043-2054 and 2073-2084 to predict flows in the short and longer term.

3.2 ARCSWAT METHODOLOGY

The most recent version of the SWAT model, ARCSWAT2012, was used for this study. The delimitation of the sub-catchment areas is based on the definition of the hydrographic network, itself based on the topography. It is therefore influenced by the resolution of the digital terrain model (DTM). The user can define a drained surface threshold above which a watercourse is created. A sub-basin is then defined between each confluence of the hydrographic network. For this study, 25 sub-basins were generated, with an outlet at the Agnéby-Agboville station (Fig.2).

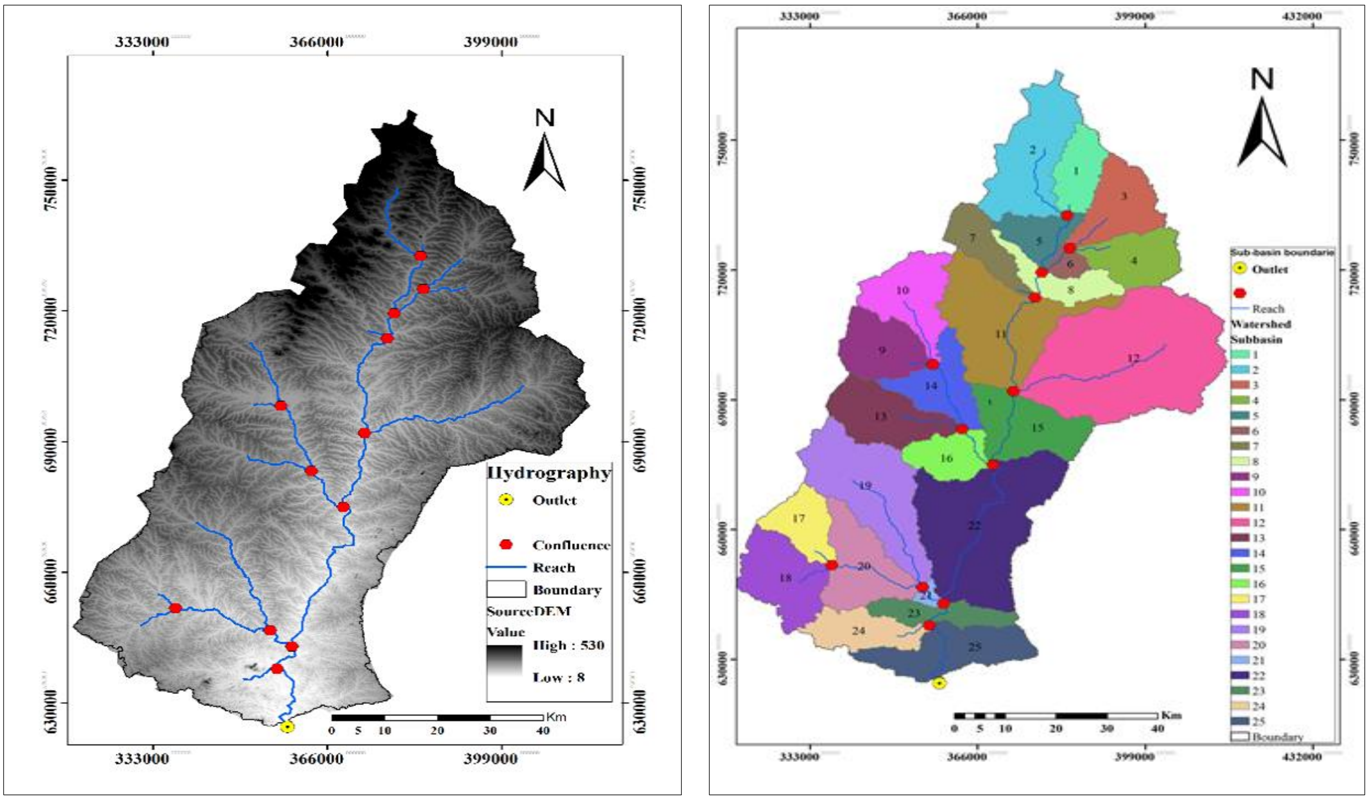

Fig. 2. Breakdown of the Agnéby catchment area into 25 sub-catchment areas

The definition of catchment areas in a project depends on a number of physical and technical factors. The division must enable areas with different physical and hydroclimatic characteristics to be described. It must also allow comparison with gauging stations, which must be located at the outlet of a sub-catchment.

3.2.1 DEFINITION OF HYDROLOGICAL RESPONSE UNITS (HRU)

As described in the model operation, the project's sub-basins are discretised into Hydrological Response Units after slope, soil and land use data have been compiled. The model therefore creates a HRU for each possible combination of these three integrated entities. For each of the three parameters mentioned above, the user can determine a threshold, in percentage terms, below which the value of a parameter will not be considered in the creation of HRUs. This has the effect of limiting the number of HRUs generated. The choice of this threshold makes it possible to exclude parameter values that are relatively anecdotal in terms of surface area. For the purposes of this project, the threshold has been set at 5% for land use type, 10% for soil type and 10% for slope class.

The SWAT model requires daily or monthly flow records at the catchment outlet for the entire simulation period.

In addition, in order to work in a climate change context, even if daily observed flows are taken into account, the period 2004-2015 has been considered as the reference period (scenario 1) and the two periods 2043-2054 and 2073-2084 are respectively the climate change scenarios 2 and 3.

3.2.2 INTEGRATION OF WEATHER STATIONS AND CREATION OF TABLES BY SWAT

The second stage involved the integration of meteorological data. This includes data on precipitation (PCP), maximum and minimum temperatures (TMPmax and TMPmin), relative humidity (HMD), solar radiation (SLR) and wind speed (WND). A hydrological survey station was selected to enable model performance to be estimated. As with the definition of the sub-basins, the selection of this station must meet a number of criteria. First and foremost, these must enable the diversity of the area under consideration to be represented and cover all the hydrological continuums simulated by the model. The Agnéby-Agbo hydrometric station was chosen to facilitate model calibration.

3.2.3 SIMULATION OF METEOROLOGICAL DATA

After checking that all the model data had been correctly integrated, the various simulations were carried out. In this stage, we determine the output time step with a minimum start-up period of two years. For this reason, we opted for a monthly time step with model outputs for the periods 2004-2015 for the reference period, and 2043-2054 and 2073-2084 for the climate change assessment.

3.3 CALIBRATION OF THE SWAT_CUP 2012 MODEL

The calibration and validation are carried out over two different periods. The research is conducted according to one principle:

- The split-sample test principle [11].

This test consists of splitting the available period into two (2) independent sub-periods of a non-stationary nature (climatic characteristics differing from one period to the next), calibrating the model on the first period (2006-2009) and validating it on the second (2010-201). For climate change, the calibration periods are 2043-2049 and 2073-2079, and the validation periods are 2050-2054 and 2080-2084.

3.3.1 NASH-SUTCLIFFE CRITERION (NSE)

The Nash-Sutcliffe criterion [18] is widely used in hydrology. It is a standardised criterion which aims to express the proportion of the variance in observed flows explained by the hydrological model by comparing it with a reference estimator, which is the mean of the observed flows. It is defined by equation 1:

$$NSE = \frac{\sum_{i=1}^{N}(O_i - S_I)^2}{\sum_{i=1}^{N}(O_i - \bar{O})^2} \qquad (1)$$

Where Oi and SI are the values of the observed and simulated flows at the time step under consideration. Based on the statistical criteria obtained up to 2007, [17] were able to establish a monthly performance evaluation grid, summarised in the following Table 1.

Table 1. Recommended model performance evaluation criteria for a monthly time step [17]

Performance evaluation	NSE	PBIAS		
		Flow	Sediment	N, P
Very good	0,75<NS≤ 1	PBIAS < ± 10	PBIAS<±15	PBIAS < ± 25
Good	0,65< NS≤ 0,75	±10≤PBIAS<±15	± 15 ≤ PBIAS < ± 30	± 25 ≤ PBIAS < ± 40
Satisfactory	0,50 <NS≤ 0,65	±15≤PBIAS<±25	± 30 ≤ PBIAS < ± 55	± 40 ≤ PBIAS < ± 70
Unsatisfactory	NS ≤ 0,50	PBIAS≥ ±25	PBIAS ≥ ± 55	PBIAS ≥ ± 70

3.3.2 VALIDATION

The validation phase is the most decisive stage in the simulation of water resource management at catchment level. Once the model's calibration performance has been judged satisfactory, the model is run with the optimal parameters from the calibration, for another period called the validation period [2].

This step has been carried out, and the initial parameter values have been replaced by the optimal parameters obtained during the calibration phase on SWAT-CUP2012.

3.3.3 MODEL SENSITIVITY ANALYSIS

The aim of this approach is to identify which parameters, for a given model configuration, will influence the simulation produced. The greater the variation in output, the greater the influence of the parameter [21]. Sensitivity thus makes it possible to lighten the calibration process by setting parameters that have no influence on the model outputs. Once the calibration parameters influencing the flow had been defined, an overall sensitivity analysis was carried out in order to reduce the number of parameters to be calibrated, by excluding those that have no influence on the phenomenon under study. This made it possible to classify the sensitive parameters for the model in order according to their degree of influence. Eleven of the 22 parameters were found to be influential (Table 2).

Table 2. Classification of the parameters most sensitive to the model (hydrological)

Rank	Parameter	Description
1	R_HRU.SLP.hru	Main slope of the HRU (linked to the flow of water in the canal)
2	R_SURLAG.bsn	Runoff delay coefficient (linked to runoff)
3	R_SUBBSN.hru	Average length of slope (linked to water flow in the canal)
4	V_ALPHA_BF.gw	Groundwater depletion coefficient (linked to the underground canal)
5	V_GWQMN.gw	Groundwater contribution threshold to channel flow, base flow (linked to underground channel)
6	R_OV_N.hru	Overall Manning coefficient for the hydrographic network (linked to surface runoff)
7	R_EPCO.hru	Soil evaporation factor as a function of depth (linked to actual and potential evapotranspiration)
8	R_ESCO.hru	Soil evaporation factor as a function of depth (linked to actual and potential evapotranspiration)
9	V_GW_DELAY.gw	Aquifer recharge time (groundwater-related)
10	R_CN2.mgt	Curve Number (related to surface runoff)
11	R_SOL_AWC(.).soil	Available water capacity in the soil layer (linked to water in the soil)

The parameters that have the greatest influence on hydrological modelling are:

- soil: soil water content;
- Surface runoff: Curve Number, response time to surface runoff and Manning's roughness coefficient, main slope of the HRU, runoff delay coefficient and mean slope length;
- Evaporation: The soil evaporation factor as a function of depth and the vegetation evaporation factor as a function of depth;
- Groundwater flow: The groundwater depletion coefficient, aquifer recharge time and channel flow, base flow.

3.3.4 WATER BALANCE MODULE

His hydrological balance consists of comparing the total flow in the catchment area and the quantity of flow leaving the outlet. The terms of the hydrological balance that we are going to highlight are: rainfall, runoff, groundwater recharge and actual evapotranspiration. It is expressed by the formula in equation 2:

$$P = R + I + RET + \Delta S \qquad (2)$$

Where:

P: Precipitation (mm)
R: surface runoff (mm)
RET: evapotranspiration
I: deep infiltration or groundwater recharge (mm).

For this study we will use the global water balance produced by the SWAT model. According to [6], the estimation of the balance terms is more refined on the SWAT model, as it takes into account all the hydrological and hydrogeological spatial variations at the catchment scale.

4 Results

4.1 Definition Of Hydrological Response Units (HRU) For The Reference Scenario

The SWAT model can be used to represent hydrological systems, particularly for dams and agricultural irrigation. Hydrological response units are determined by dividing the catchment into sub-catchments, the type of land use, soil type and slope classes. For this study, the Agnéby catchment was divided into 25 sub-catchments (Fig.3). The thresholds for the three entities were set at 5%, 10% and 10% respectively for land use, soil type and slope.

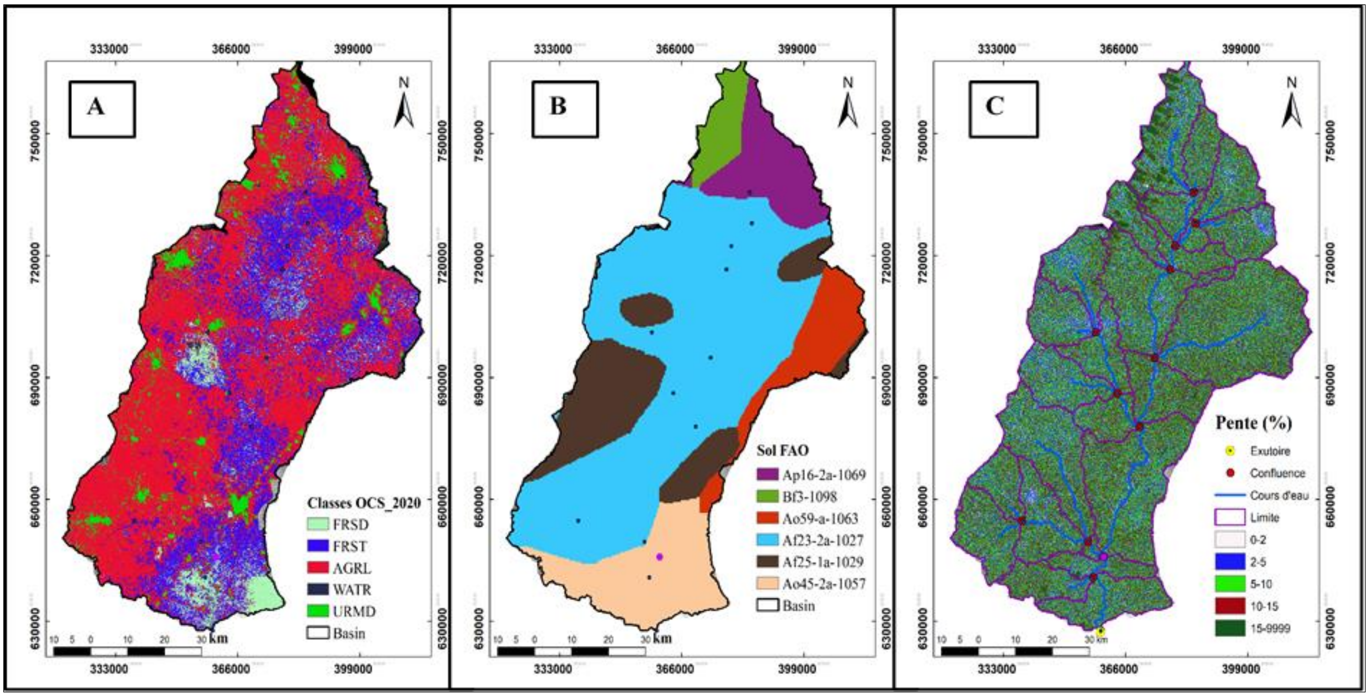

Fig. 3. Creation of Hydrological Response Units in the Agnéby catchment area

Table 3 highlights the characteristics of the catchment. The first entity taken into account is the 2020 land cover. The analysis highlights the reclassification for Hydrological Response Units such as dense forest, degraded forest, Crops/ fallow land, water (WATR) and medium density habitats occupying proportions of 6.75%, 26.46%, 62.04%, 0.04% and 4.71% respectively.

Table 3. Correspondence between Lands uses and SWAT classification

Land use	SWAT Correspondence	Surface Area (%)
Dense Forest	FRSD (Forest – Deciduous)	6.75
Degraded Forest	FRST (Forest – Mixed)	26.46
Crops and fallow land	AGRL (Agriculture Land-Generic)	62.04
Water	WATR (Water)	0.04
Residential/Bare Floors	URMD (Residential- Medium Density)	4.71

Table 4 shows the second entity taken into account. The soil reclassification showed that six soil types cover the study area with proportions of 8.10% (Ap16-20-1069), 3.83% (Bf-1098), 53.78% (Af23-2a-1027), 14.49% (Af25-1a-1029), 6.59% (Ao59-a-1063) and 13.22% (Ao45-2a-1057). The dominant soil type is Af23-2a-1029.

Table 4. Soil types in the Agnéby catchment area on SWAT

Type of Soil	Area (%)
Ap16-2a-1069	8.10
Bf3-1098	3.83
Af23-2a-1027	53.78
Af25-1a-1029	14.49
Ao59-a-1063	6.59
Ao45-2a-1057	13.22

The third and final entity taken into account is the digital terrain model. Table 5 shows the distribution of the different slope classes. The slopes range from 2-5, 10-15, 5-10, 15-9999 and 0-2 with respective percentages of 29.51%, 22.04%, 46.85%, 1.50% and 0.10%. These three entities were combined to create 381 Hydrological Response Units. In view of these analyses, we can say that the Agnéby catchment area is in a flat plateau-type zone. The Agnéby area is dominated by agricultural activities and degraded forest. Surface runoff in this area is erosive, as slopes greater than 2% account for 98.4% of the total surface area of the catchment.

Table 5. SWAT slope classes for the Agnéby catchment area

Slope class	Area drained (%)
2-5	29.51
10-15	22.04
5-10	46.85
15-9999	1.50
0-2	0.10

4.2 HYDROLOGICAL MODELLING

4.2.1 CALCULATION AND VALIDATION OF SCENARIO 1 (REFERENCE PERIOD)

Fig.4 shows the simulated flows for the calibration and validation periods. For the calibration period, seasonal variations are well represented and peak floods are estimated for the period 2006-2007. For the 2008-2010 sub-period, peak floods and base flows are underestimated. Optimisations of the model have enabled good performance to be achieved over the basin at monthly time steps. The model's performance indicators show its ability to better reproduce observed flows, with a Nash-Sutcliffe criterion of 67% and a coefficient of determination of 72%, with a PBIAIS rate of -1.3%.

Validation is an essential follow-up and complement to the calibration stage. It consists of testing whether the model is capable of simulating the behaviour of the system using a series of input data other than that with which it was identified. Identifying the value of the hydrological model parameters will therefore depend on the objective function used, which quantifies the difference between the observed and simulated variable. The validation analysis reveals that the model best simulates flood peaks and underestimates flood ebbs with statistical indicators of a Nash-Sutcliffe criterion of 65%, 70% for the coefficient of determination and a PBIAIS of -3.6%. The variations of the four (04) seasons are well represented as well as the flood flows. Between September 2011 and December 2012, phase shifts between physical and simulated flows could be explained by delayed runoff.

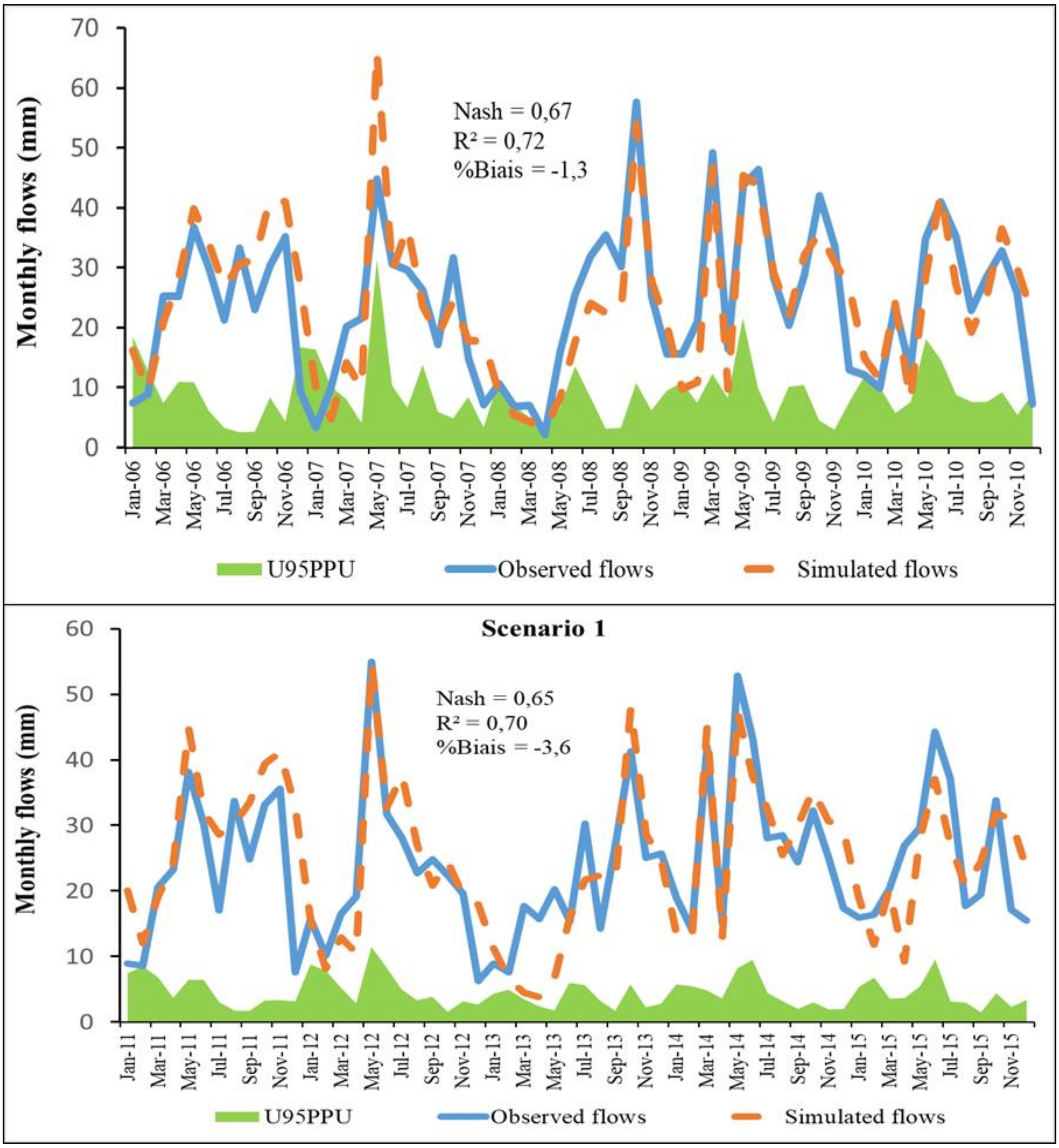

Fig. 4. Hydrographs of observed and simulated flows for calibration and validation

4.3 DEFINITION OF PREDICTED HYDROLOGICAL RESPONSE UNITS (HRUS)

Fig.5 shows the Hydrological Response Units for the 2050 and 2080 horizons. The analysis in Table 6 highlights the Hydrological Response Units generated by the SWAT model. The land use types showed changes in surface areas for the near horizon (2050) and the far horizon. The Hydrological Response Units are evaluated at 384 after their discretization into different meshes to give more precision to the dynamics that the area will experience through land practices. The results revealed that crops/fallow and habitats/bare soil will dominate and dense forest and degraded forest will decrease in area. As a hydrological consequence, the area will be more favourable to runoff and actual evapotranspiration and less favourable to infiltration and also to the storage of surface water.

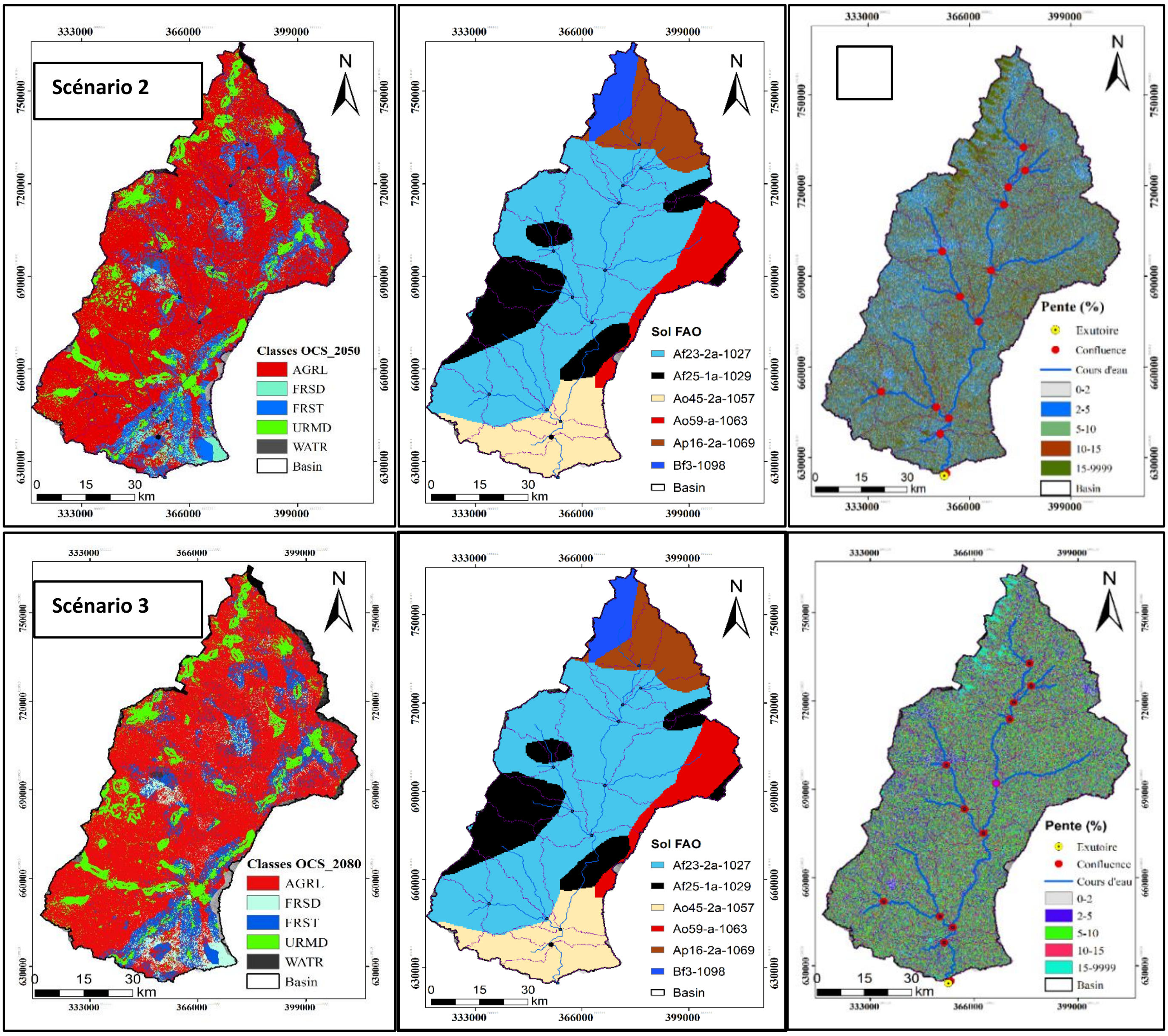

Fig. 5. Hydrological Response Units for horizons 2050 and 2080 on the Agnéby

Table 6. Correspondence between lands uses and SWAT classification

Land use	Correspondence from SWAT	Area (%)	
		2050	2080
Dense Forest	FRSD (Forest – Deciduous)	4.57	3.48
Degraded Forest	FRST (Forest – Mixed)	12.85	7.9
Crops and Fallow Land	AGRL (Agriculture Land-Generic)	69.5	75.25
Water	WATR (Water)	1.3	0.92
Residential/Bare Ground	URMD (Residential- Medium Density)	11.77	12.45

4.3.1 Hydrological Modelling 2050 And 2080

4.3.2 Calibrations

Fig.6 shows the calibration periods for the two climate change scenarios. Analysis of the graphs shows that for future calibrations, the model is better able to represent the flows of the reference period. The seasonal variations of the reference period are well reproduced. Flood peaks are well represented, with overestimates during the two rainy seasons, which could be explained by humidification or rapid urbanisation due to population growth. During the long and short dry seasons, the simulated flows also show overestimates for scenario 2. For the 2080 horizon (scenario 3), the model overestimates flood peaks over the 2075-2078 sub-period and underestimates the month of September, which marks the start of the short rainy season. This could be due to the lack of soil saturation and the scarcity of precipitation compared with the reference period. For model performance, the statistical indicators showed Nash-Sutcliffe criteria of 57% for the 2050 horizon and 56% for 2080. The coefficients of determination and the percentages of bias were 63% and 70% respectively, and -3.4% and -15.5% for the two scenarios.

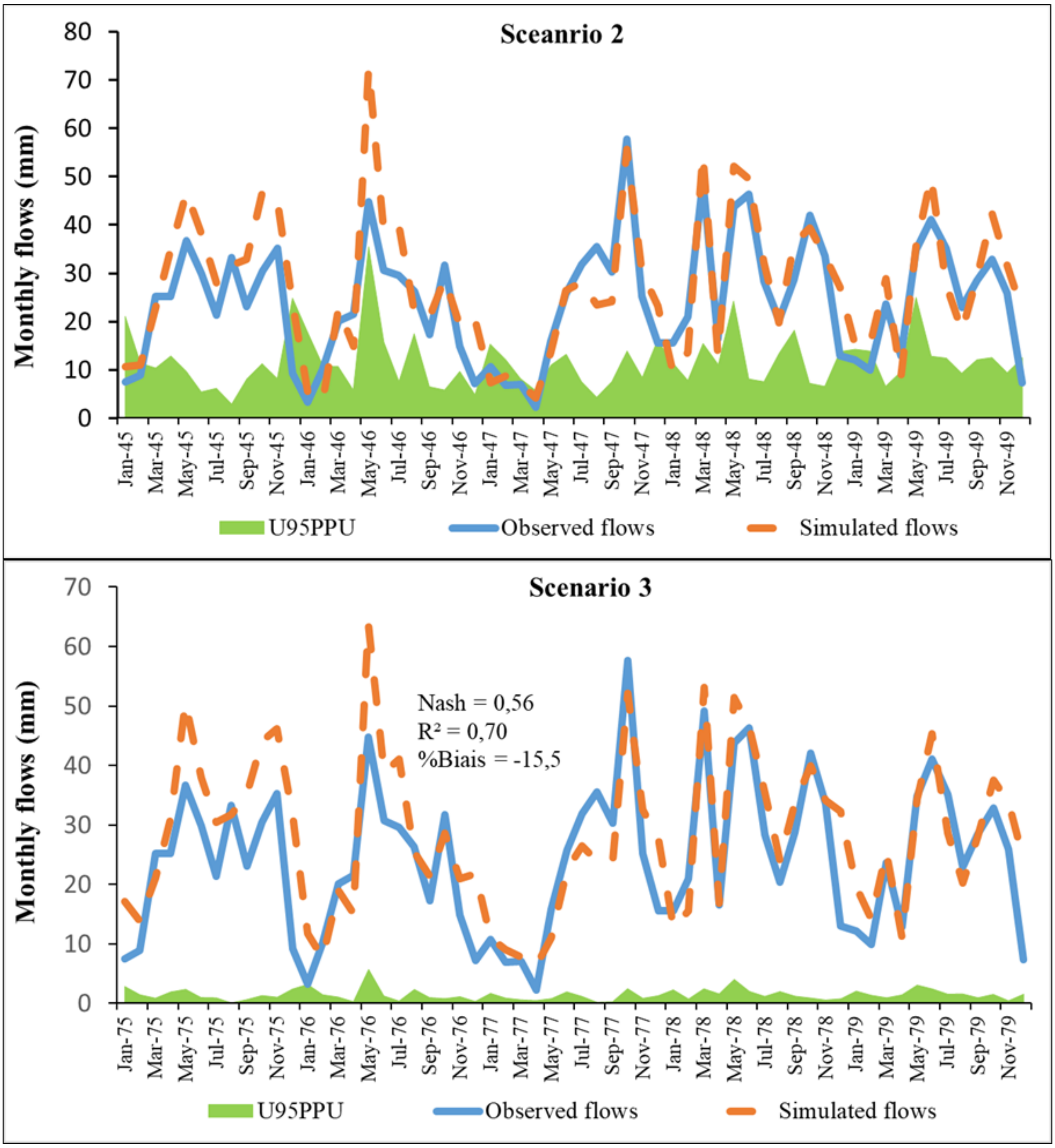

Fig. 6. Hydrographs for the calibration of scenarios 2 (2045-2049) and 3 (2075-2079)

4.3.3 VALIDATION

The graphs for the two validation scenarios show that flood flows are more or less better represented, whereas base flows are underestimated by the model (Fig. 7). These two periods chosen for future validation are representative of the climatic characteristics required, i.e. the presence of dry years, wet years and average years in the future data series.

The statistical indicators show Nash-Sutcliffe criteria of 60% for 2050 and 57% in 080. The coefficients of determination and the percentages of bias are 71%, 63% and -1.8%, -4.3% respectively. The flood peaks are well represented in scenario 2, while in scenario 3 the flood peaks are represented in April, November, May and September. In both scenarios, the month of June underestimates the observed flows for the reference period. The discrepancies between the simulated and observed flows are more noticeable during the short dry season. The fundamental observation is that, despite the low statistical values of the indicators, the model presents the observed flows better for the two scenarios.

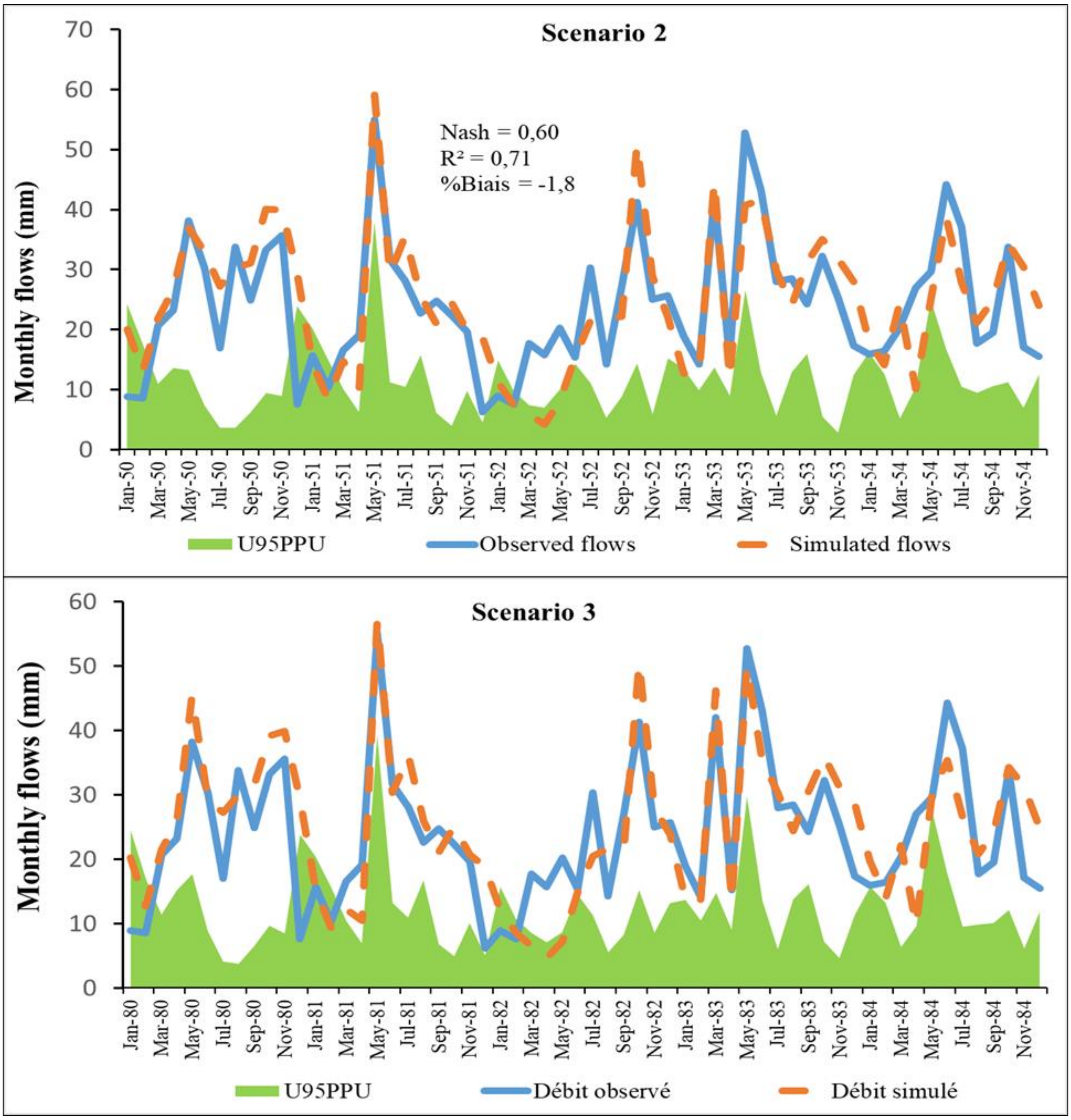

Fig. 7. Hydrographs for validating scenarios 2 (2050-2054) and 3 (2080-2084)

4.3.4 MODEL SENSITIVITY ANALYSIS

Fig. 8 highlights the most sensitive parameters for simulating future flows for the two scenarios.

Of the eleven parameters selected, the overall sensitivities of the model can be seen in the parameters related to actual and potential evapotranspiration, water content, the time taken to recharge the aquifer, surface runoff and channel flow. The behaviour of future hydrological functioning is therefore visibly influenced by the physical characteristics that drain surface runoff via SCS curves and Manning's coefficients.

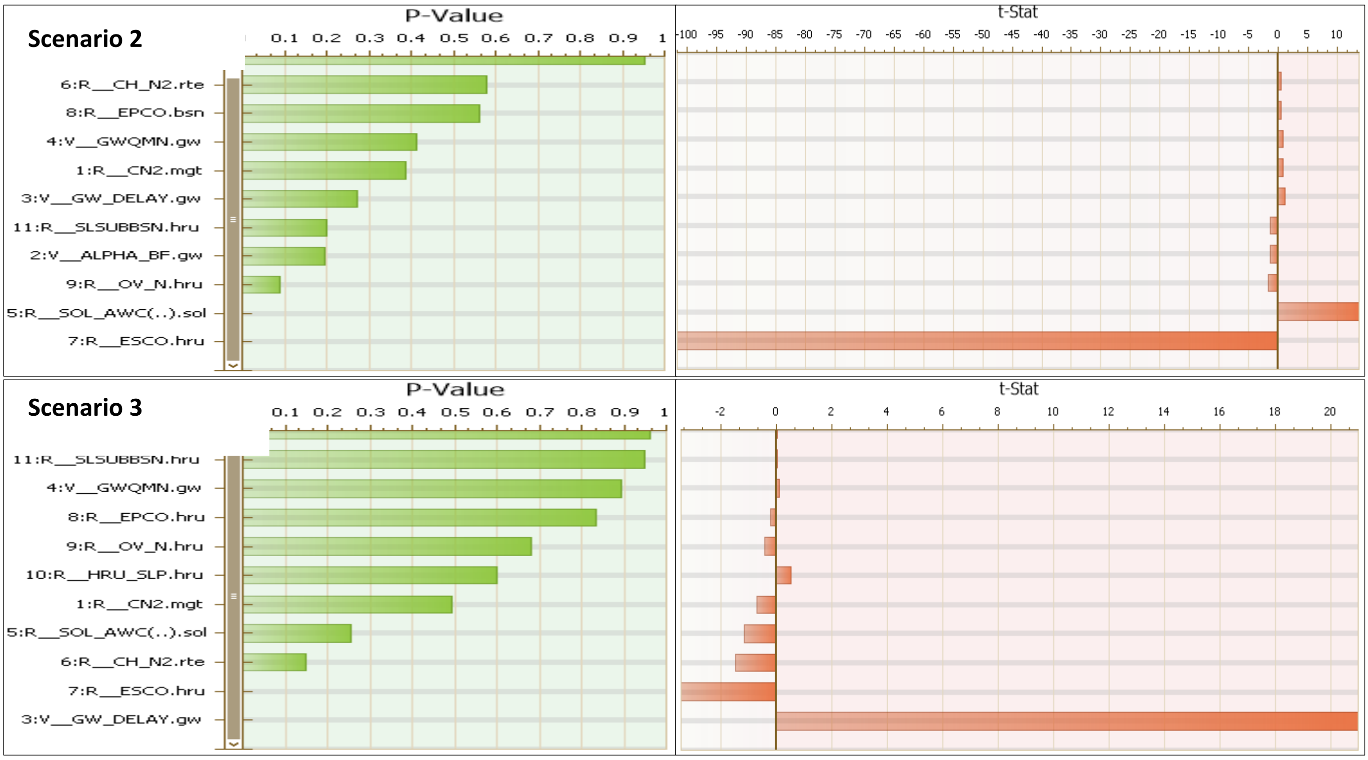

Fig. 8. Sensitivity analysis of parameters relating to future flows in the Agnéby

4.4 EVALUATION OF THE TERMS OF THE REFERENCE WATER BALANCE

The inputs are made up of rainfall on the reservoir and river contributions. There are three types of water outflows: actual evapotranspiration (AET), groundwater recharge (infiltration) and surface runoff (runoff). The overall terms of the annual water balance for the reference period are shown in Table 7. The analysis shows that for an average annual rainfall of 2007 mm, 45.18% is used for actual evapotranspiration, 32.86% for groundwater recharge and 21.96% for surface runoff. The positive water variation can be explained by the fact that the balance is in surplus, and the fact that the area is much wetter, with average annual rainfall in excess of 2000 mm.

Table 7. Annual water balance for the period 2006-2015

Annual water balance (mm) for catchment scenario 1					
Years	Precipitation (mm)	RET (mm)	Groundwater (mm)	Runoff (mm)	(Δt) (mm)
2006-2015	2007.73	907	6598	439.51	1.42

4.4.1 ASSESSMENT OF WATER BALANCE TERMS FOR CLIMATE CHANGE

Under the two climate change scenarios, the terms of the water balance are presented in Table 8. For the year 2050, the terms of the balance show that for an annual rainfall of 1970.27 mm 47.32% will be used for actual evapotranspiration, 32.65% for groundwater recharge and 20.03% for runoff. The variation in the stock will be negative, which implies that the year 2050 will be in deficit. In 2080, actual evapotranspiration will be 47.28%, groundwater recharge 32.77% and runoff 19.95%. The change in stock will be positive, which can be explained by the fact that the balance will be in surplus in 2080.

Table 8. Annual water balance for the years 2050 and 2080

Annual water balance (mm) for catchment scenario 2 and 3 (2050 and 2080)					
Years	**Precipitation (mm)**	**RET (mm)**	**Groundwater (mm)**	**Runoff (mm)**	(Δt) **(mm)**
2050	1970.27	932.37	643.29	396.55	-1.94
2080	1983.12	937.52	649.92	394.55	1.13

4.4.2 COMBINED IMPACT OF CLIMATE CHANGE AND LAND USE ON WATER RESOURCES

Fig. 9 shows the comparative assessments of past and future water balance terms for the Agnéby catchment.

For the study of the impact of climate change on water resources, the terms of the hydrological balances for the years 2050 and 2080 will be compared with the terms of the hydrological balance for the period 2006-2015. Analysis of the terms shows that the years 2050 and 2080 will record rainfall deficits of 1.9% and 1.23% compared with the reference period. Real evapotranspiration will be 2.8% higher in 2050 and 3.36% higher in 2080. As for groundwater recharge, the deficits compared with the reference period will be 2.5% in 2050 and 1.5% in 2080. Surface run-off will record deficits of 9.77% and 10.23%. Changes in surface water stocks will be 36.62% lower in 2050 and 20.42% lower in 2080. % compared with the baseline. The variations in surface water stocks and the terms of future hydrological balances clearly show that surface water resources in the Agnéby catchment area will be under threat from human activities and climate change.

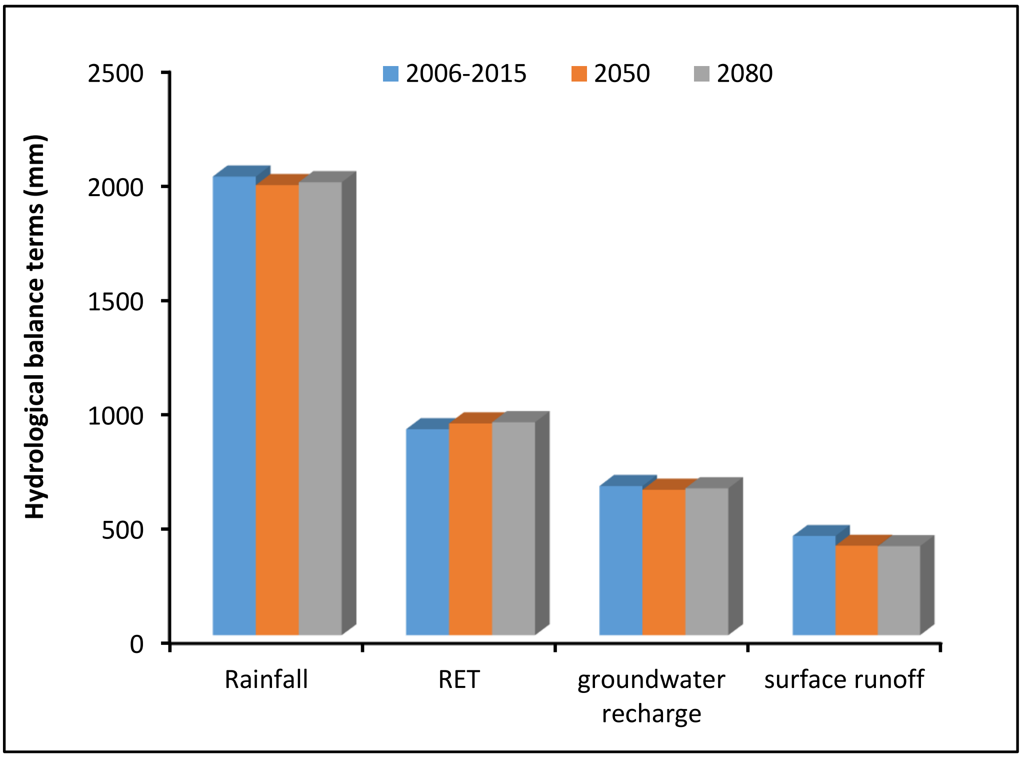

Fig. 9. Evaluation of past and future water balance terms in the Agnéby catchment area

5 DISCUSSION

For the modelling of land use types after the integration of the three entities, the hydrological response units for the years 2050 and 2080 showed that crop/fallow and degraded forest will be dominant with proportions of 69.5% and 12.85% respectively, and water will occupy 1.3% in 2050. For the year 2080, the proportions will be 7.9%, 75.25%, 12.45% and 0.92% respectively for dense forest, crops/fallow, habitats/bare ground and water. Crops/fallow land will dominate more than half of the total surface area of the basin. This could be explained by the fact that the Agnéby area will be moving from subsistence farming to modern agriculture to conquer the world market. This work also confirms the increase in agricultural activities in south-eastern Côte d'Ivoire over the 2050 and 2080 time horizons. Our results are in line with the work carried out by [5]; [12]. In their studies, these authors predicted that the Aghien and Agnéby watersheds in south-eastern Côte d'Ivoire will experience strong anthropisation due to agricultural activities, which may impact surface waters in the near and distant future. The results showed that the SWAT_CUP model is sensitive to eight parameters mainly related to runoff and soil water reserves. This implies that it is these parameters that are at the origin of the surface runoff in the case where sources and withdrawals are not taken into account. In order to better represent the flow at the outlet, the soil parameters have been refined. These parameters were used to optimise the flows produced by the model for the three scenarios in order to better reproduce the observed flows. These parameter sensitivity results are in line with the parameters used in the work by [6] using the SWAT model to model surface runoff in a poorly gauged basin in the Soudano-Sahelian zone of Burkina Faso. According to the work carried out by [9] in the Monteréal area. These present results of our work show that the hydrological behaviour of the Agnéby catchment is greatly influenced by the physical characteristics of the parameters of this area since it is the soils and their surface uses that mainly dictate surface runoff. These authors show the hydrological conditions of the model, where the Nash-Sutcliffe coefficient is considered to be good above 0.5 and very good above 0.75. The percentage bias must be between -25% and +25% to be considered satisfactory and is good within ±15%. Our results are lower than those obtained by [4] for the Nakhla catchment, who found 0.92 for calibration and 0.91 for validation using the SWAT model. The terms of the hydrological balances for the years 2050 and 2080 compared with the reference period show that the rainfall deficits will be 1.9% and 1.23% respectively. Real evapotranspiration will be 2.8% and 3.36% higher, while groundwater recharge will be 2.5% and 1.5% lower than in the reference period. Rainfall-dependent run-off will record deficits of 9.77% in 2050 and 10.23% in 2080. Variations in surface water stocks will fall by 36.62% in 2050 and 20.42% in 2080. Our results are superior to those of [23], which show a scarcity of rainfall and a drop in water availability of 55%/hbts in 2080 in Côte d'Ivoire. These results confirm the performance of the SWAT model in studies of the impacts of climate change on the sustainability of future surface water in the Agnéby catchment.

6 Conclusion

The SWAT model was implemented for the three scenarios in order to assess the combined impacts of climate change and land use on water resources. The results indicate that the area will be highly antrhopised over the two future horizons, with an increased dominance of crops/ fallow land and habitats, which will occupy more than half of the total surface area. In terms of hydrological modelling, the model has demonstrated its ability to better reproduce past physical flows over the two horizons, with statistical indicators of Nash-Sutcliffe criteria greater than 0.5 in calibrations and validations. The global water balance terms showed rainfall deficits of 1.9% and 1.23 for the 2050 and 2080 horizons compared with the reference period. Actual evapotranspiration will be higher than the reference evapotranspiration, with excesses of 2.8% and 3.36%. As for groundwater recharge and surface runoff, the deficits will be 2.5%, 1.5% and 9.77%, 10.23% respectively over the two horizons. Stock variations will also experience deficits of 36.62% and 20.42%. The variations in surface water stocks and the terms of future hydrological balances clearly show that the catchment's water resources will be under threat from human activities and climate change. The drop in surface water stock observed between the reference period and future horizons is reflected in an increase in actual evapotranspiration and a drop in runoff. The hydrological consequence of this state of affairs is the depletion of water resources over time due to human activities. The predominance of evapotranspiration is explained by the fact that the area will be covered by large farms and that the area will be less favourable to surface runoff than to infiltration. Overall recharge is the second highest.

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