Environmental Engineering and Management Journal

January 2021, Vol.20, No. 1, 13-23
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

"Gheorghe Asachi" Technical University of Iasi, Romania

APPLICATION OF THE AGRO-HYDROLOGIC SWAT MODEL ON THE TAABO RIVER BASIN (CÔTE D'IVOIRE) TO EVALUATE THE EFFECT OF THREE VEGETATIVE FILTER STRIP SCENARIOS ON STREAMFLOW AND NUTRIENTS

Kouao Armand Anoh[1*], Tanoh Jean Jacques Koua[1], Wonnan Eugène Yeo[2], Sampah Georges Eblin[1], Kan Jean Kouamé[3], Jean Patrice Jourda[3]

[1]*Environment department, Jean Lorougnon Guédé University of Daloa, Côte d'Ivoire*
[2]*Drinking Water Supply Department-Ministry of Hydraulics, Abidjan-Côte d'Ivoire*
[3]*Hydrogeology department, Felix Houphouët-Boigny University of Abidjan, Côte d'Ivoire*

Abstract

Côte d'Ivoire is one of the world's leading producers and exporters of agricultural products. Unfortunately, the multiplicity of stakeholders in this sector and the absence of legislation and regulations have contributed to the pollution of the various hydro systems, particularly those of Taabo river basin. The purpose of this study was to assess the ability of the Soil and Water Assessment Tool (SWAT) model to test the applicability of three vegetative filter strips scenarios to minimize nutrient loads downstream of the emission fields. The model calibration (1982-1986) and validation (1987-1990) were performed for daily time periods using mathematical algorithm Sequential Uncertainty Fitting, version 2 (SUFI-2) included in the SWAT-CUP software. SWAT model produce a good simulation performance because it offered realistic simulations of streamflow both in calibration (NS ≥ 0.67 and $R^2 \geq 0.68$) and validation (NS ≥ 0.6 and $R^2 \geq 0.6$). Then, three scenarios of vegetative filter strips in sensitive sub-basins were examined. The implementation of these vegetative filter strips could have a positive impact on nutrient flows. Nevertheless, scenario 2 with a ratio of, field area and vegetative filter strip of 50, appears to be the most suitable for the agro-climatic conditions of the Taabo river basin.

Keywords: Côte d'Ivoire, modelling, nutrient, SWAT, Taabo river basin, vegetative filter strips

Received: November, 2019; Revised final: July, 2020; Accepted: July, 2020; Published in final edited form: January, 2021

---

1. Introduction

For several decades, Côte d'Ivoire's economic development has been based exclusively on agriculture. This agriculture based on export crops allowed the country to occupy first places in the world and to be one of the major economic powers in West Africa. In addition to export crops, the country's survival also depends heavily on food crops, whose production system is still traditional. Yet, according to ANDE-CI (2003), agriculture which employs most of the country's active populations is subject to the misuse of agricultural inputs. Indeed, there is really no crop calendar because of the coexistence of main and associated crops on the same cultivated plot (Anoh, 2014; Anoh et al., 2018b). The inadequacy between production systems and the country land use management policies has contributed to many problems, including the pollution of hydro systems. Studies conducted by several authors of whom.

Some researchers (Aké, 2010; Anoh et al., 2012, 2017, 2018a, 2018b; Brou, 2005; Eba et al., 2013; Jourda et al., 2006a, 2006b, 2007; Koua et al., 2013, 2014b, 2019), have considered agriculture as the

---

[*] Author to whom all correspondence should be addressed: e-mail: anohkoua@gmail.com; Phone: 022503101003

main source of pollutants of the country's hydro systems. Among agricultural pollutants, nitrogen and phosphorus occupy very important place. Indeed, although these nutrients are necessary for plant growth, their excessive contribution is visible in the hydrological behaviour of watersheds. Thus, at the Taabo river basin level (TRB) chosen as test area, the pollution of the hydro systems is marked by the sedimentation of Kossou Lake and the eutrophication of Taabo Lake (Aliko et al., 2010; Anoh et al., 2012; Anoh, 2014; Biémi and Loroux, 2000; Gourène et al., 1999; Groga, 2012; Kouassi, 2002). The sediments that fill the bottom of Kossou Lake contain important toxic pollutants that disrupt the biological balance of the water (Gourène et al., 1999). As for eutrophication, which occupy 26% of the Taabo Lake surface area since the 1990s (Anoh, 2014; Vei, 2005), has led among other things to an increase in the disparity in the sex ratio of species *D. Rostratus* in favour of males (Aliko et al., 2010; Aliko et al., 2015) and the dominance of *Chlorophytes, Cyanophytes* and *Euglenophytes* (Thomas, 2003). Aware of the problem of these water resources pollution, the Ivorian authorities have opted for curative actions (Anoh, 2014; Biémi and Loroux, 2000). However, these curative actions, with their high cost and sometimes uncertain outcome, have shown limited effectiveness over time. Moreover, their implementation has led to significant disruptions in the functioning of the basin's aquatic ecosystems. In addition, the works carried out by Anoh et al. (2012) and Anoh et al. (2018a) to protect these lakes through preventive perimeters also proved to be ineffective, due to the sensitivity of subjects linked to rural land in Côte d'Ivoire.

Therefore, there is a real need to find the right strategy to promote the development of the agricultural sector without compromising the perpetuity of hydrosystems. Vegetative filter strips fit out along watercourses have the potential to reduce agricultural non-point source pollution by intercepting much of sediment and nutrients that come from upstream fields (Chiang et al., 2012; Parajuli et al., 2008). Unfortunately, while the purifying efficiency of vegetative filter strips is recognized in most developed countries, these developments are non-existent in the basin. It is in this perspective that this study, whose theme is: "Application of the agro-hydrologic SWAT model on the Taabo river basin (Côte d'Ivoire) to evaluate the effect of three vegetative filter strip scenarios on streamflow and nutrient" was initiated. It thus responds to the objective of setting up a better land management tool adapted to the TRB through the proposal of prospective scenarios of best farming practices to be extended to all the basins of Côte d'Ivoire.

2. Material and methods

2.1. Study area

The Taabo River Basin (TRB) (Fig. 1) is within the quadrilater of coordinates: Universal Transversal Mercator (UTM) 30, North zone, bounded by longitudes 4°56' and 7°11' West and latitudes 6°07' and 10°33' North. It is a sub-basin of the Bandama watershed that covers a significant part of Côte d'Ivoire, i.e. about 30% of the country's total area.

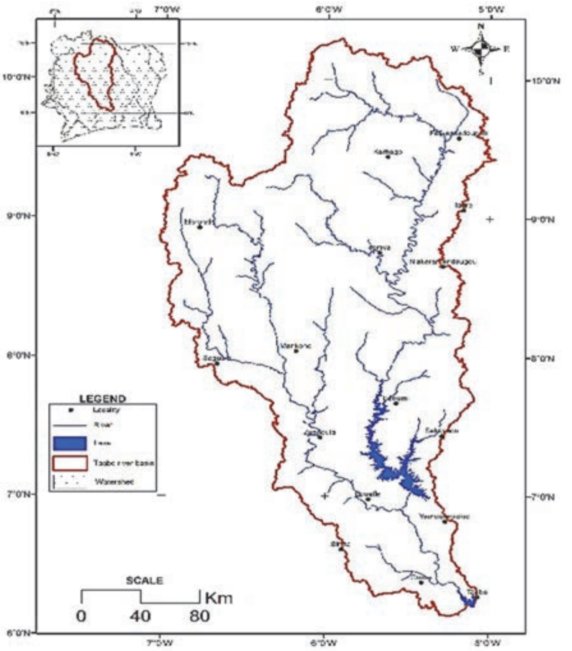


Fig. 1. Taabo river basin

The Taabo river basin (TRB) is a kind of umbilical cord connecting wetlands South areas to dry North regions. Its large surface area (60,154.26 km^2) has led to the construction of two large dams (Kossou and Taabo) whose main use is hydroelectricity (Anoh, 2014; Halle and Bruzon, 2006; Kouassi, 2007). Beyond to these two large lakes, 181 small water dams are also present in the watershed, among the 570 dams that Côte d'Ivoire has (Unicef, 2009). The value of the Gravelius index (Kg = 1.91) which characterizes the shape of the watershed (Laborde, 2000) shows that the TRB is elongated. The relief of the TRB is modest as a whole, but with a slight inclination from North to South.

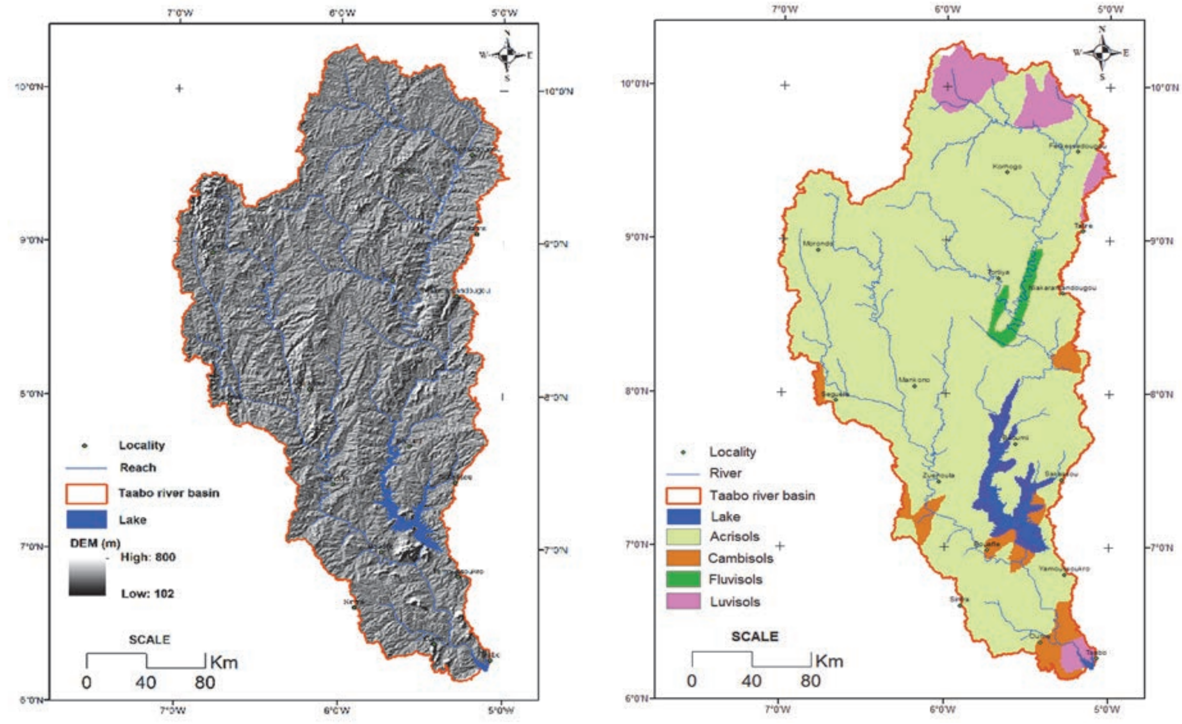
The average altitude is 310.34 m and the standard deviation of altitudes is 70.19 m (Anoh, 2014). At the soil level, the basin is mainly dominated by Acrisols, which are very acidic clay soils with a low cation exchange rate and a low saturation base (FAO et al., 1999).

In terms of climate, the northern part of the river basin is directly influenced by transitional tropical regimes characterized by two seasons (a rainy season and a dry season). The south of the basin is the domain of humid equatorial regimes. In this area, the long rainy season lasts four (4) months and occurs from March to June. Most of the basin (57.26%) is influenced by the attenuated transition equatorial climate. This climate also has four seasons. In addition to agriculture, activities such as fishing (Fig. 2a), mining (Fig. 2b) and farming (Fig. 2c) are also part of the daily life of the basin's populations.

2.2. Model input data

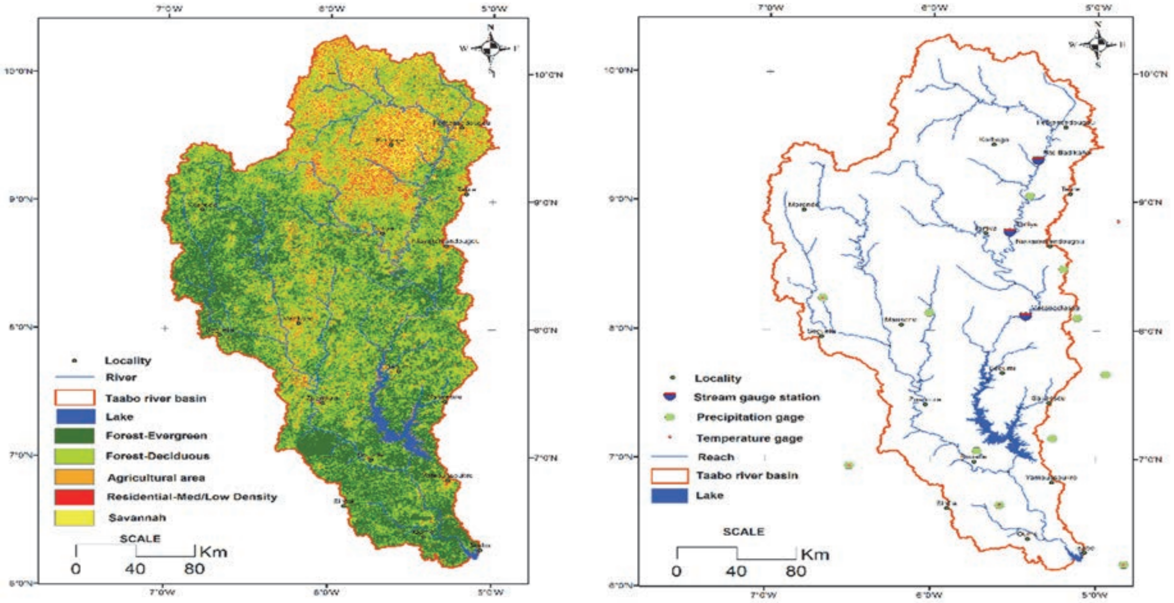
Two types of data were used in this study. They include raster data (Digital Elevation Model (DEM), soil and land use) and point data (climatic and hydrological). The digital elevation model (Fig. 3a) was obtained from Shuttle Radar Topography Mission (SRTM) images taken in 2000 with 1 arc-second (approximately 30 meters) of resolution. They were acquired free of charge via the American website ftp://e0srp01u.ecs.nasa.gov/srtm/version4/SRTM3/Africa. The soil map comes from work carried out by FAO in 1995 with a spatial resolution of 10 km, taking into account 5,000 soil types (Fig. 3b) with their physico-chemical properties from 0 to 100 cm deep (Schuol et al., 2008). The choice of this map is based on the availability of analyses of all the physico-chemical properties of soils made by Reynolds et al. (1999). The land use map (Fig. 3c) of the basin was obtained from Landsat 5 TM images. These images recorded on the periods of 07/01/1986 and 16/01/1986 were uploaded from the website http://earthexplorer.usgs.gov/. The daily climate data (rain and temperature) used in this study cover the period from 1971 to 1995 (Fig. 3d). They were generated thanks to monthly data from the climate research units (CRU) Schuol and Abbaspour (2007). Indeed, using the CRU monthly values for precipitation, minimum and maximum temperature and the number of wet days per month, Schuol and Abbaspour (2007) developed a semi-automated daily weather generator algorithm dGen, to obtain the required daily inputs. As for the hydrometric daily series (Fig. 3d), they come from the National Drinking Water Office (ONEP in french) of the Drinking Water Supply Department and extends from 1982 to 1990.

Fig. 2. Activity carried out by the population of Taabo River Basin: (a) fishing practice (b) gold panning, (c) traditional farming



(a)

(b)



(c) (d)

Fig. 3. SWAT input data: (a) Digital Elevation Model (b) soil map, (c) land use map, (d) hydro-meteorological stations

2.3. *Application of SWAT model*

The SWAT2009 (Soil and Water Assessment Tool) model used in this study is a deterministic, physical, conceptual, semi-distributed model that operates on a continuous basis with a daily time step (Arnold et al., 1993). SWAT was developed to simulate the impact of land use changes on hydrology, water quality and erosion. Its implementation requires the prior adaptation of standardized physiographic data for the entire American territory to the realities of Côte d'Ivoire in general and the TRB in particular. In the case of this study, the procedure implemented is described in three parts:

- As any hydrological model, the SWAT model requires a spatial discretization of the watershed and its subbasins. The size and number of sub-basins to be discretized varies according to the size of the entire watershed and stream network. Consequently, the Taabo river basin was discretized into a total of 108 subbasins with a smallest draining area of 350 km^2;

- SWAT then identifies hydrological response units (HRUs) within each sub-watershed, based on soil, land use, and slope. HRUs are the spatial unit where the horizontal and vertical flows of water and nutrients are calculated, then aggregated and summed for each subbasin. In order to increase the accuracy of the model, several HRUs were discretized in each sub-basin. The threshold of the area of land use, soil and slope have been set to 20%, 10% and 20% respectively. The threshold value is used to eliminate in the discretization of the HRUs, all the areas with surface less than the predefined HRU threshold. Afterward model will proceed to create the database tables;

- The creation of the database tables consists in summarizing the files of the physico-chemical characteristics of the TRB, sub-basins, HRUs, flow channels, groundwater, soils, weather, water use and agricultural practices. In this study, evapotranspiration was calculated using the Hargreaves equation, water flow by the variable storage method and runoff by the Curve Number (CN) method.

2.4. *Evaluation of SWAT model performance*

Moriasi et al. (2007) recommend to evaluate the performance of SWAT model graphically and statistically. Graphic techniques consist of a visual comparison between observed and simulated values. As for statistical techniques, they are based on equations, also known as objective functions. The evaluation of the Taabo's SWAT model performance has consisted of statistically and graphically studying the difference between the observed data and those simulated by the model. That is based respectively on two techniques: calibration and validation. To this end, the interannual variability of rainfall data from the distribution of wet and dry years made it possible to partition hydrological series in warming periods (1979-1981), calibration (1982-1986) and validation (1987 to 1990). This discretization of large seasonal variations is based on the Nicholson index carried out by Anoh (2014). The calibration period is wetter than the validation period. To reduce subjectivity due to the modeler during data collection and model configuration (Bastina et al., 2013; Refsgaard et al., 2007), a mathematical algorithm Sequential Uncertainty Fitting, version 2 (SUFI-2) included in the SWAT-CUP software (Abbaspour, 2013) was used. SWAT-CUP is an external software tool allowing SWAT users to realize automatic calibration with more comfort and efficiency (Arnold et al., 2012). In this algorithm, the extent to which all uncertainties are represented is assessed by a parameter referred to as the p-factor and r-factor. The p-factor is the percentage of the measured data bracketed by the 95% prediction uncertainty (95PPU). As for the r-factor, it indicates the thickness of the 95PPU band and it is calculated as the average distance between the upper and lower 95PPU divided by standard deviation of the observed data. The estimation of the p-factor ranges from 0 to 100%, while that of the r-factor ranges from 0 to infinite. When acceptable values of r-factor and p-factor are reached, further goodness of fit can be quantified by objective function.

2.4.1. Objective function

To quantify divergence between model results and observations, two objective function were used. The visual objective function gives an overview of the model's performance through histograms showing the evolution of flood peaks and base flows. The statistical objective function is evaluated by statistical equations; in particular, the Nash-Sutcliffe coefficient (***NS***) (Eq. 1) and the $\boldsymbol{R^2}$ determination coefficient (Eq. 2) (Table 1).

2.4.2. Sensitivity analysis of hydrological parameters

The sensitivity analysis identified the most influential parameters. The selection of hydrological parameters for sensitivity analysis was based on previous studies conducted by Anoh (2014); Anoh et al. (2017, 2018a, 2018b); Koua et al. (2013, 2014a, 2014b, 2019) with the SWAT model in Côte d'Ivoire. The hydrological parameters selected were individually analysed (one-factor-at-the-time) following the evolution of the hypercube-latin curve (latin-hypercube (LH)) in the SUFI2 algorithm (Schuol et al., 2008). A global analysis was then carried out to take into account the effect of the interactions between the parameters. Global sensitivity analysis, in contrast, allows changing random parameters simultaneously over their entire range.

2.4.3. Sensitivity analysis of physicochemical parameters

In most studies with SWAT model, hydrological data, although sometimes of poor quality, are available at a continuous time step. This feature is not observed in the water chemical data. Indeed, the discontinuity of the available nitrate and organic phosphorus data did not allow the chemical sensitivity analysis and consequently a calibration of these. However, according to Probst (1985) and Rollo (2012), phosphorus and nitrogen are closely linked to the water flows that carry them, their evolution could be visualized from the hydrological phase of the model. We are aware that the lack of observed agronomic data leads to a loss of accuracy of the simulated values. However, this precision can be considered sufficient in relation to the current level of general field knowledge for an interannual analysis of the agro-hydrological functioning of the catchment area. Thus, the nutrients will give an overall view of the pollution status of the sub-basin.

2.4.4. Simulation of the vegetative filter strips implementation

Previous studies by Anoh et al. (2012, 2014, 2017, 2018a, 2018b) revealed the complexity of the basin's land use. Thus, in order to sustainably protect the TRB's water system, three vegetative filter strip (VFS) scenarios have been implemented in the subbasins having a high value both of organic nitrogen and organic phosphorus fluxes. They consist in maintaining or planting a vegetation cover in the banks. The different simulated scenarios are:

- scenario 1 = ratio of field area to VFS area is 40;
- scenario 2 = ratio of field area to VFS area is 50;
- scenario 3 = ratio of field area to VFS area is 60.

Table 2 summarizes all the sub-basins concerned by these filtering vegetative strips. The duration of this test extends over the period from 1982 to 1986 (period of best restitution of physical phenomena).

3. Results and discussion

3.1. Model calibration and validation

Two iterations of 150 simulations each of the algorithm SUFI2 made it possible to calibrate the model. A total of nine (09) sensitive hydrological parameters on the 629 parameters were identified for calibration and validation (Table 3). The global sensitivity analysis approach, which considers the sensitivity of one parameter relative to the other parameters considered (Abbaspour, 2013), was used to determine the most sensitive parameters in this study.

Table 1. Statistical objective function of the SWAT model

Name	*Performance criteria*	*Meaning*	*Meaning*	*Source*
NS	$1-\sum_{i=1}(Q_m-Q_s)^2/-\sum_{i=1}(Q_m-QM)^2$ (1)	-∞	Very poor adjustment	(Moriasi et al., 2007)
		> 0.5	Acceptable adjustment	
		1	Perfect model	
$\mathbf{R^2}$	$[\sum_{i=1}(Q_m-QM)(Q_s-QS)]^2/\sum_{i=1}(Q_m-QM)^2\sum_{i=1}(Q_s-QS)2$ (2)	0	Very poor adjustment	(Santhi et al., 2001)
		0.5	Acceptable adjustment	
		1	*Perfect model*	

Note: Q_m *= observed flow,* Q_s *= simulated flow, QM = average of measured flows and QS = average of simulated flows.*

Table 2. Scenarios of changes in cropping practices

Sub-basins	*Soil*	*Land use*	*Slope*	*Scenario 1*	*Scenario 2*	*Scenario 3*
8, 9, 11, 15, 21, 27, 28, 72, 81, 84, 89	All	All	> 5 %	40	50	60

Global sensitivity of these parameters was measured by the value of the t-test and p-value. The first and most important parameter taken into account is the SCS Curve Number for moisture condition II (CN2). The CN2 is a function of the soil's permeability, land use and antecedent soil water conditions. According to Neitsch et al. (2011) and Winchell et al. (2009), a high CN2 results in increasing of surface runoff of flood peaks and slowing of lateral flow. On the other hand, when CN2 is low, the rain soaks in and contributes to filling soil reservoirs. On the other hand, when CN2 is low, rainfall penetrates and helps to fill soil reservoirs. In this study, most of the CN2 had to be lowered for the different land uses. Since runoff is low, the intensity of runoff should be compensated. Thus, a second sensitive parameter (baseflow alpha factor (ALPHA_BF)) was considered by the model. The ALPHA_BF is a direct index of the groundwater flow response to a change in recharge. Its value close to zero indicates that few or no water is coming out of the deep groundwater table. Its increase to 0.2 indicates that the TRB sub-basins have a rapid response to recharge. On the other hand, the water table contributes to compensation for evaporation. To regulate the exchanges between the river and water table, the model included physical parameters of the channels that control surface runoff. Thus, the hydraulic conductivity of the riverbed (CH_K2) which influences the exchanges between the river and the water table and thus makes the river less impermeable (0 mm/h by default) was increased to 182 while the "n" value of Manning's roughness for the main channel (CH_N2) which affects the concentration time and therefore the flood dynamics was reduced to 0.08. The adjustment of these parameters leads to a reduction of flood dynamics. Consequently, the groundwater delay (GW_DELAY) which is the fifth sensitive parameter was evaluated.

This parameter expresses the time lag between when water leaves the soil profile and when it enters the shallow aquifer. This delay depends on the depth of the water table and the hydraulic properties of the geological formations in the vadose zones. Since the TRB is located in the basement area, the GW_DELAY was increased to 350 days. In the TRB, the maximum canopy storage (CANMX) is greater than that defined by the model. Therefore, this parameter was increased to 71.04. Its increase of 0.25% increased the recovery time for simulated flows. To also regulate the different flows between evaporation and percolation, the soil available water capacity (SOL_AWC) was considered. As soils store more water, this should logically lead to a reduction in runoff and/or infiltration, and an increase of evaporation. To remove excess water from the soil surface, the soil evaporation compensation factor (ESCO) was increased to 0.5.

The calibrations and validation were conducted in several tributary catchments (three sites). It was found that the SWAT model produced a good simulation performance in the study area because it offered realistic simulations of streamflow. Indeed, according to the statistical performance criteria (Table 4), the ***NS*** values for calculated versus observed daily streamflow of the three subbasins ranged from 0.67 to 0.87 for the calibration period and higher than 0.5 for the validation period as suggested by Abbaspour et al. (2015), Chaponnière (2005), Sintondji et al. (2013). For the same gages' stations, the R^2 coefficients ranged from 0.68 to 0.87 and higher than 0.5 respectively for the calibration and validation period. Unlike to the calibration period, the validation period is full of uncertainties.

Indeed, the analysis of performance chart shows that the gap between observed and calculated data in general is major (Fig. 4). This remark was confirmed by the work of Anoh (2014); Anoh et al. (2017, 2018b).

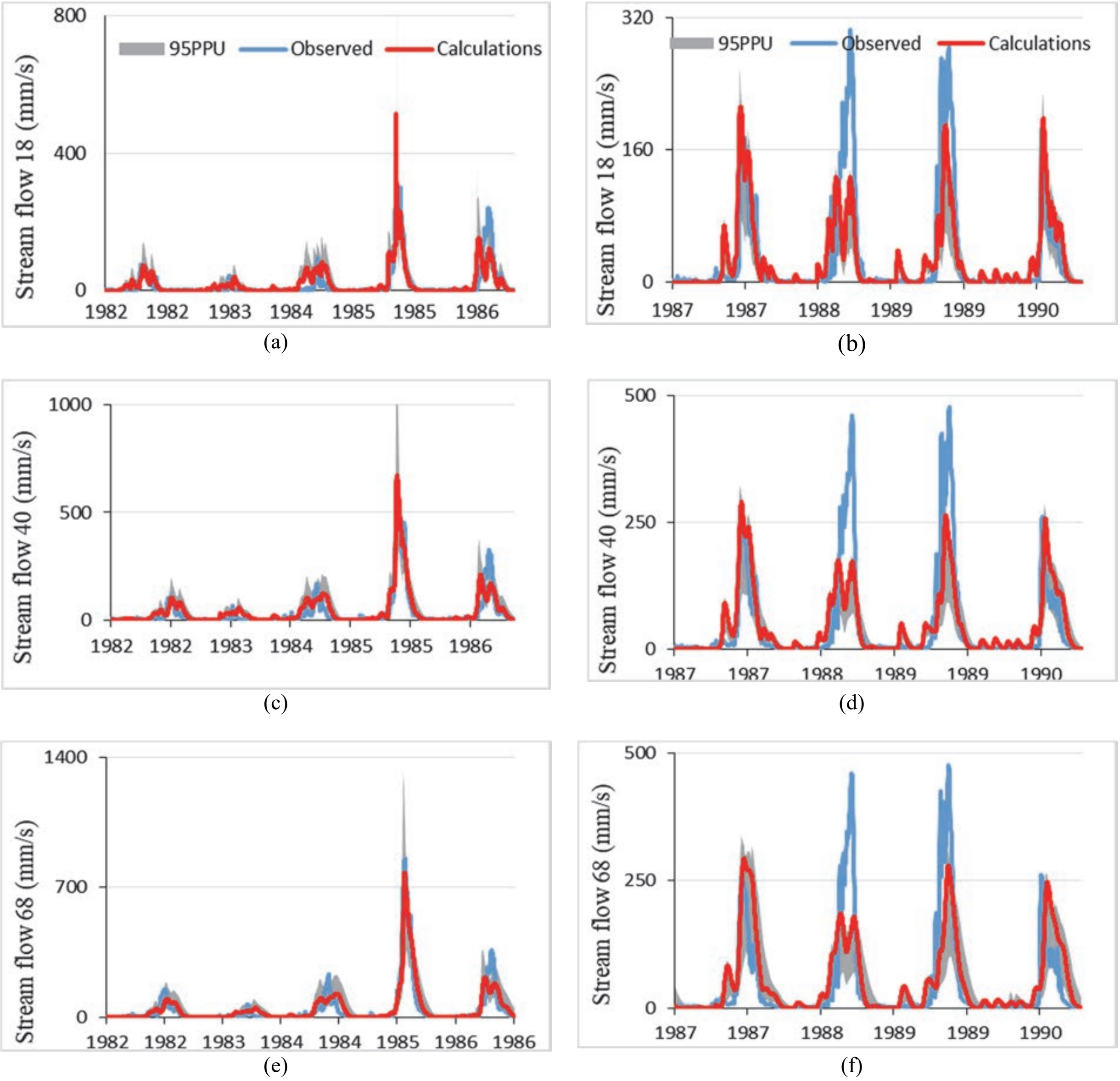
Table 3. Sensitive parameters

N°	*Parameters*	*Default value*	*Final calibrated value*
1	SCS runoff curve number (CN2)a	74.00 – 98.00	35.52 – 181.3
2	Base flow alpha factor (ALPHA_BF)	0.05	0.2
3	Effective hydraulic conductivity in the main channel (CH_K2)	0.00	182.07
4	Effective hydraulic conductivity in the main channel (CH_N2)	0.14	0.08
5	Groundwater delay time (GW_DELAY)	31.00	350.23
6	Maximum canopy storage (CANMX)	0.00	71.04
7	Soil available water capacity (SOL_AWC)b	0.00 – 1.19	0.00 – 1.44
8	Threshold contribution of the shallow aquifer (GWQMN)	0.00	2,480.45
9	Soil evaporation compensation factor (ESCO)	0.00	0.5

Note: a = inclusion of land use type; b = inclusion of soil texture

Table 4. Parameters evaluating the performance of the model

	CALIBRATION				*VALIDATION*			
Variable	*p-factor*	*r-factor*	R^2	*NS*	*p-factor*	*r-factor*	R^2	*NS*
Streamflow 18	0.34	0.61	0.68	0.67	0.39	0.42	0.6	0.6
Streamflow 40	0.44	0.59	0.85	0.83	0.46	0.43	0.61	0.6
Streamflow 68	0.64	0.56	0.87	0.87	0.53	0.58	0.56	0.56



(a) (b) (c) (d) (e) (f)

Fig. 4. Comparisons of the daily observed and calculated streamflow hydrographs for calibration (a, c and e) and validation (b, d and f) period

Obtaining a good simulation performance is not only dependent on good data quality, but also on the processes modeled by SWAT. Poor performance of the SWAT model has been obtained in some cases of inadequate representations of rainfall stations (Cao et al., 2006; Obuobie, 2008). Thus, according to the quality indicators, the model's performance can have several causes. Among other things, it may be due to the quality of available climate data. Indeed, the number and location of rain stations has reduced the performance of Taabo's SWAT model. Out of the 108 subbasins discretized, only 11 rainfall stations and 5 temperature stations are present on the TRB. The other stations were obtained by interpolation. However, according to Jourda et al. (2006a), since interpolation can lead to errors in the achievement of parameters, is only reliable within the intervals delimited by the point data. The performances of the Taabo's SWAT model can be enhanced furthermore by integration of some other climatic data such as solar radiation, humidity and wind. In addition to the climatic data, the small-scale of soil map does not clearly define the different layers. This gap has reduced the discretization of HRUs and consequently the accuracy of the model's predictions (Neitsch et al., 2011). According to Gassman et al. (2007), the performance of the Taabo's SWAT model can also be due to the model parameterizing. Indeed, the HRU approach represents a gap in pollutant modelling in that it does not take into account the flow and pathways of pollutants within the subbasin.

3.2. Impact of vegetative filter strips

The map of organic phosphorus and nitrogen flow (Fig. 5) is the average of the flow transmitted by channels of a subbasin. The analysis of these maps shows very strong releases of organic nitrogen and phosphorus in the Centre of the TRB precisely in the subbasins 8, 9, 11, 15, 21, 27, 28, 72, 81, 84 and 89.

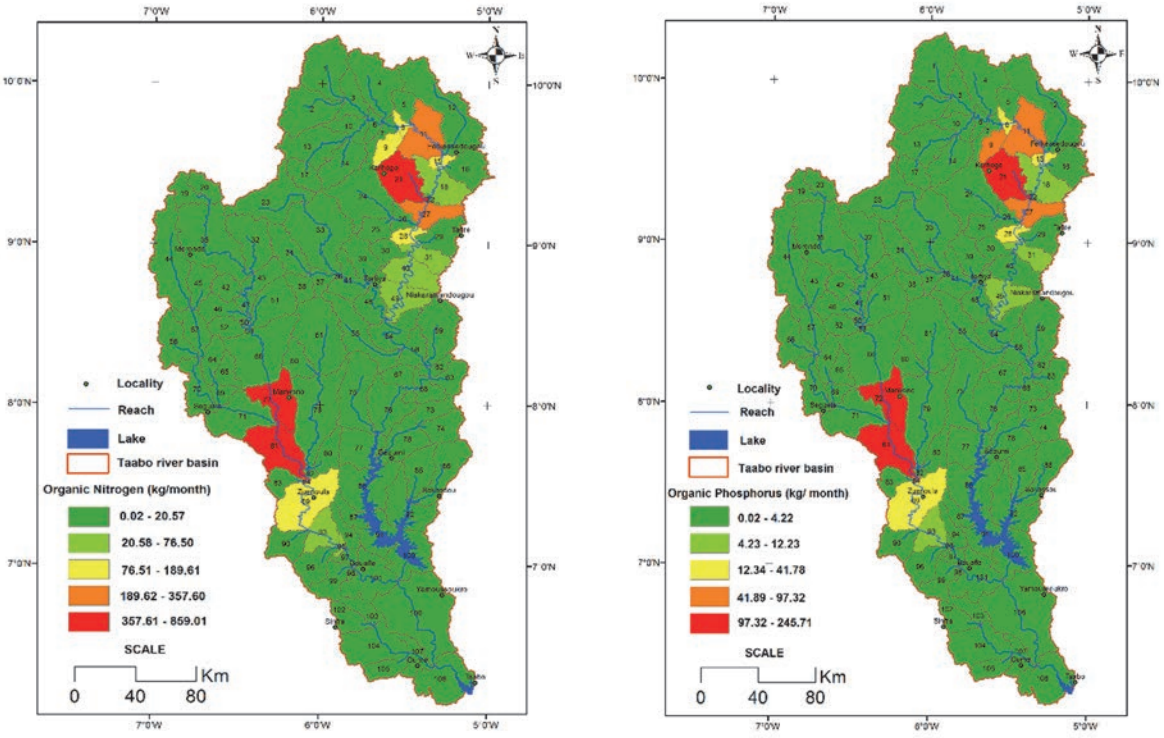
The masses of organic nitrogen released into the hydrographic network vary between 126.34 and 859.01 kg per month (Fig. 5a). As for organic phosphorus, the masses released into the hydrographic network vary between 25.90 and 245.71 kg per month (Fig. 5b).

Although of natural origin, the intense nutrient flows in these parts of the basin are due to agriculture. It should therefore be pointed out that most cities in Côte d'Ivoire are at the mercy of gold panning. Among others, the localities of Yaouré, Tongon, Tortiya, Séguéla and Angovia, in addition to being agricultural areas, are home to aluminium, gold, carbon and diamond mines. The latter, through the creation of ditches and the conservation of bare surfaces, cause pollution of downstream systems. Similarly, according to the work of ANDE-CI (2003), the misuse of agricultural inputs by the populations could reflect this nutrient enrichment in Lakes.

The implementation of vegetative filter strips in sensitive subbasins could have a positive impact on nutrient flows. Indeed, nutrients not absorbed by the crops have been partly consumed by the vegetative filtering strips located in the banks. On average, the best rate of reduction of organic nitrogen transported with water in the hydrographic network (ORGN_IN) during the calibration period was observed with scenario 3 (Table 5).

As for the organic phosphorus flux transported with water in the river system (ORGP_IN) during the calibration period, its concentration was also less present in the hydrographic network with scenario 3 (Table 6).

The approach to reducing pollutant loads by targeting sub-basins vulnerable to pollution has been approved by Parajuli et al. (2008). Thus, when the vegetative filter strip is wide then less nutrients reach the river system. However, it is noticed that, the water takes enough time to reach the stream. But, according to Sahu and Gu (2009), the choice of the scenario to be implemented must be motivated by economic reasons. The TRB's lakes were created for hydroelectricity purposes. Thus, given the main use of the lakes, scenario 2 is best suited to the agro-climatic conditions of the Taabo river basin. Moreover, it would be utopian to impose a fairly large area of vegetative filtering strip in this region of Côte d'Ivoire where rural land issues are always source of conflict.



(a) (b)

Fig. 5. Spatial distribution of organic nitrogen (a) and organic phosphorus (b) flows by subbasin

Table 5. Impact of the VFS implementation on organic nitrogen flows

	STANDARD	***SCENARIO I***	***SCENARIO II***	***SCENARIO III***
SUB-BASIN	***ORGN_IN (kg N)***			
8	133.142	132.649	132.511	133.415
9	189.617	189.447	189.018	189.819
11	305.94	305.462	304.557	305.767
15	126.336	126.203	125.761	126.389
21	639.791	638.942	637.957	638.65
27	351.446	350.962	350.223	350.44
28	167.37	167.139	166.774	166.79

72	791.397	583.371	582.935	575.727
81	859.01	691.978	693.026	678.918
84	357.6	320.784	324.912	312.279
89	149.729	139.44	142.556	134.247
AVERAGE	370.125	331.489	331.839	328.404
TOTAL	4,441.503	3,977.866	3,982.069	3,940.845

Table 6. Impact of the VFS implementation on organic phosphorus flows

	STANDARD	***SCENARIO I***	***SCENARIO II***	***SCENARIO III***
SUB-BASIN	***ORGP_IN (kg P)***			
8	41.786	41.632	41.587	41.882
9	62.608	62.551	62.405	62.676
11	97.323	97.187	96.881	97.26
15	29.229	29.208	29.096	29.237
21	211.233	210.951	210.611	210.857
27	90.469	90.357	90.148	90.211
28	33.854	33.811	33.732	33.736
72	245.705	174.204	173.674	171.425
81	240.484	187.154	186.943	183.274
84	75.82	66.7	67.447	64.848
89	25.903	23.849	24.316	22.831
AVERAGE	104.947	92.509	92.440	91.658
TOTAL	1,259.361	1,110.113	1,109.280	1,099.895

4. Conclusions

Fighting agricultural pollution while helping TRB farmers to adopt appropriate land management techniques are challenges that this study faces. In this study the ArcSWAT2009 interface implemented in the ArcGIS10 software was used in order to implement three scenarios of vegetative filter strips. The calibration of the model showed a good performance of the SWAT model with all objective functions greater than 0.65 and validation greater than or equal to 0.6.

It has been found that scenario 2 (ratio of field area and VFS of 50) with an average balance of 331.839 kg of organic nitrogen and 92.440 kg of organic phosphorus released into the hydrographic network, proved to be the most effective and most adapted to the social and agro-economic conditions of the TRB.

This study, although theoretical requires a practical phase in order to find the best width and type of plant to implement.

Acknowledgments

The authors wish to thank Dr Gabriel Lazar at the Vasile Alecsandri University of Bacau for his help in building the model. The authors would also like to thank the Romanian Government through the "Eugen Ionescu" scholarship of the Francophonie University Agency (AUF).

References

Abbaspour C.K., (2013), *SWAT-CUP 2012: SWAT Calibration and Uncertainty Programs*, A User Manual, Eawag: Swiss Federal Institute of Aquatic Science and Technology, On line at: https://swat.tamu.edu/media/114860/usermanual_swatcup.pdf

Abbaspour K.C., Rouholahnejad E., Vaghefi S., Srinivasan R., Yang H., Kløve B., (2015), A continental-scale hydrology and water quality model for Europe: Calibration and uncertainty of a high-resolution large-scale SWAT model, *Journal of Hydrology*, **524**, 733-752.

Aké G.E., (2010), *Impact of climate variability and anthropogenic pressure on waters resources in the Bonoua region* (*South-east of Côte d'Ivoire*), (in French), PhD Thesis, University Félix Houphouet Boigny, Abidjan, Côte d'Ivoire.

Aliko N.G., Assemian N.E., Boussou K.C., Konan K.F., (2015), Some biological characteristics of ten fish species in a tropical man-made lake, Taabo reservoir, West Africa, *American Scientific Research Journal for Engineering, Technology, and Sciences*, **14**, 27-34.

Aliko N.G., Da Costa K.S., Dietoa Y.M., Ouattara A., Gourène G., (2010), Characteristics of the Distichodus rostratus Günther, 1864 (pisces: Distichodontidae) population from the Taabo dam lake (Bandama basin, Côte d'Ivoire). Implications for rational stock management, (in French), *Tropicultura*, **28**, 50-56.

ANDE-CI, (2003), Taabo environmental profile, (in French), Ministry of Construction and Living Environment, Abidjan, Ivorian Ministry of Environment and Sustainable Development.

Anoh K.A., (2014), *Contribution of a GIS and agro-hydrological SWAT model in the sustainable management of water resources in the catchment area of Taabo Lake (Center of Côte d'Ivoire),* (in French), PhD Thesis, University Félix Houphouët Boigny, Abidjan, Côte d'Ivoire.

Anoh K.A., Jourda J.P., Kouamé K.J., Koua T.J.J., Éba E.A.L., Lazar G., (2012), Demarcation of protection perimeters for surface waters of Taabo (Ivory Coast) watershed using GIS and multicriteria analysis, *Environmental Engineering and Management Journal*, **11**, 2123-2131.

Anoh K.A., Koua T.J.J., Eblin S.G., Kouamé K.J., Jourda J.P., (2017), Modelling freshwater availability Using SWAT Model at a Catchment-Scale in Ivory Coast, *Journal of Geoscience and Environment Protection*, **05**, 70-83.

Anoh K.A., Koua T.J.J., Eblin S.G., Koudou A., Kouamé K.J., Jourda J.P., Lazar G., (2018a), Mapping of the Lake Taabo watershed surface waters intrinsic vulnerability in Côte d'Ivoire to diffuse phosphorus fluxes, (in French), *Revue Internationale des Sciences et Technologie*, 131-152.

Anoh K.A., Koua T.J.J., Kouamé K.J., Jourda J.P., Laurent F., (2018b), Modelling water flow in a complex watershed in humid a tropical area using swat: a case study of Taabo watershed in Ivory Coast, *International Journal of River Basin Management*, **16**, 157-167.

Arnold J.G., Allen P.M., Bernhardt G., (1993), A comprehensive surface-groundwater flow model, *Journal of Hydrology*, **142**, 47-69.

Arnold J.G., Moriasi D.N., Gassman P.W., Abbaspour K.C., White M.J., Srinivasan R., Santhi C., Harmel R., Van Griensven A., Van Liew M.W., (2012), SWAT: Model use, calibration, and validation, *Transactions of the ASABE*, **55**, 1491-1508.

Bastina L., Cornford D., Jones R., Heuvelink G.B.M., Pebesma E., Stasch C., Nativi S., Mazzetti P., Williams M., (2013), Managing uncertainty in integrated environmental modelling: The UncertWeb framework, *Environmental Modelling and Software*, **39**, 116-134.

Biémi J., Loroux B.F., (2000), *Impacts of major development projects on Côte d'Ivoire's environment. Preliminary environmental impact study* (in French), Research report, JICA-High Commission for Waterworks, Abidjan, Cote d'Ivoire.

Brou Y.T., (2005), *Climate, socio-economic changes and landscapes in Côte d'Ivoire* (in French), PhD Thesis, University of Science and Technology, Lille, France.

Cao W., Bowden W.B., Davie T., Fenemor A., (2006), Multi-variable and multi-site calibration and validation of SWAT in a large mountainous catchment with high spatial variability, *Hydrological Processes*, **20**, 1057-1073.

Chaponnière A., (2005), *Hydrological functioning of a semi-arid mountainous watershed: case of the Rehraya watershed (Moroccan High Atlas)* (in French), PhD Thesis, National Agronomic Institute, Paris-Grignon, France.

Chiang L.C., Chaubey I., Hong N.M., Lin Y.P., Huang T., (2012), Implementation of BMP strategies for adaptation to climate change and land use change in a pasture-dominated watershed, *International Journal of Environmental Research and Public Health*, **9**, 3654-3684.

Eba A.E., Kouamé K.J., Jourda J.P., Aké G.E., Saley M.B., Anoh K.A., Deh S.K., (2013), Demarcation of surface water protection perimeters by using GIS: Case of Gagnoa Reservoir in West Central of Côte d'Ivoire, *International Journal of Scientific & Engineering Research*, **4**, 1311-1320.

FAO, ISRIC, AISS, (1999), World reference base for soil resources, World Soil Ressources Reports N°84, Rome, Italy, On line at: http://www.fao.org/3/a-w8594f.pdf.

Gassman P.W., Reyes M.R., Green C.H., Arnold J.G., (2007), The soil and water assessment tool: historical development, applications, and future research directions, *Transactions of the ASABE*, **50**, 1211-1250.

Gourène G., Teugels G.G., Hugueny B., Thys V.D.A., (1999), Assessment of the ichthyological diversity of a West African basin after the construction of a dam, (in French), *Cybium*, **23**, 147-160.

Groga N., (2012), *Structure, functioning and dynamics of phytoplankton in Taabo lake (Côte d'Ivoire)* (in French), PhD Thesis, Toulouse University, France.

Halle B., Bruzon V., (2006), Environmental Profile of Côte d'Ivoire, (in French), *2006/119741/1.*

Jourda J.P., Kouamé K.J., Adja M.G., Deh S.K., Anani A.T., Effini A.T., Biémi J., (2007), *Assessment of the groundwater protection degree: vulnerability to Bonoua aquifer pollution (south-eastern Côte d'Ivoire) using the DRASTIC method* (in French), Act of Francophone Conference-ESRI, 10-11 October, Versailles, France.

Jourda J.P., Kouamé K.J., Saley M.B., Kouadio B.H., Oga Y.S., Deh S.K., (2006a), *Contamination of the Abidjan Aquifer by Sewage: An Assessment of Extent and Strategies for Protection*, In: *Groundwater Pollution in Africa*, Xu Y., Brent U., (Eds.), Taylor & Francis/Balkema, Great-Britain, 291-300.

Jourda J.P., Kouamé K.J., Saley M.B., Kouamé K.F., Kouadio B.H., Kouamé K.J., (2006b), *A New Cartographic Approach to Determine the Groundwater Vulnerability of the Abidjan Aquifer*, In: *Groundwater Pollution in Africa*, Xu Y., Brent U., (Eds.), Taylor & Francis/Balkema, Great-Britain, 103-114.

Koua J.J.T., Anoh A.K., Soro D.T., Kouame J.K., Jourda R.J.P., (2019), Evaluation of agricultural practices scenarios for reducing erosion in Buyo Lake Catchment (Sassandra; Côte d'Ivoire) by use of GIS, *Journal of Geoscience and Environment Protection*, **7**, 154-171.

Koua T.J.J., Jourda J.P., Kouame K.J., Anoh K.A., (2013), Assessment of sediment and pollutants in Buyo Lake, Ivory Coast, using SWAT (Soil and Water Assessment Tool) model, *Journal of Chemistry and Chemical Engineering*, **7**, 1054-1059.

Koua T.J.J., Jourda J.P., Kouame K.J., Anoh K.A., Balin D., Lane S.N., (2014a), Potential climate change impacts on water resources in the Buyo Lake Basin (Southwest of Ivory Coast), *International Journal of Innovation and Applied Studies*, **8**, 1094-1111.

Koua T.J.J., Jourda J.P., Kouame K.J., Anoh K.A., N'Dri W.K.C., Lazar G., Lane S., (2014b), Effectivness of soil and water assessment tool model to simulate water flow in a large agricultural complex watershed: Case of Buyo Lake Basin, West of Côte D'Ivoire, *Environmental Engineering and Management Journal*, **13**, 1735-1742.

Kouassi K.L., (2002), *Hydrology and sedimentation of the hydroelectric dam of Taabo lake: State of the morphology of the lake bottom* (in French), Advanced Study Diploma Thesis, Abobo-Adjamé University, Abidjan, Côte d'Ivoire.

Kouassi K.L., (2007), *Hydrology, solid transport and modelling of sedimentation of hydroelectric dams in Côte d'Ivoire lakes: Case of Taabo lake* (in French), PhD Thesis, Abobo-Adjamé, Abidjan, Côte d'Ivoire.

Laborde J.P., (2000), *Elements of Surface Hydrology* (in French), U.d. Nice (Ed.), Fascicule, CNRS. Sophia Antipolis.

Moriasi D.N., Arnold J.G., Van Liew M.W., Bingner R.L., Harmel R.D.,Veith T.L., (2007), Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, *Transactions of the ASABE*, **50**, 885-900.

Neitsch L.S., Arnold J.G., Kiniry J.R., Williams J.R., (2011), Grassland, Soil and Water Research Laboratory – Agricultural Research Service. Blackland Research Center – Texas Agricultural Experiment Station. Texas Water Resources Institute, College Station, Texas TWRI Technical Report TR, **192**, 472.

Obuobie E., (2008), *Estimation of groundwater recharge in the context of future climate change in the White Volta River Basin. West Africa*, PhD Thesis, University of Bonn, Germany.

Parajuli P.B., Mankin K.R., Barnes P.L., (2008), Applicability of targeting vegetative filter strips to abate fecal bacteria and sediment yield using SWAT, *Agricultural Water Management*, **95**, 1189-1200.

Probst J.L., (1985), Nitrogen and phosphorus exportations in the Garonne Basin (France), *Journal of Hydrology*, **76**, 281-305.

Refsgaard J.C., Sluijs J.P., Højberg A.L., Vanrolleghem P.A., (2007), Uncertainty in the environmental modelling process - A framework and guidance, *Environmental Modelling and Software*, **22**, 1543-1556.

Reynolds C.A., Jackson T.J., Rawls W.J., (1999), Estimating available water content by linking the FAO soil map of the world with global soil profile database and pedo-transfer functions, *Water Resources Research*, **36**, 3653-3662.

Rollo N., (2012), *Modelling the diffuse pollution dynamics in the Auray river watershed. Quantification, characterization and management of terrigenous nutrient inputs* (in French), PhD Thesis, Nantes University, France.

Sahu M., Gu R.R., (2009), Modeling the effects of riparian buffer zone and contour strips on stream water quality, *Ecological Engineering*, **35**, 1167-1177.

Santhi C., Arnold J.G., Williams J.R., Dugas W.A., Srinivasan R., Hauck L.M., (2001), Validation of the swat model on a large rwer basin with point and nonpoint sources, *Journal of the American Water Resources Association*, **37**, 1169-1188.

Schuol J., Abbaspour C.K., Srinivasan R., Yang H., (2008), Estimation of freshwater availability in the West African sub-continent using the SWAT hydrologic model, *Journal of Hydrology*, **352**, 30-49.

Schuol J., Abbaspour K.C., (2007), Calibration and uncertainty issues of a hydrological model (SWAT) applied to West Africa, *Advances in Geosciences*, **9**, 137-143.

Sintondji L.O., Dossou Y.E.R., Kossi A., (2013), Modelling the hydrological balance of the Okpara catchment at the Kaboua outlet in Benin, *International Journal of AgriScience*, **3**, 182-197.

Thomas C.S., (2003), Protist phylogeny and the high-level classification of Protozoa, *European Journal of Protistology*, **39**, 338-348.

Unicef, (2009), Feasibility study of manual drilling. Identification of potentially favourable areas (in French), Technical report, study carried out in collaboration with the Water and Sanitation Direction of the Ministry of Water, Partica Foundation, Enterprise Works/VITA, Côte d'Ivoire.

Vei K.N., (2005), *Monitoring and evaluation of the socio-temporal impact of a land development project in West Africa. Example of the Taabo dam in Côte d'Ivoire. Contribution of remote sensing and GIS*, (in French), PhD Thesis, University of Cocody, Abidjan, Côte d'Ivoire.

Winchell M., Srinivasan R., Di Luzio M., Arnold J., (2009), Arc SWAT interface for SWAT 2009, Users' guide, On line at: file:///C:/Users/ENV/Desktop/ArcSWAT2009Englishtextbook.pdf.