International Journal of AgriScience Vol. 4(1): 74-88, January 2014 *www.inacj.com*
ISSN: 2228-6322© International Academic Journals

Modelling the water balance of Ouémé catchment at the Savè outlet in Benin: contribution to the sustainable water resource management

Sintondji Luc Ollivier [1*], Zokpodo Barnabé [1], Ahouansou D. Maurice [1], VISSIN W. Expédit [2], Agbossou Kossi Euloge [1]
[1]Laboratory of Hydraulics and Water Control, Faculty of Agronomic Sciences, University of Abomey-Calavi, Benin. Author for correspondence (email: o_sintondji@yahoo.fr)
[2]Faculty of Letters, Arts and Human Sciences, University of Abomey-Calavi, Benin

Received November; accepted in revised form December 2013

ABSTRACT

The present modelling study carried out on the water balance of Ouémé catchment at the Savè outlet (23,000 km^2), had its main objective as to assess the water availability of the basin. To achieve, the agro hydrological model SWAT (Soil and Water Assessment Tool) was used. With this model the Hydrological Response Units (HRUs) were generated and used as spatial units for the evaluation of all water balance components and transport of soil particles. Within the SWAT model, surface runoff has been estimated by the runoff curves number method. Soil water was measured by the method of routing with storage and the actual evapotranspiration has been quantified using Penman - Monteith method. Meanwhile, the erosion in this catchment has been estimated with the modified universal soil loss equation. Digital elevation model (DEM), soil characteristics, vegetation parameters, climate data and farming practices were the principal data of the study area that have been integreated into the model. After the model calibration and validation, it was realised that runoff, actual evapotranspiration and the total groundwater recharge represent respectively 7.8 % ; 73 % and 18.8 % of the total annual rainfall. Regarding erosion, an average value of 4.4t/ha/a was obtained for the watershed with a maximum value for the croplands with ridges parallel to the slope (20/ha/a) whereas plots with ridges perpendicular to the slope have showed 9.3t/ha/a. Using these results some suggestions have been made for a sustainable water resources management.

Keywords: Benin, catchment , sustainable, water balance

INTRODUCTION

Benin like all West Africa countries, has increasingly been experiencing climate fluctuations since 1970. This has manifested itself, particularly through changes in the rainfall regime and by the decreasing annual amounts. These changes have affected the water resources of West African watersheds (Le Lay, 2006; Linsoussi, 2000; Vissin, 1998). According to Benin Department of Water, the country receives an average of between700 mm and 1300 mm of rainfall per year (MMEE, 1999). The surface water resources are estimated at roughly 13 billion m^3 and the annual groundwater recharge capacity is far from being well estimated with a current mobilization level about 2 % This present situation shows that the Benin water resources could meet the country needs in the long-term as long as these resources are properly controlled and qualitatively preserved. In Benin, the adequacy of resources / needs at long term does not arise in terms of resource deficit, but in terms of water resources control. At the watershed scale, the drinking water sources in relation to the demographic aspects falls far short of the recommendations of the FAO (i.e. 250 inhabitants by hydraulic pump and 20 liters/capita/day) in the field (Bossa, 2007). Also, the water sources used by the population are not permanent because, the geomorphology and the rainfall regime do not permit good drainage but only allow seasonal rivers feed into the main river. In addition, the steepslopes and the low permeability of the soils reduce the movement of groundwater through the wells, due to the shallow rocky outcrops within the wells. So, in the context of sustainable development, it is important to understand the dynamics of water exchanges within the whole biophysical and socio-economic systems. This study therefore aims to quantify the annual turnover of surface and groundwater resources. This will contribute to the sustainable use of water resources in the basin through concrete protection strategies, retention and productivity increased hydro systems of the basin.

MATERIAL AND METHODS

Study area

Located in West Africa, Benin is watered by a dense river network with the Ouémé which is 510 km as the main river and represents the largest watershed of the country. The Ouémé catchment at the Savè outlet (Figure 1), covers an area of 23,007 km^2 which is 20.1 % of the total surface of Benin (114,763 km^2).

The catchment is located between 8 ° 00 ' - 10 ° 03' latitudes N and 1 ° 30 ' - 2 ° 32' longitudes E to the northern and 2 ° 02 '- 2 ° 32' East to the south. It consists of several sub-catchments; the major ones being Donga sub-basin (586 km^2), Térou-Igbomakoro sub-basin (2336 km^2) and Bétérou sub-basins (9670 km^2). The annual average rainfall is between 1100 and 1300 mm and the normal total number of rainy days in the year varies between 80 and 110 days. These high rainfall observed in the north of the basin is related to the influence of the terrain (orographic phenomena which forms a series of rock outcrops (inselbergs) or chains of isolated and barren hills (Bio Bigou, 1990)) . The mean annual temperature is 27°C with relative humidity ranging from 15% to 95 %. The basin consists mainly (> 98 %) of tropical ferruginous soils with several variations of lateritic and waterlogged soils. The vegetation is dominated by tree and shrub savannah (67 % of the area).

Data presentation

In this study, the data used consisted of:

a Digital Elevation Model in a 90 m resolution data from the Shuttle Radar Topography Mission (SRTM) of the NASA. From the DEM, the model SWAT (Soil and Water Assessment Tool) which was used, derived the overland and channel slope and length, the surface time of concentration, flow direction and others properties for each sub basin;

digital land use maps of 300 m x 300 m resolution genereted from 30 m resolution Landsat images of February 2003 by the National Centre of Remote Sensing and Forest cover monitoring (Centre National de Télédétection et de surveillance du couvert forestier, CENATEL);

digital soil map (scale 1/200,000) obtained from the German project IMPETUS, supplemented by soil surveys for the determination at the lab the physical parameters that govern the dynamics of water in the soil (saturated hydraulic conductivity, organic carbon levels, water retention capacity, texture);

daily climate data of the climate stations (Parakou and Savè) and the daily rainfall of the rain gauges (Djougou, Pénéssoulou, Pélébina, Savalou Gouka, Bantè, Ouessé, Partago, Toui) for the period from 1995 to 2006 with, the average monthly climate data (rainfall, humidity, maximum and minimum temperatures, wind speed, solar radiation) and their standard deviation computed for the period 1946 – 2005;

hydrological data (daily discharge) of the hydrometric station of Savè used for the model calibration and validation;

data on the physical parameters of vegetation and the main crops cultivated in this area (maize, cotton, yams) such as leaf area index (LAI), biomass, the potential heat units of plants (PHU) obtained from German project IMPETUS and Hydraulics laboratory and Control of Water (LHME).

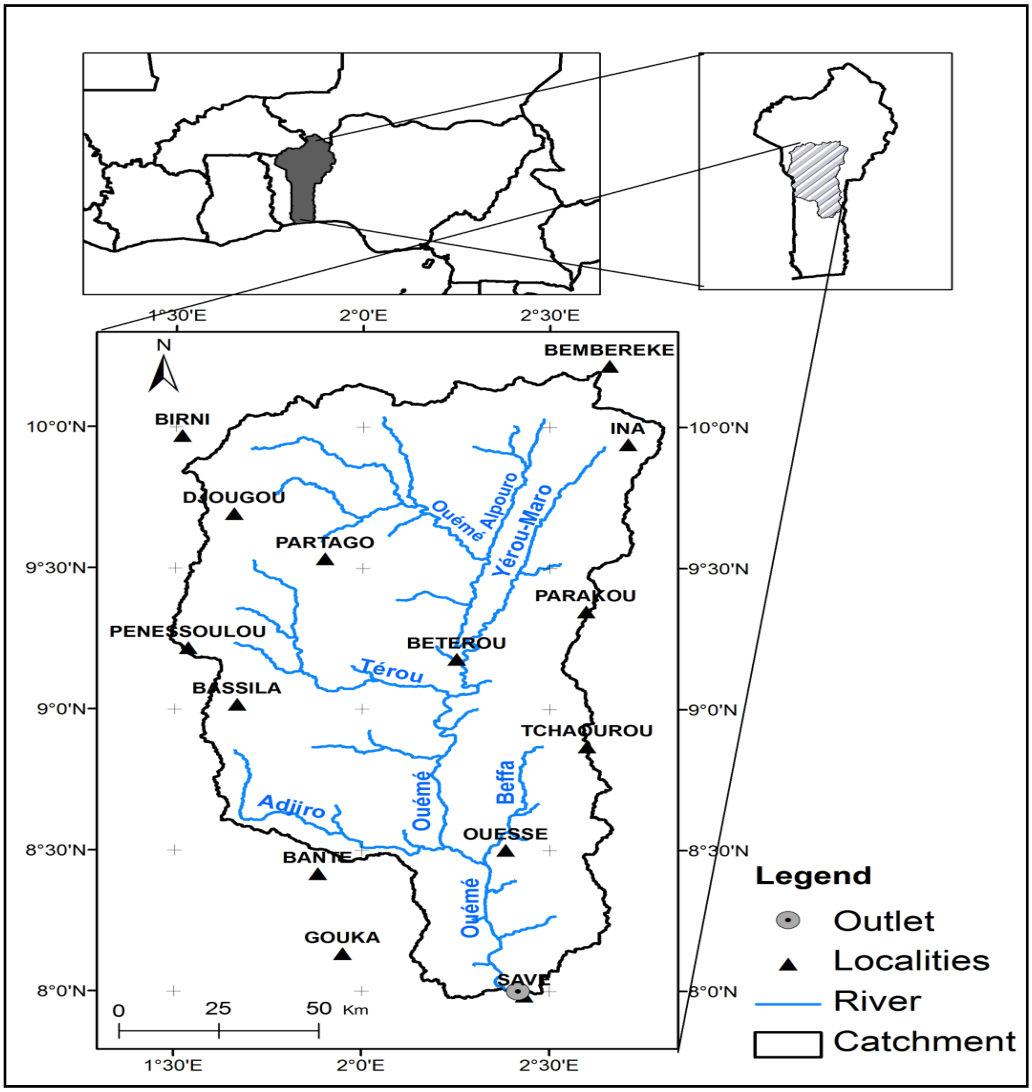

Figure 1: Ouémé catchment at the Savè outlet

SWAT model description

The SWAT model - Soil and Water Assessment Tool - (Arnold et al. 1998) is a semi- distributed watershed model with a GIS interface that outlines the sub basins and stream networks from a Digital Elevation Model (DEM) and calculates daily water balances from meteorological, soil and land-use data. SWAT is a hydrologic / water quality model developed by the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) (Arnold et al. 1998). The model was developed to foresee the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods of time.

Model components include weather, hydrology, sedimentation, crop growth, nutrients cycling, pesticides dynamics and agricultural management. We use for this study SWAT 2003 model to assess the hydrologic balance in the Ouémé at Savè basin, particularly spatial variation of runoff and sediment yields with regard to the land use.

Indeed, SWAT model first partitions a watershed into sub basins which allow accounting of land uses and soils properties impact on hydrology. Then, the model subdivides the previous partitions in Hydrologic Response Units (HRU) which are lumped land areas within the sub basin that are constituted of unique land cover, soil and management combinations.

SWAT has been applied in several basin scale studies involving assessment of water supply and nonpoint source pollution in the United States. The results of SWAT application for hydrologic simulation in all river basins in the United States have been reported (Arnold et al. 1999). Several other studies in other Continents (Europe, Africa, Asia) (e.g. Srinivasan et al. 1998, 2003, King et al. 1999, Santhi et al. 2001, 2005, Huisman et al. 2003, Sintondji 2005, Sintondji et al. 2013, Bossa 2007, Awoye 2007, Ahouansou 2008) indicate the strength of SWAT model in simulating streamflow and sediment movement in large basins.

Water balance assessment

An assessment of surface water and groundwater availability was made by estimating the hydrological cycle components (rainfall and interception, runoff, infiltration into the soil and in the root zone, evapotranspiration, groundwater flow and recharge) throughout the whole watershed. The spatial unit for these calculations is the HRU, which is the result of a combination of soil type and land use in the watershed. The water balance equation for a time interval is:

$$SW_t = SW_0 + \sum_{t=1}^{t}\left(R_{day} - Q_{surf} - ET_a - W_{seep} - Q_{gw}\right)$$

Where SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day i (mm H_2O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface runoff on day i (mm H_2O), ET_a is the amount of evapotranspiration on day i (mm H_2O), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H_2O), and Q_{gw} is the amount of return flow on day i (mm H_2O).

The details of the components of water balance exist in the theoretical model documented by Neitsch et al. (2011), as Sintondji et al. (2013), Sintondji (2005), Bossa (2007), Ahouansou (2008) and Hiepe (2008).

In order to well estimate the water balance components, SWAT model automatically performs by triangulation the distribution of climatic variables on the different sub-basins of daily data from different gauged stations. In addition, based on monthly average weather data calculated over the period 1946-2005, the model generates the missing values in the process of disintegration in the daily scale precipitation series from the weather generator (WXGEN). Thus, the days with data gaps were filled by the model. In this way, the consistency between generated daily data and the observed monthly data can be maintained for the months which have a few days of missing data.

To estimate the runoff, the SWAT model provides two methods namely the "SCS curve number procedure" (SCS, 1972) and the infiltration method of Green and Ampt (1911). The first was used and the time of concentration, the flow point and the amount of final water for each HRU and for each sub-catchment. The choice of the first method is made because it provides a consistent basis for estimating the flow under varying land use and soil types (Rallison and Miller, 1981). Runoff curves were provided and they are computed using tables from the SCS Engineering Division, (1986) taking into account the soil hydraulic conductivity at saturation (Ks), slope, and initial ground cover.

Furthermore, for the water in the soil and in the vadose zone, the SWAT model directly simulates the movement of water in saturated conditions, if the water content of a soil horizon is greater than field capacity and for each horizon. The unsaturated flow conditions is indirectly modeled with the depth distribution of the root water uptake and the depth of soil evaporation. The amount of water migrating from one soil horizon to another is estmated by the storage method of Sloan and Moore (1984), which explains the distribution of the water flow of each horizon into its various components of lateral flow and percolation.

To estimate the ETP, three commonly used methods are proposed by SWAT including the Penman-Monteith method. This was chosen for this study because it is the most complete and allows the integration of all climate parameters. SWAT models also computes the ski water capillary to the unsaturated layers as a function of water demand for the evaporatranspiration.

Erosion assessment

The soil loss measurements were made in cotton fields where the ridges are parallel to the steepest slope and where they are perpendicular to the steepest slope. Sediments were collected and fresh weights recorded every two weeks. Sediment sampling was made from the quantities of soil trapped in the sediment traps. These were then dried in an oven at 105ºC for the dry weight determination and the equivalent of sediment loss in each plot was determined in tons per hectare.

Measurements of soil loss were taken from August to October 2008 in sub-basin 59 (at the outlet for the catchment). The sediment traps were installed in fields with slope close to the average slope of the basin (3 %). In total, two sediment traps (length 0.75 m, width 0.30 m and height 0.30 m) with three repetitions were installed in two different cotton plots: one trap in a plot of cotton with ridges parallel to the slope and a second in a plot of cotton with a ridge perpendicular to the slope.

The bottom of each sediment trap was perforated with very small holes to allow water to seep into the ground, protected by a fine mesh screen that retained sediment. The trap was inserted into a hole of the same size, so that the upper edges were flush with the ground in order not to affect cohesion of the soil. Sediment traps were installed at the lowest part of the plot precisely at the section that received all the water falling into the plot. This technique has been used to measure soil loss in fields with different crops (cotton, maize, and yam) and tillage systems (Junge 2004, Sintondji et al. 2013).

Cotton fields were selected because it is the crop that occupies a huge area in the middle, bottom and top of the slopes of the catchment. Measurements were not recorded for amounts of sediment to arrive at outlets, but estimates were made using the following Modified Universal Soil Loss Equation (Williams 1995).

$$Sed = 11.8 \cdot \left(Q_{surf} \cdot q_{peak} \cdot area_{hru}\right)^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG$$

where *sed* is the sediment yield on a given day (metric tons), $Qsurf$ is the surface runoff volume (mm H2O/ha), q_{peak} is the peak runoff rate (m^3/s), $area_{hru}$ is the area of the HRU (ha), K_{USLE} is the USLE soil erodibility factor (0.013 metric ton m^2 hr/(m^3-metric ton cm)), C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor and $CFRG$ is the coarse fragment factor.

The way SWAT model computes the different parameters of this equation exist in the theoretical model documentation (Neitsch et al. 2011) as Sintondji (2005), Bossa (2007) and Hiepe (2008),

Model Set up, calibration, validation and evaluation procedures

The time period from 1999 – 2006 was used for model simulation since there was data overlap between the observed flow data and the input weather data. The first two years of the simulation were used as a model “warm-up”, during which period the model conditions stabilized. These years were therefore omitted from final result comparisons and the results reported in this study for various simulations therefore consist of data for the time period from 2001 – 2006.

To adjust the water balance that controls all of the hydrological processes in the basin, two criteria were taken into account to calibrate the water flow. The level of correlation between the simulated flows and observed flows at the outlet was first considered, and then the agreement on the allocation of volumes of water passed between surface and subsurface flow was estimated. To estimate the relative contributions of the basin to the surface and subsurface flow, the flows separation program “Baseflow” has been used (Arnold et al. 1999). Once the contributions are estimated, calibration is carried out in two steps. The first step is to adjust the runoff until it is in line with the estimated value for the Baseflow program. When the runoff is acceptable, the contribution of groundwater flow is adjusted.

Since the non availability of field measurements data regarding to the soil loss for a minimum period of three years, they were not rigged. But when the hydrological processes in the watershed are well estimated, the values obtained for sediments carried along are plausible. Thus, the sediments were estimated after flow calibration and were compared with the observed values of several studies carried out in the same ecological area (Diallo et al. 2002, Yacouba et al. 2002, Shahin 2002, Junge 2004).

For the model calibration and validation, Mean, Standard deviation, Coefficient of determination (R^2), Model Efficiency (ME) of Nash & Sutcliffe (1970) and Index of Agreement (IA) of Willmott (1981) were used to evaluate the model prediction.

The R^2 value is the square of the Pearson’s product-moment correlation coefficient and describes the proportion of the total variance in the observed data that can be explained by the model. It ranges from 0.0 to 1.0 with higher values indicating better agreement.

$$R^2 = \left\{ \frac{\sum_{i=1}^{N}\left(O_i - \overline{O}\right)\left(P_i - \overline{P}\right)}{\left[\sum_{i=1}^{N}(O_i - \overline{O})^2\right]^{0.5}\left[\sum_{i=1}^{N}(P_i - \overline{P})^2\right]^{0.5}} \right\}^2$$

With: O_i: Observed data, P_i: simulated data, $\overline{O}$: Observed mean, $\overline{P}$: simulated mean, N: Number of compared values

This is an indicator of strength of relationship between the observed and simulated values.

Model efficiency, according to Nash and Sutcliffe, indicates how well the plot of observed versus simulated value fits the 1:1 line. Estimation efficiency is commonly used in hydrologic model evaluation and is calculated as:

$$ME = 1 - \frac{\sum_{i=1}^{N} (O_i - P_i)^2}{\sum_{i=1}^{N} \left(O_i - \overline{O}\right)^2}$$

With: O_i: Observed data, P_i: simulated data, $\overline{O}$: Observed mean, N: Number of compared values.

If the measured variable is simulated most accurately by the model, then ME = 1; If the coefficient is negative, the quality of the model results is smaller than the average value of the measured variables. ME has a range of values from $-\infty$ to 1.

A disadvantage of the model efficiency coefficient is that the larger events have a strongly weight on this coefficient. Thus a deviation of larger events affects more strongly the coefficient than a deviation of smaller events.

For the evaluation of the quality of the temporal reproduction of the discharges, the Index of Agreement is used. Index of Agreement (*IA*) according to Willmott (1981) is calculated as:

$$IA = 1 - \frac{\sum_{i=1}^{N} (O_i - P_i)^2}{\sum_{i=1}^{N} \left(\left|P_i - \overline{O}\right| + \left|O_i - \overline{O}\right|\right)^2}$$

It's varies from 0 to 1, with higher values indicating better agreement between the model and observations, similar to the interpretation of the coefficient of determination R². It represents a decided improvement over the coefficient of determination, but also is sensitive to the extreme values (Legates & McCabe 1999). For all of the 3 efficiency coefficients, the value 1 represents the complete agreement of the measured and simulated values.

RESULTS AND DISCUSSION

Observed versus simulated flow during calibration period (2001 - 2004)

The calibration of SWAT model at weekly intervals, to take into account the intra seasonal variations, showed very satisfactory coefficients of model valuation; for instance, we obtained 0.86 for the coefficient of determination, 0.83 for the model efficiency coefficient and 0.96 for the Index of Agreement (Table 1). Figures 2 and 3 show the degree of agreement between simulated and observed flows at the Savè outlet for the calibration period extending from 1 January 2001 to 31 December 2004.

Average annual water balance

Table 2 below summarizes the average annual values of water balance components of Ouémé catchment at the Savè outlet during calibration period (2001 - 2004).

Table 2 shows that surface runoff is about 7.8% of the total rainfall received by the basin. The total aquifer recharge and the actual evapotranspiration are respectively around 18.8 % and 73 % of the total rainfall. These results show that the potential of water resources is important just as well in terms of surface water and groundwater. Therefore the average water volume produced (runoff + total aquifer recharge) amounts to about 7 billion m^3/year. Accordingly a very large proportion (73 %) of the precipitated water returns to the atmosphere through evapotranspiration. The contribution rate of total precipitation to the total aquifer recharge and actual evapotranspiration in the basin are higher than those obtained by Sintondji (2005) and

Awoyé (2007) respectively in Térou-Igbomakoro basin in Upper Ouémé and Klou basin located in the south of our study catchment. These authors found respectively that evapotranspiration represent 67.3 % and 68.9 % of the annual rainfall., This rate of 73 % is very close to the value found by Bossa (2007), which is 72.4 % in Zou catchment at Atchérigbé outlet located in southwest of our study basin.

Table 1: Model efficiency coefficients for the calibration period (2001 – 2004)

Weekly average (m3/S)		Efficiency Coefficients		
Observed Flow	Simulated Flow	R²	ME	IA
157.8	166.1	0.86	0.83	0.96

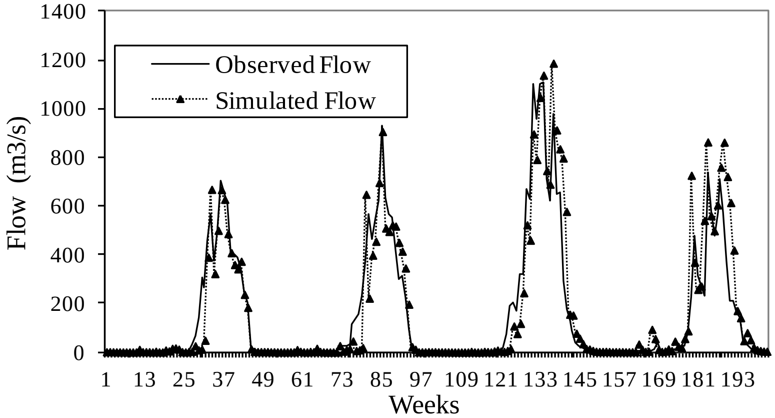

Figure 2: Comparison of Ouémé catchment at the Savè outlet weekly stream flow for the calibration period (2001 – 2004)

Table 2: Average annual Basin Values for the calibration period (2001 – 2004)

Components of water balance	Values (mm)	Proportion of the components related to the precipitation (%)
Annual rainfall	1153.6	100.00
Surface runoff	89.73	07.78
Lateral flow	4.7	0.41
Groundwater flow	138.15	11.98
Total aquifer recharge (shallow + deep)	217.39	18.84
Deep aquifer recharge	10.87	0.94
Transmission loss	1.82	0.15
Evapotranspiration	841.1	72.91
Potential evapotranspiration	1711	-
Change in soil water storage	-1.14	-0.10

Regarding the contribution rate of rainfall to the surface runoff, these authors found respectively 11.1 %, 13.5 %, and 7.3 %. We note that the surface runoff rate of 7.8 % that we got is very close to Bossa (2007) who worked on a smaller watershed than ours but much larger (6980 km^2) than Sintondji (2300 km^2) and Awoyé (309.9 km^2). These differences observed in actual evapotranspiration and runoff can be explained by the size of the watershed. Indeed, over a large watershed, the water arrives at the outlet less quickly and the probability of having a low coefficient of runoff is higher.

With regard to the total rate of aquifer recharge, 18.8%obtained for our study area is similar to the rates of 18.3 % and 19 % respectively obtained by Bossa (2007) and Awoyé (2007). The similarity observed between our values and those of Bossa (2007) and Awoyé (2007) can be explained by the geomorphology of our region and Zou basin in which the authors have had to carry out their work. Indeed these two basins are located in the bedrock region that represents about 80% of Benin's territory and have large rock formations (hills). Moreover, these two basins still have enough vegetation (protected areas, forest and scrublands) that satisfy the water demand of the atmosphere through evapotranspiration.

These results confirm those found by Giertz et al. (2006) where the surface runoff is ranging from 9.5 % to 18.7 % in Aguima and Niaou catchments which are located in Upper Ouémé during 2002 and 2003 with annual rainfall contained between 1145 mm and 1230 mm.

Observed versus simulated flow during validation period (2005 - 2006)

The degree of agreement between simulated and observed flows at weekly interval for the

validation period extending from 1 January 2005 to 31 December 2006 are showed by the figures 4 and 5.

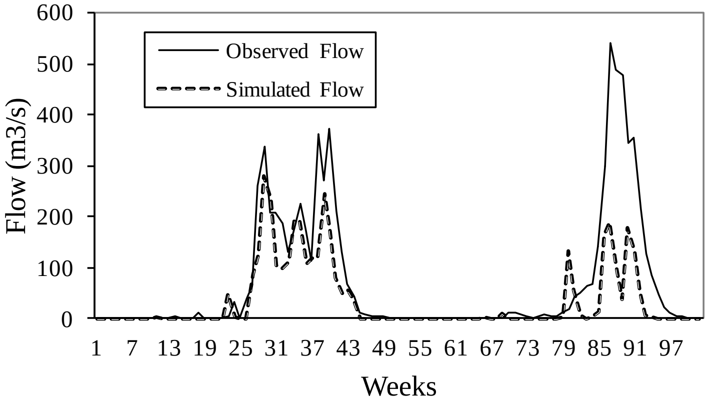

Figure 4: Comparison of Ouémé catchment at the Savè outlet weekly stream flow for the validation period (2005 – 2006)

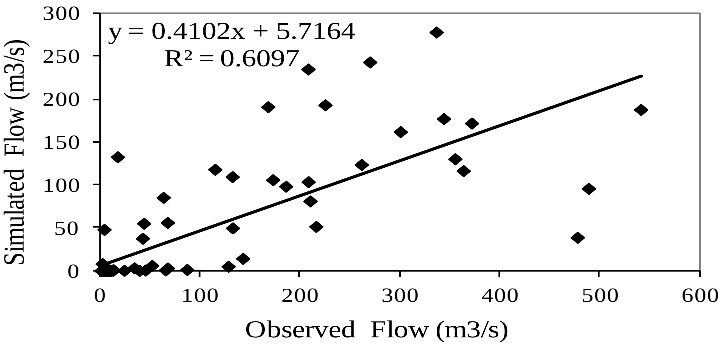

Figure 5: Scatter plot of weekly simulated versus observed flow for the validation period (2005 – 2006)

The three coefficients used to evaluate the model prediction (coefficient of determination R2, Model efficiency according to Nash and Sutcliffe ME and Index of Agreement IA) here are slightly lower values (R2 = 0.6, ME = 0.5 and AI = 0.8) relative to the calibration period. These slightly lower values obtained after validation of the model can be explained by the deficiencies contained in the different climatic data in the model. These values reflect that SWAT model simulates correctly the hydrological processes of our study basin.

Average annual water balance for the validation period

The annual average values of water balance components are presented in Table 3. We deduce from this table that the runoff coefficient is about 7.3 % while the total aquifer recharge is around 17.6 % and 74.6 % for the actual evapotranspiration. These proportions are close to those obtained for the calibration period.

Table 3: Average annual basin values for the validation period (2005-2007)

Components of water balance	Values (mm)	Proportion of the components related to the precipitation (%)
Annual rainfall	1064.9	100.00
Surface runoff	77.73	7.30
Lateral flow	2.47	0.23
Groundwater flow	25.57	2.40
Total aquifer recharge (shallow + deep)	187.42	17.60
Deep aquifer recharge	2.53	0.24
Transmission loss	0.82	0.08
Evapotranspiration	794.75	74.63
Potential evapotranspiration	1917.2	-
Change in soil water storage	1.71	0.16

According to these results, the total average water volume produced (surface runoff and total aquifer recharge) amounts to a little over 6 billion m^3/year. While, wells, boreholes and the national water company (SONEB) provide about 1,000,000 m^3/year to the population against the current need of about 8,000,000 m^3/year. Considering the FAO standards for water availability for populations (250 inhabitants/water point and 20 litres of water per capita per day) and the population and the water sources available in the basin, the annual water needs of the population amounts to nearly 8 million m^3/year of which functional water points supply 620,500 m^3/year. In addition, SONEB provides to his subscribers 381,206 m^3/year. With these figures we realize that only 13 % of the people water needs are satisfied whereas the basin provides 875 times the amount of water needed to the people for their well being. With this situation, the implementation of management techniques of water resource and subsequent hydraulic structures would be a strong asset for the development of this potential in order to provide this resource to the population full time which they lack during dry periods of the year.

Sediment transport

The soil losses are quite high in the sub-basins 18, 23, 35, 45, 46, 51, 53 and 58 which must now be a priority in the programs of erosion control. The average annual rate of soil particles actually transported to the streams in the sub-basin 59, where the soil loss measures were done, varied between 3.4 and 7.1 t/ha / year (Figure 6). The amount of land moderately eroded annually, simulated by the model is

4.4 tonnes/ha year during the calibration period (2001-2004). These results are similar to those obtained by some authors. Awoyé (2007) and Bossa (2007), obtained respectively 4.32 t/ ha/year and 4.3 t/ha/year as soil loss values simulated by the model used at Klou and Zou at Atchérigbé outlet. These values are also similar to soil loss obtained by Shahin (2002) who found out that the amount of sediments that reach the oceans in Africa is between 1.37 to 6.3 t /ha/year.

Measurement tests of the average weight of sediment trapped in the cotton fields in the sub-basin 59, varied according to both agricultural practices (Figure 7). It is noted that the average weight of sediment trapped on the slopes where the ridges are parallel to the slope are higher than those recorded in the parts where they are more perpendicular to the slope.

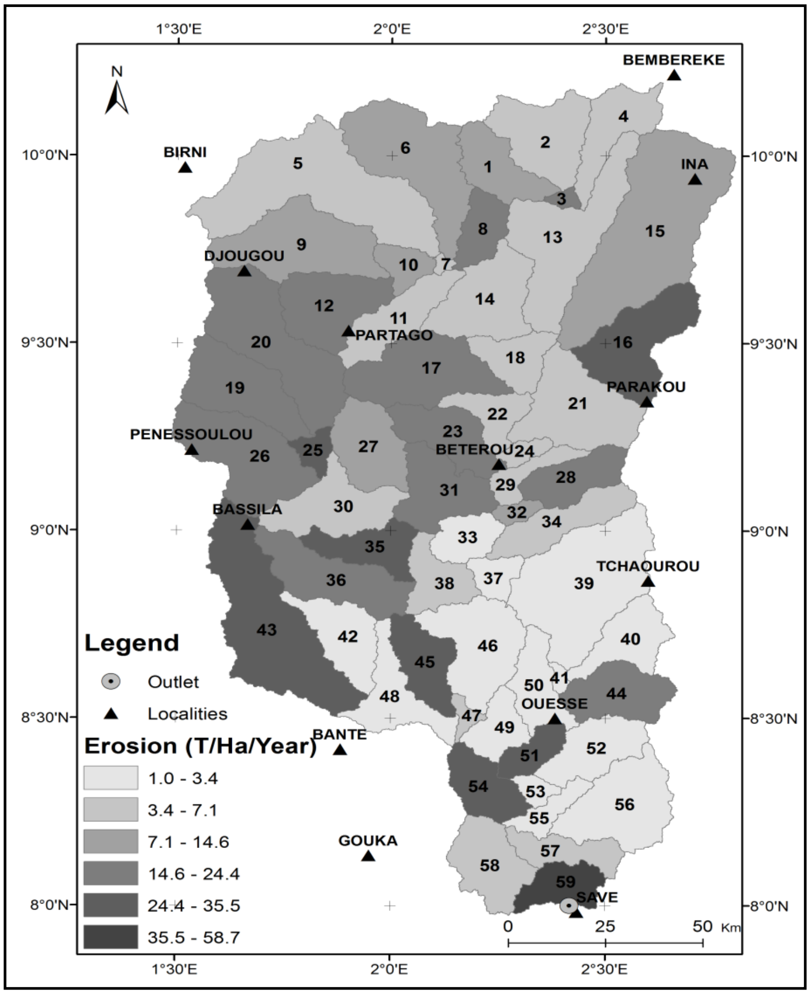

Figure 6: Annual average soil loss per sub-basin during the calibration period (2001-2004)

It is observed that significant soil losses about 20.1 t/ha and 9.3 t ha respectively on plots with ridges parallel to the slope and on plots with ridges perpendicular to the slope during the three months tested (i.e. 30 July to 24 October 2008). While, the simulation results for the same period (years of timing) indicate in the same sub-basin (59) a soil loss about 4.4 tons per hectare. Roose et al. (2004) have pointed out that following the application of the universal soil loss equation, the tropical rains are very aggressive vis-à-vis tropical soils and are quite stable and resistant to smearing.

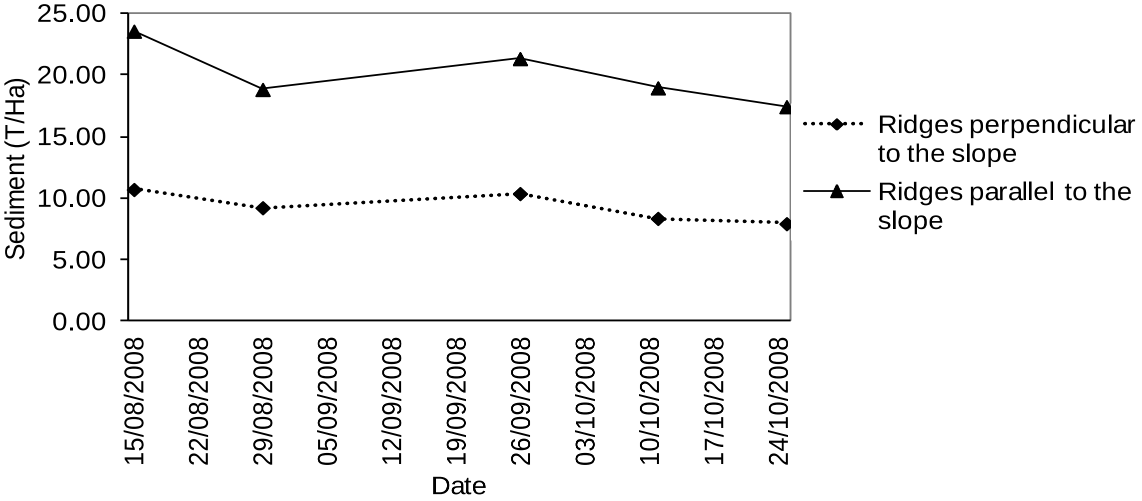

Figure 7: Sediment loss according to the agricultural practices

The measurements made by Junge (2004), for a period of one year reported 123.8 tonnes per hectare of soil lost in the cotton fields in Térou sub-basin of upper Ouémé where the logs were placed parallel to the slopes. This large gap observed between the magnitudes of the measured values (9.32 to 20.05 t/ha for the three months of measurement) and simulated (3.4 to 7.1 tonnes / ha / year) is due to the fact that only a small fraction of the transported particles actually joined the river after rainfall events. Most of it was shifted so it is difficult to extrapolate point measurements of erosion to a whole wide area.

Our measured values correspond to those of Diallo et al. (2002) who obtained on farmland in the Sudano-Sahelian zone losses between 4.8 and 18.4 t / ha/year. Sintondji (2005), meanwhile, noted that in Térou-Igbomakoro catchment the sediments losses are around 21 t / ha/year in the agricultural zone.

CONCLUSION

The agro-hydrological model SWAT showed in this study its adaptability to the agro-ecological realities of our study area. The model calibration and validation showed that the productivity of hydro systems varies in space and time, due to climate variability, human activities and local soil conditions. The annual water balance obtained from the model results indicated water availability that does not meet the annual needs of population. This circumstance reflects the acute problems of access to water arising in this region especially in dry periods. Thereforethe implementation of management techniques of water resources and/or subsequent hydraulic structures would be adopted for the development of this potential in order to full time provide this resource throughout the year to population.. Moreover, the potential water resource is not negligible at the unconfined aquifer. It would be wise to conduct a comprehensive program of building large dams, wells or boreholes associated with underground dams upstream in all areas of the basin. The agro-hydrological model SWAT also allow us to see that the soil losses are important in the basin since our direct measurements reported huge losses in agricultural areas., We therefore recommend anti erosion control practices and the dissemination of good agricultural practices.

ACKNOWLEDGEMENTS

We would like to thank the OUEME 2025 Project for their contributions by financing this study. We thank also the lecturers for their valuable input.

REFERENCES

Ahouansou DM (2008) Modélisation du bilan hydrologique du bassin versant de l'Ouémé à l'exutoire de Savè : contribution à la gestion integrée des ressources en eau. Dissertation, University of Abomey-Calavi

Arnold JG, Srinivasan R, Muttiah RS, Allen PM (1999) Continental scale simulation of the hydrologic balance. Journal of The American Water Resources Association 35(5): 1037 – 1051.

Arnold J, Srinivasan R, Muttiah R, Williams J (1998) Large area hydrologic modeling and assessment Part I: Model development. JAWRA Journal of the American Water Resources Association 34 (1):73-89

Awoyé H (2007) Modélisation du bilan hydrologique dans le bassin du Klou au Centre-Bénin : contribution a l'utilisation durable des ressources en eau. Dissertation, University of Abomey-Calavi

BioBigou L (1990) Equipements et infrastructure dans le département du Zou : Ouessè-Savè-Glazoué-Savalou-Djidja-Zakpota**.** Service d'Etudes Régionales d'Habitat et d'Aménagement Urbain.

Bossa YA (2007) Modélisation du bilan hydrologique dans le bassin du zou à l'exutoire d'Atchérigbé: contribution à l'utilisation durable des ressources en eau. Dissertation, University of Abomey-Calavi

Diallo D, Roose E, Orange D, Morel A (2002) Influence des pratiques agricoles sur le ruissellement et l'érosion des sols en zone soudanienne du Mali, 5ème Conférence Inter-Régionale sur l'Environnent et l'Eau – Envirowater 2002, 326-335.

Giertz S, Diekkrüger B, Jaeger A, Schopp M (2006) An interdisciplinary scenario analysis to assess the water availability and consumption in the Upper Ouémé catchment in Benin, Adv. Geosci. 9: 3-13.

Green WH, Ampt GA (1911) Studies on soil physics, 1 The flow of air and water through soils. Journal of Agricultural Sciences 4:11-24.

Hiepe C (2008) Soil degradation by water erosion in a sub-humid West-African catchment: a modelling approach considering land use and climate change in Benin. Dissertation, University of Bonn

Huisman JA, Breuer L, Frede H-G (2003) Spatial consistency of automatically calibrated SWAT simulations in the Dill catchment and three of its sub-catchments. DBG-Mitteilungen 102(2): 653-654

Junge B (2004) Die Böden des oberen Ouémé-Einzugsgebietes in Benin/Westafrika- Pedologie, Klassifizierung, Nutzung und

Degradierung. Dissertation, University of Bonn

King KW, Bingner RL, Arnold JG (1999) Comparison of Green-Ampt and curve number methods on Goodwin Creek watershed using SWAT. Transactions of the American Society of Agricultural Engineers 42(4): 919-925

LeLay M (2006) Modélisation hydrologique dans un contexte de variabilité hydro-climatique. Une approche comparative pour l'étude du cycle hydrologique à méso-échelle au Bénin. Dissertation, University of Joseph Fourrier, INPG, LTHE.

Legates DR, McCabe GJ (1999) Evaluating the use of 'goodness-of-fit' measures in hydrologic and hydroclimatic model validation. Water Resources Research 35: 233-241.

Linsoussi AC (2000) Evaluation des risques en matière de gestion des ressources : contribution à la caractérisation événementielle des régimes Ouest-Africain et de leurs fluctuations. Dissertation, University of Abomey-Calavi

MMEE (1999) Vision nationale de l'eau pour 2025 Rapport de synthèse, République du Bénin

Nash JE, Sutcliffe JV (1970) River flow forecasting through conceptual models part I – a discussion of principles. Journal of Hydrology 10: 282-290.

Neitsch SL, Arnold JG, Kiniry JR, Williams JR (2011) Soil and Water Assessment Tool Theoretical Documentation Version 2009. Texas Water Resources Institute Technical Report No. 406 Texas A&M University System College Station, Texas 77843-2118.

Rallison RE, Miller N (1981) Past, present and future SCS runoff procedure. In Singh VP (ed) Rainfall runoff relationship. Water Resources Publication, Littleton, Colorado 80161, USA, pp 353-364

Roose E, De Noni G (2004) Recherches sur l'érosion hydrique en Afrique : revue et perspectives, Science et changements planétaires / Sécheresse 15(1):121-129.

Santhi C, Muttiah RS, Arnold JG, Srinivasan R (2005) A GIS-Based Regional Planning Tool for Irrigation Demand Assessment and Savings Using SWAT. Transactions of the American Society Agricultural Engineers 48(1): 137-147

Santhi C, Arnold JG, Williams JR, Dugas WA, Srinivasan R, Hauck LM (2001) Validation of the SWAT model on a large river basin with point and non point sources. Journal of the American Water Resources Association 37(5): 1169-1188

Shahin M (2002) Hydrology and water ressources of Africa. In: Water Science and Technology Library, Vol 41. Kluwer Academic Publishers, New York, Boston, Dordrecht, London, Moscow

Sintondji LO, Dossou-Yovo ER, Agbossou KE (2013) Modelling the hydrological balance of the Okpara catchment at the Kaboua outlet in Benin. International Journal of AgriScience Vol. 3(3): 182-197.

Sintondji LO (2005) Modelling the rainfall-runoff process in the Upper Ouémé catchment (Terou in Benin republic) in a context of global change: extrapolation from the local to the regional scale. Dissertation, University of Bonn

Sloan PG, Moore ID (1984) Modeling subsurface stormflow on steeply sloping forested watersheds. Water Resources Research. 20 (12), pp 1815-1822.

Soil Conservation Service Engineering Division (1986) Urban hydrology for small watersheds. U.S. Department of Agriculture, Technical Release 55. 210-VI-TR-55, p26

Srinivasan R, Jacobs J, Angerer J, Vitale J, Kaitho R, Stuth J, Clarke N (2003) Exploring the Potential Impact of Reforestation on the Hydrology of the Upper Tana River Catchment and the Masinga Dam, Kenya. Draft. Available via.www.ssl.tamu.edu/media/10343/tana_report_2004.pdf. Cited 10 August 2013

Srinivasan R, Ramanarayanan TS, Arnold JG, Bednarz, ST (1998) Large area hydrologic modelling and assessment, Part II. Model application. Journal of the American Water Resources Association 34(1): 91-101

SCS (U.S. Department of Agriculture - Soil Conservation Service) (1972) National Engineering Handbook. Part 630 Hydrology, Section 4, U.S. Government Printing Office, Washington, D.C. p762

Vissin WE (1998) Contribution à l'étude du fonctionnement hydrologique du bassin de la Sota. Dissertation, University of Abomey-Calavi

Williams JR (1995) The EPIC Model. In Computer Models of Watershed Hydrology. Water Resources Publications. Highlands Ranch, CO. p. 909-1000

Willmott CJ (1981) On the validation of models. Physical Geography 2: 184 pp.

Yacouba H, Da DE, Yonkeu S, Zombre P, Soule M (2002) Caractérisation du ruissellement et de l´érosion hydrique dans le bassin supérieur du Nakambe (Burkina Faso) 5ème Conférence Inter-Régionale sur l´Environnement et l´Eau – Envirowater 2002, 318-324.