JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2023, 24(4), 343–356
https://doi.org/10.12911/22998993/161043
ISSN 2299–8993, License CC-BY 4.0

Received: 2023.01.09
Accepted: 2023.02.08
Published: 2023.03.01

Hydrological Modelling in the Ouergha Watershed by Soil and Water Analysis Tool

Lamia Erraioui[1*], Soufiane Taia[1], Kamal Taj-Eddine[2], Jamal Chao[1], Bouabid El Mansouri[1]

[1] Natural Resources and Sustainable Development Laboratory, Ibn Tofail University, Campus Maamora, 14000 Kenitra, Morocco

[2] Laboratory of Geosciences Semlalia, Faculty of Sciences Semlalia, Cadi Ayyad University, 4000 Marrakech, Morocco

* Corresponding author's e-mail: lamia.er-raioui@uit.ac.ma

ABSTRACT

Streamflow modelling is crucial for developing successful long-term management, soil conservation planning, and water resource management strategies. The current work attempts to develop a robust hydrological model that simulates streamflow with the slightest uncertainty in the calibration parameters. A physical-based and semi-distributed hydrological SWAT model was employed to assess the hydrological simulation of the Ouergha watershed. The monthly simulation of the SWAT model achieved in the time frame from 1990 to 2013 has been split into warm-up (1990–1996), calibration (1997–2005), and validation (2006-2013). The SUFI-2 algorithm's preliminary sensitivity and uncertainty analysis was done to calibrate the model using 11 hydrologic parameters. The model's performance and robustness findings are promising. To evaluate the model, the coefficient of determination (R^2), Nash-Sutcliffe efficiency (NSE), and percent of bias (PBIAS) were utilized. The value of R^2, NSE, and PBIAS ranged from 0.45–0.77, 0.6–0.89, and +12.72 to +21.89% during calibration and 0.51–0.85, 0.64–0.88, and +8.82 to +22.19% during validation period, respectively. A high correlation between the observed and simulated streamflow was recorded during the calibration and validation periods. More than 68% of the observation data are encompassed by the 95PPU across both the calibration and validation intervals, which is excellent in terms of the P-factor and R-factor uncertainty criterion. The projected streamflow matches the observed data well graphically. According to the total hydrological water balance study, 29% of precipitation is delivered to streamflow as runoff, whereas 54% of precipitation is lost through evapotranspiration. The recharge to the deep aquifers is 8%, whereas the lateral flow is 10%. The findings of this study will help as a roadmap for the anticipated water management activities for the basin since the management and planning of water resources require temporal and spatial information.

Keywords: SWAT, Ouergha watershed, hydrological modelling, water balance.

INTRODUCTION

Morocco has a varied climate, ranging from subhumid in the north to semi-arid to dry in the center, and Saharan in the south (Dafouf et al., 2022), all of which are accompanied by increasingly frequent droughts (Tramblay et al., 2012; Driouech et al., 2021). A significant space-time irregularity is the dominant feature of rainfall patterns. In the northern mountainous regions bordering the Mediterranean, the annual precipitation average reaches 1000 mm and progressively declines to less than 300 mm as one moves east and south. Recently, Morocco has faced drought conditions. As a result, most watersheds have experienced a decrease in the runoff. This decline also accounts for extremes (high and low water) and annual discharge. One of the reasons restricting a region's ability to develop is the reduction of its water resources. Thus, the Ouergha watershed's surface water resources are used for hydropower, agriculture, and drinking water (Jabri et al., 2022). In addition, the physical parameters of the basin have changed. For instance, the dense forest region has been converted into agricultural land, leaving it only in the summits. Traditional farming practices have led to the construction of drainage ditches, which have accentuated surface runoff and harmed the quality and quantity of the water network. Given that environmental change has a negative impact on resource quality, hydrologic modelling should be considered. Prior to managing the qualitative aspects, it is necessary to handle the quantitative ones at the watershed level (Levesque et al., 2008).

The main objective of this article is to exploit a hydrological model to assess streamflow over the river network to protect the watershed. Understanding current rivers are necessary for managing water supplies and reducing the menace of flooding. This problem is especially significant for the Ouergha watershed because rainfall is the primary source of water supply (Snoussi et al., 1999; Haida, 2000; Bahin et al., 2018). Furthermore, this watershed was selected because it supplies the largest barrage in the state. Hydrological models are frequently employed to forecast and comprehend hydrological systems (Daide et al., 2022). Thus, a model that includes an agricultural activity and considers the spatial variability of the region in its assessments will be the most appropriate for our research. In order to manage water quantity following these two essential criteria, the Soil and Water Assessment Tool model (SWAT) has been applied to the Ouergha watershed. This model was chosen because it adequately captures the complex relations involving soil, plants, and the atmosphere (Arnold et al. 1998).

Chaponnière, in 2005 carried out the first SWAT modelling on the semi-arid watershed Ourika. Numerous studies have been carried out in the Moroccan context at various sites using the SWAT model to perform hydrological prediction (Chadli K., 2017; Mimich et al., 2018; Boufala et al., 2019; Taleb et al., 2019). Also, some researchers treated the impact of siltation and prolonging dam lifespan besides assessing sediment yield (Markhi et al., 2019; Ouatiki et al., 2016; Ait M'Barek et al., 2021). The application of this agro-hydrological model was also performed to test the effects of the quality and resolution of soil data on the watershed response (Bouslihim et al., 2019). Further, a study was conducted to assess how the winter wheat crop and sunflower, two key rainfed crops in the R'dom watershed, responded to the effects of climate change. (Brouziyne et al., 2018).

In this study, the water entering the catchment will be measured to help basin managers choose the best management strategies for the watershed. The SWAT model has been tested in the US. Thus, it was crucial first to adjust the standardized baseline data set by changing parameters to meet Morocco's general conditions and the Ouergha basin in particular. Then, the parallel processing functionality of SUFI-2 (Sequential Uncertainty Fitting Version 2) in the SWAT-CUP program will be applied to calibrate and validate the SWAT model (Rouhollahnejad et al. 2012, Abbaspour 2013).

STUDY AREA

Situated in the northwest of Morocco, between latitudes 35°07' and 34°24' north and longitudes 5°05' and 3°05' west, the Ouergha watershed covers an area of 7220 km^2 (Figure 1). Three geographic units can be identified by the watershed's vast range of heights and slopes, which provide a diversity of hydrological behaviors: the Prérif to the south, the Rif to the north, and the plain stuck between them. The basin exhibits a modest incline from East to West in its form. Due of the basin's location and size, a sizeable dam has been built. The production of hydroelectricity and hydro-agriculture is their main usage. It has a water volume of 3.800 Mm^3. Several smaller dams are used for hydro-agricultural purposes in addition to this large dam. As a result of the construction of hydroelectric dams, there has been a substantial population emigration to the periphery. Most of them are engaged in agriculture, covering more than 22% of the basin's surface. Agriculture is based on cereals, wheat, and barley, the dominant crops. Arboriculture is generally made up of olive trees and leguminous plants (figs, almonds, etc.). Rainfall in the basin is widely dispersed, with an annual average ranging from 497 mm/yr to 1383 mm/yr. The Ouergha River has two distinct seasons: the rainy season lasts from October through the end of May, and the dry season lasts from June to September.

MATERIAL AND DATA

SWAT model description

The Soil and Water Assessment Tool (SWAT) is a catchment scale, physically based,

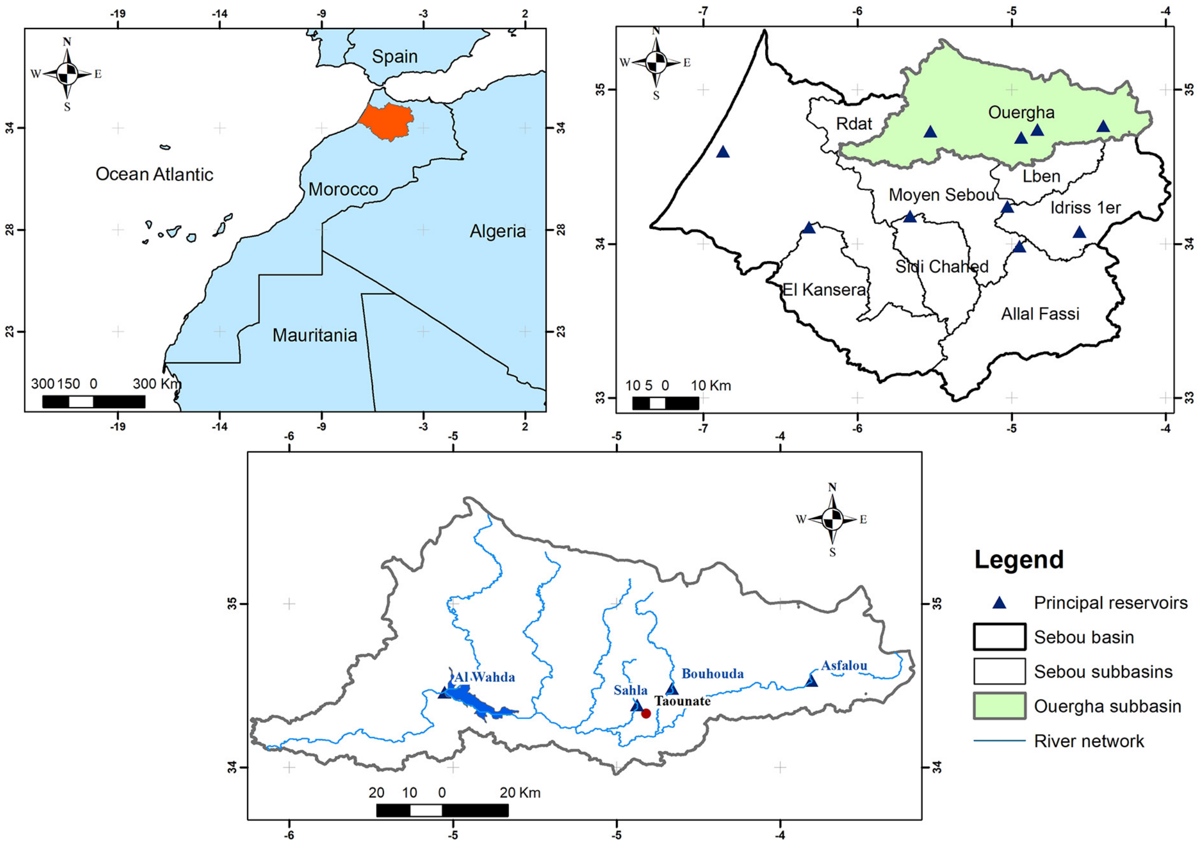

Figure 1. Map of the study area: the Ouergha catchment.

semi-distributed, and dynamic model that includes several routines to simulate the quantity and quality of water. SWAT is extensively utilized worldwide to evaluate the consequences of fertilizer loading, sediment transport, and other water management techniques in an agricultural watershed (Arnold et al. 2012). For continuous simulation of a catchment model running on various time steps and at various spatial scales, ArcSWAT, a version of SWAT coupled with ArcGIS, can be used. SWAT divides a watershed into several subbasins, which are also subdivided into Hydrological Response Units. In fact, within sub-basins, analogous land use, soil characteristics, and slope are grouped into reduced hydrological response units (HRUs) for which the water balance elements could be simulated (Neitsch et al. 2005). SWAT effectively forecasts flow volumes on a daily, monthly, and yearly basis. (Gassman et al. 2007; Devia et al. 2015). Climatic inputs include daily rainfall, lowest and highest temperatures, relative humidity, wind velocity, and solar radiation. In addition, the SWAT model may mimic various hydrologic processes, such as evapotranspiration, surface runoff, lateral subsurface flow, snowmelt, and groundwater flow… (Gassman et al. 2007). The following equation determines the water balance in SWAT at the watershed echelon. (Neitsch et al. 2011; Arnold et al. 2012).

$$SW_t = SW_0 + \sum_{i=1}^{t} \begin{pmatrix} R_{day} - Q_{surf} - \\ -E_a - W_{seep} - Q_{gw} \end{pmatrix}_i \quad (1)$$

where: SW_t – last soil water content (mm);
SW_0 – initial water content in the soil for plant uptake (mm);
R_{day} – daily rainfall (mm);
Q_{surf} – surface daily runoff (mm);
E_a – evapotranspiration (mm);
W_{seep} – percolation (mm);
Q_{gw} – return flow (mm).

Data preparation

The efficient adaption of SWAT in a subhumid area strongly relies upon data accessibility and precision. Thus, the ArcSWAT 2009 software, which is connected to ArcGIS 10.0, was employed to predict water flow efficiently. However, it necessitates using a Digital Elevation Model (DEM), land use, a soil map, meteorological data, and hydrometric data (Figure 2).

The ASTER's Global Digital Elevation Model, which has a spatial resolution of 30 m, was used to obtain topographic data (Hirt et al., 2010). It was pre-processed in ArcGIS software using a geospatial toolbox. The DEM is treated to get data on flow accumulation, flow direction, stream network construction, and basin and sub-basin delimitation. The digital elevation model also gave information on the stream network properties, including length, width, and channel slope, as well as sub-basin metrics like length and grade of the terrain's slope. The pre-treated image's elevation band spans 50 to 2450 m (Figure 2c).

Various types of soil and their physical and chemical characteristics are needed for SWAT simulations. (Neitsch et al. 2011). The soil map is extracted from the FAO's global digital soil map (FAO -Unesco Soil map of the world, 1977), the scaled-down soil map of Ouergha (1:100 000) (Water and Forest Administration and Soil Conservation, 1994), and the soil map of Central Morocco at a (1: 500 000) (National Institute of Agronomic Research, 2001). It indicates 12 different types of soil. A set of information detailing the physical and chemical features of every kind of soil, for instance, soil water accessibility, texture, deepness, soil organic carbon, and conductivity, is required for the SWAT model to complement a soil map. Figure 2b illustrates several soil types in the Ouergha basin, including brown soils, calcimagnetic soils, raw mineral soils, poorly developed soils.

Land use is one of the most crucial elements influencing a watershed's water supplies. The map of land cover is created through the supervised classification of a Landsat 8 satellite image via the built-in features of the ArcGis DESKTOP software. In this classification, six main classes are taken into account. Accordingly, about 53% of the Ouergha basin is covered by matorrals, 17% by forest, 22% by agriculture, and 6% by various land use classes (Figure. 2a). In order to conduct studies on water resources and hydrological modelling, it was necessary to evaluate the accuracy and consistency of the available weather data (Talaee, 2014). The model was initially set up and run using 24 years' worth of daily climatic observations (1990–2014). The input data, which came from the climate forecast system reanalysis (NCEP: the National Center for Environmental Prediction) (Saha et al., 2010), includes solar radiation, wind speed, lowest and highest temperatures, and relative humidity. In addition, data on precipitation was collected from eight monitoring stations that the Hydraulic Basin Agency of Sebou maintains within the basin (ABHS). Table 1 provides information about the study's stations. Different evapotranspiration calculation techniques are available in the SWAT model. With this climate data, evapotranspiration was calculated by default using the Hargreaves method. Since actual and simulated data must be compared to calibrate models, a database of hydrometric data was provided by six gauging stations. Table 1 displays the stations' positions (Lambert coordinates) and their characteristics.

Table 1. Characteristics of the ABHS measuring stations within the Ouergha watershed (S : Stage V : Volume P : Precipitation)

Gauging station	Lambert coordinates (Zone 1)			Measured parameter	Commissioning date	River	Yearly average
	X	Y	Z				
Sahla dam	566876	440850	372	S, V	1994	Sahla	1.34 m³/s
Al Wahda dam	517768	444369	166	S, P, V	1997	Ouergha	74.10 m³/s
							544 mm
Jbel Outka	553000	459000	1115	P	1978	Aoulai	1383 mm
Galez	555325	439850	214	P	1978	Amzaz	684 mm
Tabouda	524250	461600	201	S, P	1978	Aoudour	12.61 m³/s
							656 mm
Bab Ouender	579500	440100	312	S, P	1952	Ouergha	16.80 m³/s
							691 mm
Aïn Aïcha	564800	428800	230	S, P	1980	Ouergha	23.21 m³/s
							497 mm
Khenichet	473700	425900	17	S, P	1963	Ouergha	72.22 m³/s
							520 mm
Mjaara	513510	443250	81	P	1958	Ouergha	609 mm

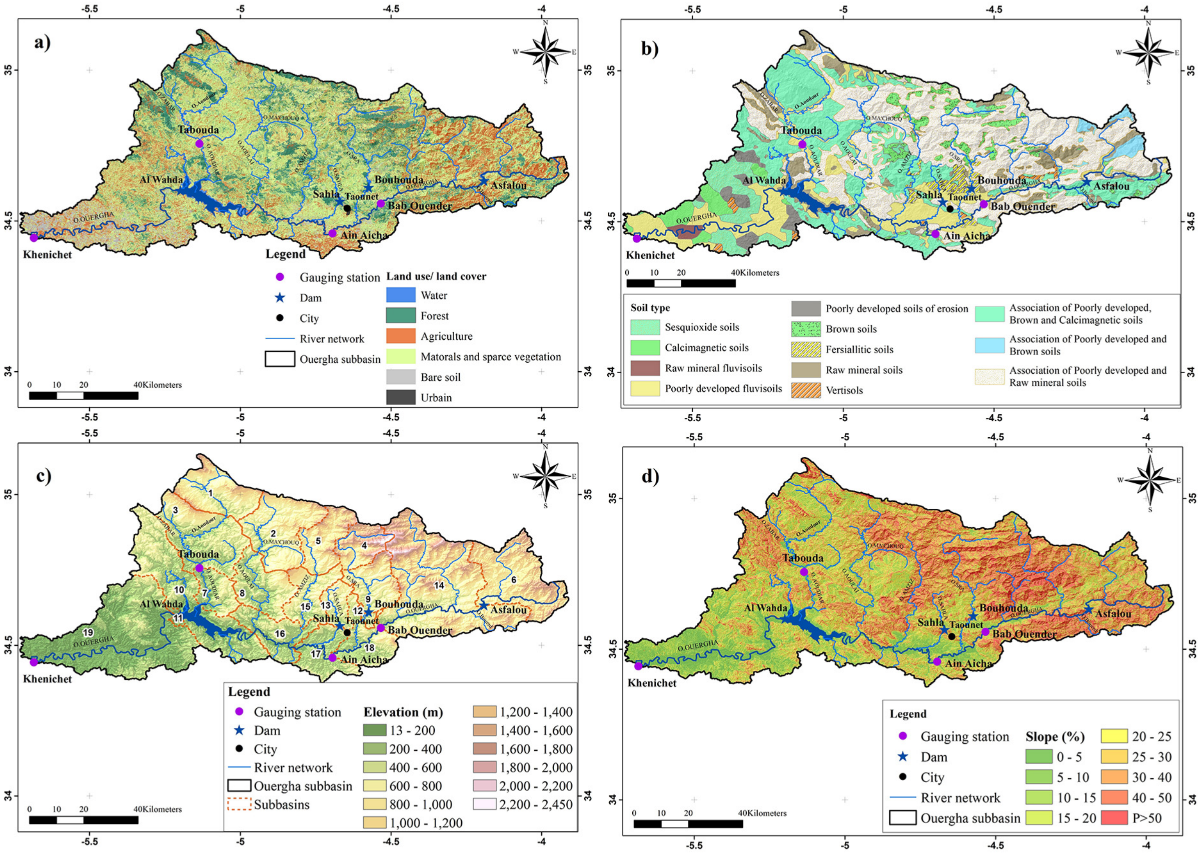

Figure 2. Input data for SWAT model. (a) land use, (b) soil, (c) Digital Elevation Model and (d) slope

Model setup

Practically, SWAT hydrological assessment is executed as follows: 1) the establishment of the watershed's boundaries and the stream flow network using a digital elevation model, 2) hydrological response units (HRU) description based on slope, soil type, and land usage, 3) the incorporation of weather data that will enable the calculation of the several components of the hydrological balance (runoff, percolation, soil moisture, and evapotranspiration) based on the types of soils and land-use.

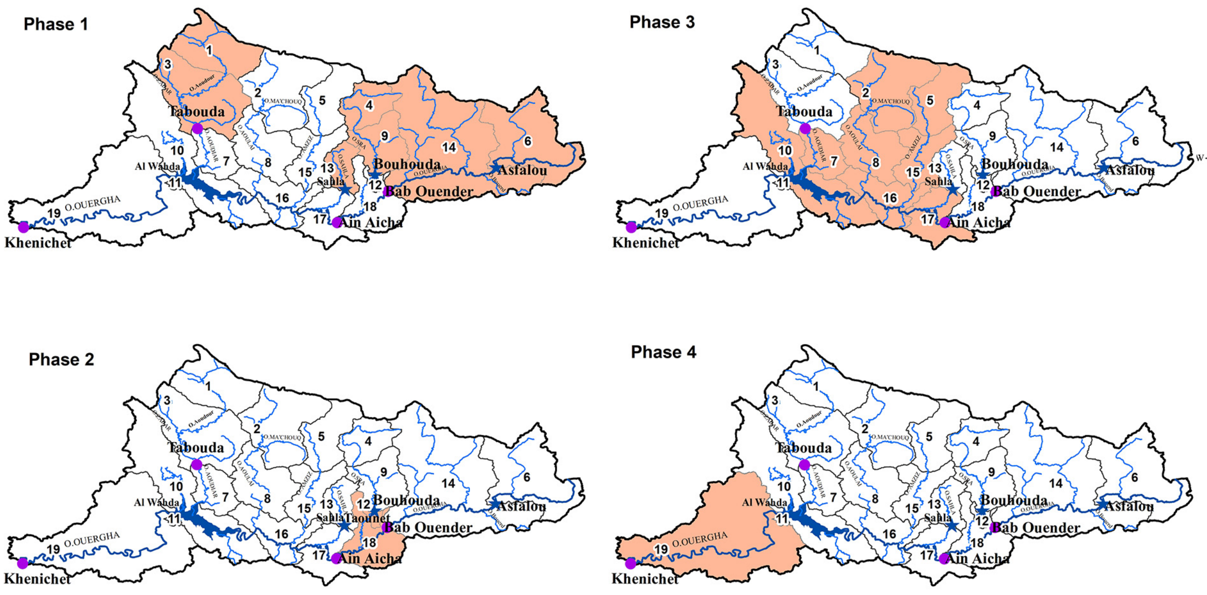

Figure 3. Spatial calibration approach adopted for Ouergha Watershed

However, the watershed was separated into 19 sub-basins which were divided into 227 HRUs. The study period chosen was from January 1990 to December 2013, with the initial five years serving as a warm-up. The years 2006 to 2013 were selected as the validation period after the calibration was completed between 1997 and 2005. The calibration was carried out on monthly time steps because the gauging stations only had access to monthly observed flow data. First, the Ouergha model was calibrated separately for each upstream catchment to identify the appropriate parameters for Bab Ouender, Bouhouda, Tabouda stations, and Sahla dam (Figure 3). Keeping the initial set of parameters constant, the model was then calibrated for the middle watershed (Ain Aicha). Next, all prior optimal parameters for each sub-basin were fixed while calibrating the Al Wahda dam, followed by the Khenichet station, which represents the Ouergha watershed exit.

Model performance

Statistical performance criteria for hydrological models are used to assess how well the model's simulated values match those observed. Table 2 provides an adequate range of values for the three statistical measures (NSE, R^2, and PBIAS) (Moriasi et al. 2007), that were utilized in this work to assess the model's efficiency. NSE has a value ranging from -∞ to 1. While an NSE of 0 denotes that the simulated variables are equally accurate to the mean of the observed variables, an NSE of 1 signifies that the simulated variables are identical to the observed variables (Nash and Sutcliffe 1970). R^2 has a value ranging from 0 to 1. There is no agreement between the simulated and observed variables when the R^2 value is 0, but an R^2 of 1 means that the simulated and observed variables are equal. (Krause et al. 2005). PBIAS has an optimal value of zero, and smaller extent values imply more accurate model simulations. A positive PBIAS number means that the model underestimates, whereas a negative PBIAS value suggests it is overestimating (Gupta et al. 1999).

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \quad (2)$$

where: O_i is representing measured discharge;
S_i– simulated discharge;
$\bar{O}$ – average of measured discharges;
$\bar{S}$ – average ofdischarges simulatedand nthe number of observations.

$$R^2 = \left[\frac{\sum_{i=1}^{n}(O_i - \bar{O})(S_i - \bar{S})}{\left[\sum_{i=1}^{n}(O_i - \bar{O})^2\right]^{0.5}\left[\sum_{i=1}^{n}(S_i - \bar{S})^2\right]^{0.5}}\right] \quad (3)$$

where: O_i is representing measured discharge;
S_i – simulated discharge;
$\bar{O}$ – average of measured discharges;
$\bar{S}$ – average of discharges simulated and n the number of observations.

$$PBIAS = 100 \cdot \frac{\sum_{i=1}^{n} O_i - S_i}{\sum_{i=1}^{n} O_i} \quad (4)$$

where: O_i is representing measured discharge;
S_i – simulated discharge,

Uncertainty analysis

Several uncertainties may lead the model to malfunction during the setup of a modeling project. Refsgaard et al. (2007), Abbaspour et al. (2007), and Bastin et al. (2013) assert that these uncertainties may be introduced: both at the level of the input data (missing or incorrect data) and the level of the model (formalization and parameterization). Therefore, the model must be utilized to enhance and check its performance (Rollo 2012). This process involved statistical and graphical evaluation of the differences and similarities between observed and simulated data. The Sequential Uncertainty Fitting ver.2 (SUFI-2) approach was utilized for calibration and validation in our work for the reason that it integrates all

Table 2. Recommended model performance evaluation criteria for a monthly time step (Moriasi et al. 2007)

Performance evaluation	NS	PBIAS		
		Flow	Sediment	Nutrients
Very good	0.75 < NS ≤ 1.00	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

uncertainties from the entire sources (parameters and input database) (Yang et al. 2008). It can assess a sizable number of parameters and simultaneously observe data from numerous gauging stations. It starts with a high parameter uncertainty, which drives observed variables to stay inside the 95% prediction uncertainty (95PPU). Afterward, it progressively diminishes this uncertainty till the 95PPU band encompasses the majority of observations and the mean gap between the major (at 97.5% level), and minor (at 2.5% level) parts of the 95PPU are tiny. SUFI2 provides two factors (P-factor and R-factor) to measure the inclusion of uncertainty and, as a result, where the model ends. The P-factor is the percentage of measured data that falls within the 95% forecast uncertainty (95PPU). In contrast, the R-factor is determined by dividing the standard deviation of the observed data by the average width of the 95PPU band. (Schuol et al. 2008a).

RESULTS

Sensitivity analysis

Any model calibration is preceded by a sensitivity analysis, especially when the model admits a huge amount of parameters that ought to be modified, such as the SWAT model. This step aims to detect which parameters, for a given model configuration, will influence the simulation produced. Based on a global approach, the sensitivity analysis was conducted on the parameters most commonly modified in the literature during model calibration. More than five thousand simulations were performed by changing the value of the parameters at each simulation in order to evaluate their impact. The choice of values is made according to a Latin hypercube sampling that covers the range of possible values each parameter can take (McKay et al., 1979). By successive iterations, the results of sensitivity analysis obtained for the flows (see Table 3) show that out of the 28 parameters considered, eleven were found to be more sensitive. They also illustrate that the first sensitive parameters are related to surface runoff (CN2), soil (soil moisture density (SOL_BD), moist soil albedo (SOL_ALB) and soil available water capacity (SOL_AWC)) and the soil evaporation compensation factor (ESCO). These parameters control the portion of flow contributing to surface runoff. The majority of the groundwater flow parameters (percolation coefficient to the deep aquifer (RCHRG_DP), groundwater depletion coefficient (ALPHA_BF), groundwater delay (GW_DELAY)) come later, demonstrating how crucial it is to calibrate the surface runoff first. The calibrated parameters are generally heterogeneous among the hydrometric stations. The baseflow alpha factor (ALPHA_BF) is between 0.01 and 0.63, depending on the station. The deep aquifer percolation portion (RCHRG_DP) is between 0.27 and 0. 79. The water routing delay in the unsaturated zone (GW_DELAY) is between 1 and 14 days. The initial depth of water in the shallow aquifer (SHALLST) varies between 8 and 43 m. The soil evaporation factor as a function of depth (ESCO) is 0.82, except at Tabouda and Ain Aicha stations, where it reaches 0.99. Effective

Table 3. SWAT model sensitive parameters and their optimal values obtained during calibration

Calibrated parameters	Sensibility rank	Group of sub-basins							
		Tabouda	Al Wahda	Ain Aicha	Bab Ouender	Khenichet	Sahla	Min	Max
		1-3	2-5-7-8-10-15-16-17	9-4-12-18	6-14	11-19	13		
ALPHA_BF	1	0.13	0.31	0.14	0.63	0.01	0.23	0.01	0.63
RCHRG_DP	2	0.32	0.52	0.66	0.39	0.79	0.27	0.27	0.79
GW_DELAY	3	1.39	8.29	14.88	8.49	14.62	6.99	1.39	14.88
CH_K2	4	95.2	104.97	30.52	71	11.44	109.98	11.4	110
SOL_BD	5	-0.5	-0.24	-0.5	-0.24	-0.08	-0.15	-0.5	-0.08
CN2	6	0.08	-0.13	0.14	-0.19	-0.06	-0.07	-0.19	0.14
CH_N2	7	0.13	0.27	0.26	0.22	0.3	0.16	0.13	0.3
SOL_AWC	8	-0.12	-0.02	-0.02	0.06	-0.16	-0.08	-0.16	0.06
SOL_ALB	9	0.07	0.12	0.01	0.04	0.02	0.05	0.01	0.12
ESCO	10	0.98	0.82	0.84	0.83	0.82	0.99	0.82	0.99
SHALLST	11	27085	35829	22185	8315	25027	43568	8315	43568

hydraulic conductivity in the main channel (CH_K2) varies from about 109 mm/h at the level of the group of sub-basins of Al Wahda station and 11 mm/h at the level of the sub-basins of Khenichet station. It was found that the modified parameters are relatively near to the initial values, mainly at the Al Wahda dam station, which includes most sub-basins (almost 40% of the watershed area). The model thus presents an excellent capacity to reproduce the flows in different contexts.

SWAT model performances

In this section, we used three statistical measures, Nash-Sutcliffe coefficient (NS), percent bias (PBIAS), and coefficient of determination (R^2) at six control points. The precision of the SWAT model was assessed with monthly river flow data from nine and eight years, respectively, for calibration (1997-2005) and validation (2006-2013). The discharge forecasts go with actual measurements, as illustrated in Table 4. However, comparing the statistical variables reveals that the model performed better during validation than during calibration. The total efficiency criteria are 0.64 for the calibration period and 0.66 for the validation period. The coefficient of determination (R^2) values for the calibration and validation periods are, respectively, between 0.64 and 0.88 and 0.60 and 0.89, indicating that the agreement between observed and simulated streamflow for both times was reliable. The PBIAS values vary between +8.82 to +22.19% and between +12.72 to +21.19% for the calibration and validation, respectively, which demonstrated that the model somewhat overestimated the streamflow for the period of calibration and validation concerning the observed data.

Concerning the uncertainties, the p-factor (percentage of observations enveloped in the 95PPU uncertainty band), the score obtained in validation (0.71) is higher than that obtained in calibration (0.68) on the monthly values. These results show that the 95PPU uncertainty band, defined in validation, is positioned to encompass more observations than in calibration. However, as far as the r-factor is concerned, both cases (calibration and validation) present a 95PPU band of adequate width as less than 1.7 (Abbaspour et al., 2015), except for the Bab Ouender station (r-factor = 2.1). Therefore, the values obtained are very satisfactory, reducing uncertainties related to the calibration and thus having a better estimate of the studied processes.

A thorough investigation of the model's efficiency involves a graphical comparison of various flows to ensure that the model is reproducible (Figure 4). The analysis of these hydrographs confirms the performance criteria for the stations where good performances are obtained. Furthermore, it indicates that the model faithfully reproduces the flow variation in most sites (Ain Aicha, Tabouda, Sahla, and Al Wahda) for the different overflow states and baseflow. However, simulated streamflow could be underestimated or overestimated for some episodes compared to those observed (Khenichet and Bab Ouender).

For the cases showing average to unsatisfactory performances or some instability, this analysis contributes to understanding the biases present in the simulation of streamflow by the model. The stations of Khenichet and Bab Ouender show minor good performances. Simulation inaccuracies persist despite the effort taken to calibrate these two stations, which are located upstream and downstream of the hydrographic network. However, hydrograph analysis reveals that the problem is different for these two stations. The Bab Ouender station presents an overestimation of the flows, particularly visible for the base flow.

In contrast, the simulations at the Khenichet station tend to underpredict streamflow, which is reflected in a more visible way on the peaks. These stations are part of a complicated terrain

Table 4. Calibration and validation performance of six discharge stations

Station		Calibration 1997-2005					Validation 2006-2013		
		NSE	R2	PBIAS	p-factor	r-factor	NSE	R2	PBIAS
Station	Ain Aicha	0.75	0.84	13.82	0.58	1.69	0.77	0.82	12.72
	Bab Ouender	0.51	0.77	28.47	0.66	2.1	0.45	0.76	31.96
	Tabouda	0.58	0.81	22.19	0.51	1.64	0.75	0.89	13.21
	Khenichet	0.56	0.66	21.4	0.49	1.49	0.55	0.6	21.89
Barrage	Barrage Sahla	0.62	0.64	22.07	0.66	1.58	0.69	0.74	18.01
	Barrage Al Wahda	0.85	0.88	8.82	0.68	1.72	0.76	0.8	14.11

where altitude and anthropization issues are intertwined. The contradictory simulation errors discovered at each site demonstrate the modeling challenges that might occur in this region. The downstream station (Khenichet) hydrograph shows that the flows are very close, except for some flood peaks, simulated differently (in 2009 and 2010, for example).

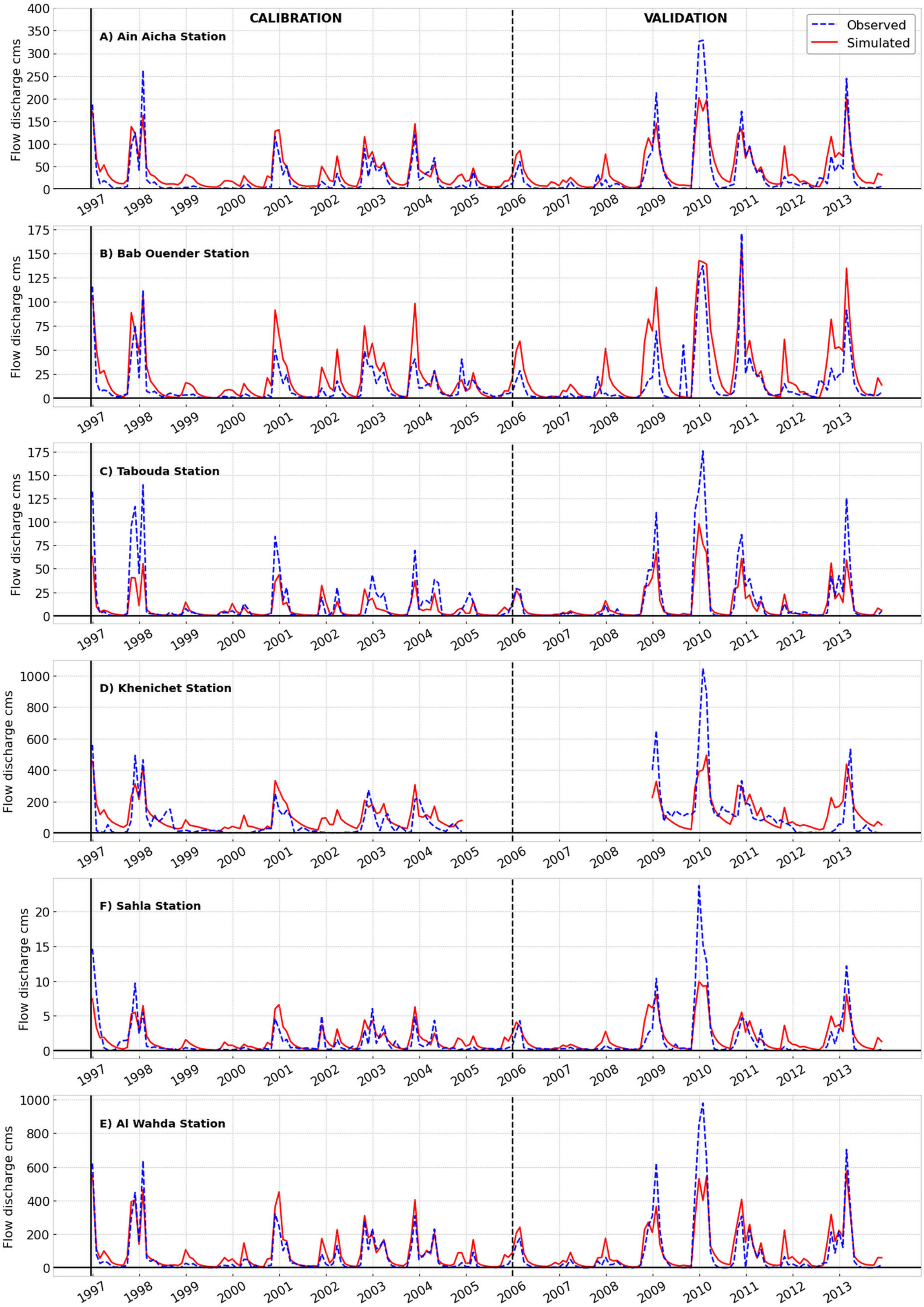

Figure 4. Comparison between observed streamflow (blue line) and simulated streamflow (red line)

In fact, 2009 and 2010 were stormy years with severe flooding (in February 2010, the flow measured at this station surpassed 1000 m^3/s). The Bab Ouender station, located upstream, also has instabilities. Its hydrograph shows that overflow and baseflow are both overestimated. This station references an area with extremely high anthropization of the hydrographic network. This overprediction at certain peaks is due to overexploitation by extracting water from the rivers for agriculture. These withdrawals still need to be considered in a conceptual model at the catchment level, as SWAT, whose formalism does not now permit their representation. This region's water extraction during summer makes simulation challenging to accomplish. The convergence of simulated and observed data throughout the validation period shows the model's capacity to reflect a range of environmental situations. Therefore, the quality and quantity of input data are primarily responsible for these gauging stations' low performance, in addition to the model itself. Although significant progress, agro-hydrological modeling with the SWAT model largely relies on the amount and precision of accessible data. Besides rainfall, the coarse soil map simplifies the complexity of soil repartition observed in the ground. However, despite their high resolution, the satellite images employed for mapping land cover need to define the watershed's various

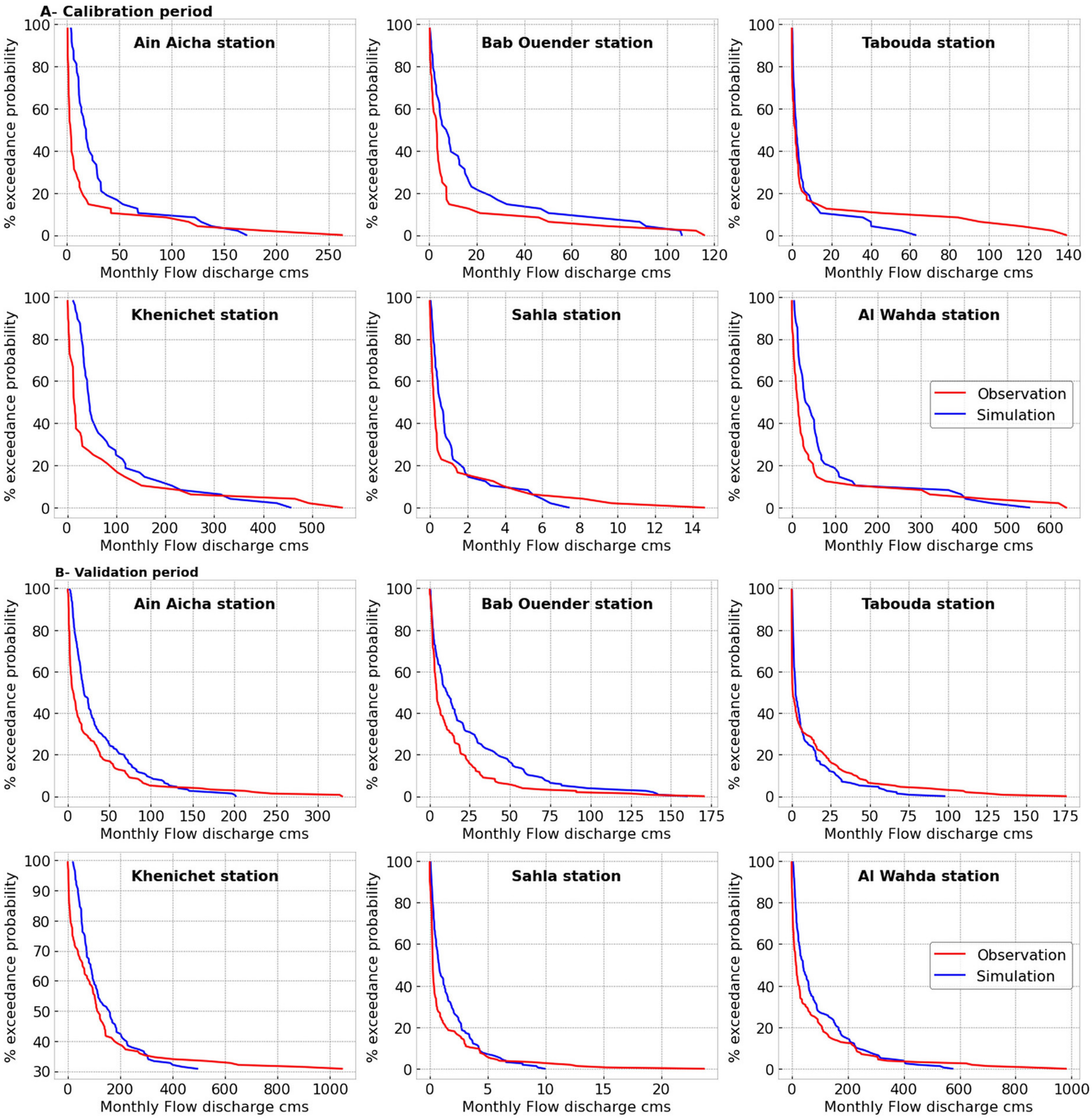

Figure 5. Percent exceedance probability curves of observed and simulated (a) calibration period, (b) validation period

vegetation covers adequately. This gap decreases the HRU's discretization and, consequently, the model's prediction accuracy (Neitsch et al. 2011).

The performance of a model may be assessed using flow-duration curves (TCD). Poor FDC reproduction indicates subpar model performance (Ley et al. 2015). Assessing the reproduction of discharges of varied strengths is made easier with the help of the FDCs (Vogel and Fennessey 1994, Van Liew et al., 2007, Yokoo and Sivapalan 2011). It was used to compare simulated and observed monthly flows. Figure 5 reveals the adequacy curves between observed and simulated flows. This graph displays how accurately the model simulates the monthly flows observed throughout the calibration and validation periods. The estimated flow duration curve deviates from the data in various ranges by a certain amount. More flow is simulated in the low and medium intervals, while it needs to be sufficiently simulated in the higher intervals. The figure shows the percentage exceedance probability curves at the different stations. While the simulated and observed flow frequencies commonly have good conformity in the upper intervals, the Tabouda station shows much more divergence in calibration in this interval. As a result, it shows fewer simulated flows. Other station combinations were able to simulate the entire range of streamflow accurately. The observed streamflow range is well predicted for most of the flow exceedance, excluding the shallow flows where simulated discharge was overestimated.

Hydrological water balance

Table 5 provides a summary of the hydrographs study's investigations. It recreates how

Table 5. Water balance components of Ouergha Watershed simulated by SWAT model

Water balance components	Value	Percentage of contribution
Rainfall (mm)	807	100%
Runoff (mm)	231	29%
Lateral flow (mm)	81	10%
Infiltration and percolation (mm)	61	7%
Actual evapotranspiration (mm)	434	54%
Potential evapotranspiration (mm)	1642	–

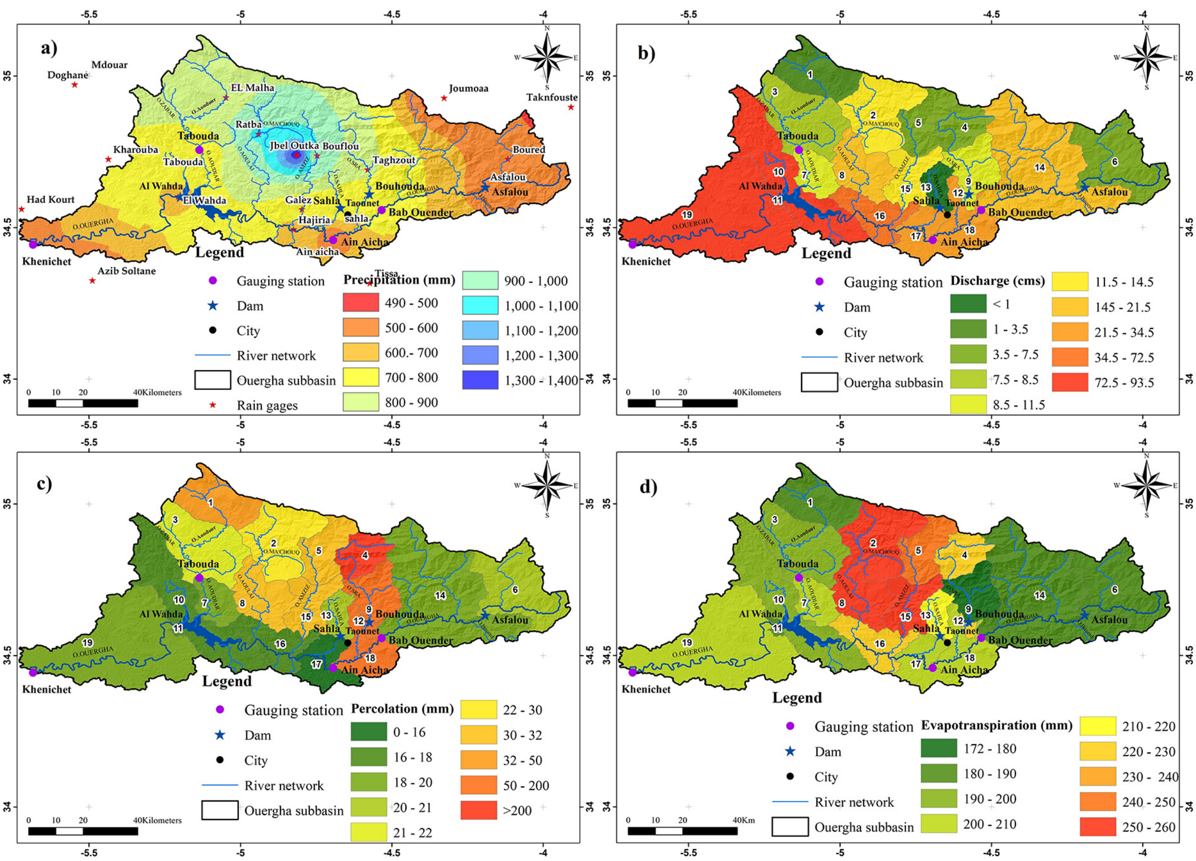

Figure 6. Map of rainfall (a), simulated discharge (b), percolation (c), and evapotranspiration (d), across the Ouergha watershed

precipitation is distributed throughout the soil, runoff, evapotranspiration, and infiltration. Actual evapotranspiration (54%) is far and away the most crucial component of the water balance. Agriculture is responsible for its high value. The significant water withdrawals for irrigation cause evapotranspiration to rise, which reduces streamflow. Also, during the dry period, the high evapotranspiration causes a considerable capillary increase. Infiltration and percolation (7%) account for a relatively minor proportion of the water balance. This is attributable to the character of the soils in the study region. Annual runoff is predicted to be 230 mm (29%). Figure 5 depicts a complete description of these ratios.

Rainfall variability is depicted on the map of the Ouergha watershed's regional and temporal dispersion of average rainfall (Figure 6a). The average water received between 1997 and 2013 was 807 mm/yr. Rainfall on the basin's center and north were more than on the basin's eastern and western edges (650 mm). This unequal distribution of rainfall impacts different elements of the hydrological cycle. Because evapotranspiration is primarily influenced by temperature and precipitation, it reaches its maximum when the latter is sufficient. The basin's yearly evapotranspiration ranged from 205 to 328 mm, and like precipitation, its value was highest in the basin's north and center (Figure 6d). The runoff and percolation of soil are predicted 231 mm and 61 mm respectively. Due to the poor hydraulic conductivity of the bedrock made of schist, marl, and clay, percolation is at a lower value. (Figure 6b and 6c).

CONCLUSIONS

The Ouergha basin's hydrological processes and water balance components were modelled using the semi-distributed hydrological model. A significant number of soils, climatic, topography, land cover, and gauging data had to be mobilized for the SWAT model to estimate the water balance. The model was calibrated and validated by employing monthly streamflow data and the SUFI-2 technique in SWAT-CUP2012. A sensitivity analysis was conducted to find flow-sensitive parameters. It was determined that the groundwater flow characteristics were more responsive to streamflow. In order to accomplish calibration, several hydrologic factors, including the runoff coefficient, soil, evaporation, and groundwater, were modified. The effectiveness of the model is assessed using the statistical measurements of percent of bias (PBIAS), coefficient of determination (R^2), and Nash-Sutcliffe efficiency (NSE). The simulation period, which ran from 1990 to 2013, was split into three sub-periods: warming (1990–1996), calibration (1997–2005), and validation (2006–2013).

The SWAT model has reproduced monthly streamflow statistically similar to the observed, despite the limitations linked to the quality and quantity of input data. The model performed better during the validation period ($0.45<NSE<0.77$; $0.6<R^2<0.89$; $12.72<PBIAS<31.96$) compared to the calibration period ($0.51<NSE<0.85$; $0.64<R^2<0.88$; $8.82<PBIAS<28.47$). The hydrological balance's investigation shows that runoff accounts for 29% of total water loss, while evapotranspiration losses are predicted to be greater than 54%. The recharge to the deep aquifers is 8%, while the lateral flow is 10%. The Ouergha SWAT model simulates actual streamflow in various soil, land-use, and meteorological conditions. The Ouergha catchment's water resources could be better protected in the future via research that considers climate change and cultural practices.

REFERENCES

1. Abbaspour, K.C., 2013. Swat-cup 2012. SWAT calibration and uncertainty program – A user manual.
2. Abbaspour, K.C., Rouholahnejad, E., Vaghefi, S.R.I.N.I.V.A.S.A.N.B., Srinivasan, R., Yang, H. and 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.
3. Ait M'Barek, S., Rochdi, A., Bouslihim, Y. and Miftah, A., 2021. Multi-Site Calibration and Validation of SWAT Model for Hydrologic Modeling and Soil Erosion Estimation: A Case Study in El Grou Watershed, Morocco. Ecological Engineering & Environmental Technology, 22.
4. Arnold, J.G., Moriasi, D.N., Gassman, P.W., Abbaspour, K.C., White, M.J., Srinivasan, R., Santhi, C., Harmel, R.D., Van Griensven, A., Van Liew, M.W. and Kannan, N., 2012. SWAT: Model use, calibration, and validation. Transactions of the ASABE, 55(4), 1491-1508.
5. Arnold, J.G., Srinivasan, R., Muttiah, R.S. and Williams, J.R., 1998. Large area hydrologic asining and assessment part I: model development 1. JAWRA Journal of the American Water Resources Association, 34(1), 73-89.

6. Ayele, G.T., Teshale, E.Z., Yu, B., Rutherfurd, I.D. and Jeong, J., 2017. Streamflow and sediment yield prediction for watershed prioritization in the Upper Blue Nile River Basin, Ethiopia. Water, 9(10), p.782.
7. Bahin, E.Y.B. and Haida, S., 2018. Hydrogeochemical Characterization of the Dissolved Load of the Major Elements Downstream of the Watershed of the Wadi Sebou, Morocco. Journal of Geoscience and Environment Protection, 6(07), p.159.
8. Bastin, L., Cornford, D., Jones, R., Heuvelink, G.B., Pebesma, E., Stasch, C., Nativi, S., Mazzetti, P. and Williams, M., 2013. Managing uncertainty in integrated environmental modelling: The UncertWeb framework. Environmental Modelling & Software, 39, 116-134.
9. Boufala, M., El Hmaidi, A., Chadli, K., Essahlaoui, A., El Ouali, A. and Taia, S., 2019. Hydrological asining of water and soil resources in the basin upstream of the Allal El Fassi dam (Upper Sebou watershed, Morocco). Modeling Earth Systems and Environment, 5(4), 1163-1177.
10. Bouslihim, Y., Rochdi, A., Paaza, N.E.A. and Liuzzo, L., 2019. Understanding the effects of soil data quality on SWAT model performance and hydrological processes in Tamedroust watershed (Morocco). Journal of African Earth Sciences, 160, p.103616.
11. Brouziyne, Y., Abouabdillah, A., Bouabid, R. and Benaabidate, L., 2018. SWAT streamflow asining for hydrological components' understanding within an agro-sylvo-pastoral watershed in Morocco. J. Mater. Environ. Sci, 9(1), 128-138.
12. Chaponniere, A., 2005. Fonctionnement hydrologique d'un asin versant montagneux semi aride. Cas du bassin versant du Rehraya (Haut Atlas marocain), These, Institut National Agronomique de Paris Grignon.
13. Dafouf, S., Lahrach, A., Tabyaoui, H., El Hafyani, M. and Benaabidate, L., 2022. Meteorological Drought Assessment in the Ziz Watershed (South East of Morocco). Ecol. Eng, 6, 243-263.
14. Daide, F., Afgane, R., Lahrach, A. and Chaouni, A.A., 2022. Beht Watershed (Morocco) Rainfall-Runoff Simulation with the HEC-HMS Hydrological Model. Ecological Engineering & Environmental Technology, 23.
15. Devia, G.K., Ganasri, B.P. and Dwarakish, G.S., 2015. A review on hydrological models. Aquatic procedia, 4, 1001-1007.
16. Driouech, F., Stafi, H., Khouakhi, A., Moutia, S., Badi, W., ElRhaz, K. and Chehbouni, A., 2021. Recent observed country-wide climate trends in Morocco. International Journal of Climatology, 41, 855-874.
17. Food and Agriculture Organization of the United Nations, 1977. Soil map of the world 1/5 000 000, Africa, Vol. 6, p. 346.
18. Gassman, P.W., Reyes, M.R., Green, C.H. and Arnold, J.G., 2007. The soil and water assessment tool: historical development, applications, and future research directions. Transactions of the ASABE, 50(4), 1211-1250.
19. Gupta, H.V., Sorooshian, S. and Yapo, P.O., 1999. Status of automatic calibration for hydrologic models: Comparison with multilevel expert calibration. Journal of hydrologic engineering, 4(2), 135-143.
20. Haida, S., 2000. Transport de matière et bilan de l'érosion mécanique et de l'altération chimique dans un bassin versant de zone semi-aride: le Sebou. Impacts des variations climatiques et des activités humaines. Doctoral dissertation, Ibn Tofail University, Morocco.
21. Jabri, B., Hessane, M.A., Morabbi, A. and Msatef, K., 2022. Application of soil conservation service curve number method for runoff estimation in Sebou watershed, Morocco. Ecol. Eng, 6, 70-81.
22. Khalid, C., 2018. Hydrological modeling of the Mikkés watershed (Morocco) using ARCSWAT model. Sustainable Water Resources Management, 4(1), 105-115.
23. Krause, P. and Flügel, W.A., 2005. Integrated research on the hydrological process dynamics from the Wilde Gera catchment in Germany. In Headwater Control VI: Hydrology, Ecology and Water Resources in Headwaters, IAHS Conference, Bergen.
24. Levesque, E., Anctil, F., Van Griensven, A.N.N. and Beauchamp, N., 2008. Evaluation of streamflow simulation by SWAT model for two small watersheds under snowmelt and rainfall. Hydrological sciences journal, 53(5), 961-976.
25. Ley, R., Hellebrand, H., Casper, M.C. and Fenicia, F., 2016. Comparing classical performance measures with signature indices derived from flow duration curves to assess model structures as tools for catchment classification. Hydrology Research, 47(1), 1-14.
26. Markhi, A., Laftouhi, N., Grusson, Y. and Soulaimani, A., 2019. Assessment of potential soil erosion and sediment yield in the semi-arid N′ fis basin (High Atlas, Morocco) using the SWAT model. Acta Geophysica, 67(1), 263-272.
27. McKay, M.D., Beckman, R.J. and Conover, W.J., 1979. A comparison of three methods for selecting values of input variables in the analysis of output from a computer code. Technometrics, 21(2), 239-245.
28. Mimich K., Essahlaoui A., El Ouali, A., El Hmaidi A., 2018. Using SWAT to simulate a moroccan watershed, including an assessment of the most sensitive modelling parameters with SUFI2. The International Journal of Engineering and Science, 7(10), 50–63.
29. Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D. and Veith, T.L., 2007. Model evaluation guidelines for systematic quantification

of accuracy in watershed simulations. Transactions of the ASABE, 50(3), 885-900.

30. Nash, J.E. and Sutcliffe, J.V., 1970. River flow forecasting through conceptual models. Part I. A discussion of principles. Journal of hydrology, 10(3), 282-290.
31. Neitsch, S.L., Arnold, J.G., Kiniry, J.R. and Williams, J.R., 2011. Soil and water assessment tool theoretical documentation version 2009. Texas Water Resources Institute. p. 647.
32. Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R. and King, K.W., 2005. Soil and water assessment tool theoretical documentation version 2005. Grassland. Soil and Water Research Laboratory, Agricultural Research Service, Blackland Research Center, Texas Agricultural Experiment Station, Texas, 1. p. 494.
33. Ouatiki, H., Boudhar, A., Tramblay, Y., Jarlan, L., Benabdelouhab, T., Hanich, L., El Meslouhi, M.R. and Chehbouni, A., 2017. Evaluation of TRMM 3B42 V7 rainfall product over the Oum Er Rbia watershed in Morocco. Climate, 5(1), p.1.
34. Refsgaard, J.C., van der Sluijs, J.P., Højberg, A.L. and Vanrolleghem, P.A., 2007. Uncertainty in the environmental modelling process–a framework and guidance. Environmental modelling & software, 22(11), 1543-1556.
35. Rollo N., 2012. Modélisation des dynamiques de pollution diffuse dans le bassin versant de la rivière d'Auray. Quantification, caractérisation et gestion des apports nutritifs terrigènes. Ph.D. Thesis, Nantes University, France.
36. Rouholahnejad, E., Abbaspour, K.C., Vejdani, M., Srinivasan, R., Schulin, R. and Lehmann, A., 2012. A parallelization framework for calibration of hydrological models. Environmental Modelling & Software, 31, 28-36.
37. Saha, S., Moorthi, S., Pan, H.L., Wu, X., Wang, J., Nadiga, S., Tripp, P., Kistler, R., Woollen, J., Behringer, D. and Liu, H., 2010. The NCEP climate forecast system reanalysis. Bulletin of the American Meteorological Society, 91(8), 1015-1058.
38. Schuol, J., Abbaspour, K.C., Srinivasan, R. and Yang, H., 2008. Estimation of freshwater availability in the West African sub-continent using the SWAT hydrologic model. Journal of hydrology, 352(1-2), 30-49.
39. Senoussi, S., Agoumi, A., Yacoubi, M., Fakhraddine, A., Sayouty, E.H., Mokssit, A. and Chikri, N., 1999. Changements climatiques et ressources en eau Bassin versant de I'Ouergha (Maroc). Hydroécologie Appliquée, 11, 163-182.
40. Talaee, P.H., 2014. Iranian rainfall series analysis by means of nonparametric tests. Theoretical and applied climatology, 116(3), 597-607.
41. Taleb, R.B., Naimi, P.M., Chikhaoui, P.M., Raclot, D. and Sabir, P.M., 2019. Evaluation Des Performances Du Modele Agro-Hydrologique SWAT à Reproduire Le Fonctionnement Hydrologique Du Bassin Versant Nakhla (Rif occidental, Maroc). European Scientific Journal ESJ, 15(5), 311-333.
42. Tramblay, Y., Badi, W., Driouech, F., El Adlouni, S., Neppel, L. and Servat, E., 2012. Climate change impacts on extreme precipitation in Morocco. Global and Planetary change, 82, 104-114.
43. Van Liew, M.W., Veith, T.L., Bosch, D.D. and Arnold, J.G., 2007. Suitability of SWAT for the conservation effects assessment project: comparison on USDA agricultural research service watersheds. Journal of Hydrologic Engineering, 12(2), 173-189.
44. Vogel, R.M. and Fennessey, N.M., 1994. Flow-duration curves. I: New interpretation and confidence intervals. Journal of Water Resources Planning and Management, 120(4), 485-504.
45. Yang, J., Reichert, P., Abbaspour, K.C., Xia, J. and Yang, H., 2008. Comparing uncertainty analysis techniques for a SWAT application to the Chaohe Basin in China. Journal of hydrology, 358(1-2), 1-23.
46. Yokoo, Y. and Sivapalan, M., 2011. Towards reconstruction of the flow duration curve: development of a conceptual framework with a physical basis. Hydrology and Earth System Sciences, 15(9), 2805-2819.