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

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

Lamia Erraioui*, Soufiane Taia1, Kamal Taj-Eddine2, Jamal Chao1, Bouabid El Mansouri1

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.
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 (Chadi K., 2017; Mimich et al., 2018; Boufala et al., 2019; Taleb et al., 2019). Also, some researchers treated the impact of silting 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. (Brouzyne 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 km² (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 Mm³. 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,
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 sub-basins, 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). The following equation determines the water balance in SWAT at the watershed echelon. (Neitsch et al. 2011; Arnold et al. 2012).

\[ SW_t = SW_0 + \sum_{i=1}^{t} \left( R_{\text{day}} - Q_{\text{surf}} - E_a - W_{\text{seep}} - Q_{\text{gw}} \right) \]  

(1)

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

**Data preparation**

The efficient adaptation of SWAT in a sub-humid 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>
<thead>
<tr>
<th>Gauging station</th>
<th>Lambert coordinates (Zone 1)</th>
<th>measured parameter</th>
<th>Commissioning date</th>
<th>River</th>
<th>Yearly average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sahla dam</td>
<td>566876 440850 372</td>
<td>S, V</td>
<td>1994</td>
<td>Sahla</td>
<td>1.34 m³/s</td>
</tr>
<tr>
<td>Al Wahda dam</td>
<td>517768 444369 166</td>
<td>S, P, V</td>
<td>1997</td>
<td>Ouergha</td>
<td>74.10 m³/s</td>
</tr>
<tr>
<td>Jbel Outka</td>
<td>553000 459000 1115</td>
<td>P</td>
<td>1978</td>
<td>Aoulai</td>
<td>1383 mm</td>
</tr>
<tr>
<td>Galez</td>
<td>555325 439850 214</td>
<td>P</td>
<td>1978</td>
<td>Amzaz</td>
<td>684 mm</td>
</tr>
<tr>
<td>Tabouda</td>
<td>524250 461600 201</td>
<td>S, P</td>
<td>1978</td>
<td>Aoudour</td>
<td>12.61 m³/s</td>
</tr>
<tr>
<td>Bab Ouender</td>
<td>579500 440100 312</td>
<td>S, P</td>
<td>1952</td>
<td>Ouergha</td>
<td>16.80 m³/s</td>
</tr>
<tr>
<td>Ain Aïcha</td>
<td>564800 428800 230</td>
<td>S, P</td>
<td>1980</td>
<td>Ouergha</td>
<td>23.21 m³/s</td>
</tr>
<tr>
<td>Khenichet</td>
<td>473700 425900 17</td>
<td>S, P</td>
<td>1963</td>
<td>Ouergha</td>
<td>72.22 m³/s</td>
</tr>
<tr>
<td>Mjaara</td>
<td>513510 443250 81</td>
<td>P</td>
<td>1958</td>
<td>Ouergha</td>
<td>609 mm</td>
</tr>
</tbody>
</table>

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

![Input data for SWAT model](image1)

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

![Spatial calibration approach adopted for Ouergha Watershed](image2)

**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 Wåhda 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, R², 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). R² has a value ranging from 0 to 1. There is no agreement between the simulated and observed variables when the R² value is 0, but an R² 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).

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

(2)

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

\[ R^2 = \frac{\sum_{i=1}^{n}(O_i - \bar{O})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2} \sqrt{\sum_{i=1}^{n}(S_i - \bar{S})^2}}^{0.5} \]  

(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 the number of observations.

\[ PBIAS = 100 \cdot \frac{\sum_{i=1}^{n} O_i - S_i}{\sum_{i=1}^{n} O_i} \]  

(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>
<thead>
<tr>
<th>Performance evaluation</th>
<th>NS</th>
<th>PBIAS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flow</td>
<td>Sediment</td>
</tr>
<tr>
<td>Very good</td>
<td>0.75 ≤ NS ≤ 1.00</td>
<td>PBIAS &lt; ± 10</td>
</tr>
<tr>
<td>Good</td>
<td>0.65 ≤ NS ≤ 0.75</td>
<td>± 10 ≤ PBIAS ≤ ± 15</td>
</tr>
<tr>
<td>Satisfactory</td>
<td>0.50 ≤ NS ≤ 0.65</td>
<td>± 15 ≤ PBIAS ≤ ± 25</td>
</tr>
<tr>
<td>Unsatisfactory</td>
<td>NS ≤ 0.50</td>
<td>PBIAS ≥ ± 25</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Calibrated parameters</th>
<th>Sensibility rank</th>
<th>Group of sub-basins</th>
<th>Tabouida</th>
<th>Al Wahda</th>
<th>Ain Aicha</th>
<th>Bab Ouender</th>
<th>Khenichet</th>
<th>Sahla</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1-3</td>
<td>2-5-7-8-10-15-16-17</td>
<td>9-4-12-18</td>
<td>6-14</td>
<td>11-19</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALPHA_BF</td>
<td>1</td>
<td>0.13</td>
<td>0.31</td>
<td>0.14</td>
<td>0.63</td>
<td>0.01</td>
<td>0.23</td>
<td>0.01</td>
<td>0.63</td>
<td></td>
</tr>
<tr>
<td>RCHRG_DP</td>
<td>2</td>
<td>0.32</td>
<td>0.52</td>
<td>0.66</td>
<td>0.39</td>
<td>0.79</td>
<td>0.27</td>
<td>0.27</td>
<td>0.79</td>
<td></td>
</tr>
<tr>
<td>CH_K2</td>
<td>4</td>
<td>95.2</td>
<td>104.97</td>
<td>30.52</td>
<td>71</td>
<td>11.44</td>
<td>109.98</td>
<td>11.4</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>SOL_BD</td>
<td>5</td>
<td>-0.5</td>
<td>-0.24</td>
<td>-0.5</td>
<td>-0.24</td>
<td>-0.08</td>
<td>-0.15</td>
<td>-0.5</td>
<td>-0.08</td>
<td></td>
</tr>
<tr>
<td>CN2</td>
<td>6</td>
<td>0.08</td>
<td>-0.13</td>
<td>0.14</td>
<td>-0.19</td>
<td>-0.06</td>
<td>-0.07</td>
<td>-0.19</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>CH_N2</td>
<td>7</td>
<td>0.13</td>
<td>0.27</td>
<td>0.26</td>
<td>0.22</td>
<td>0.3</td>
<td>0.16</td>
<td>0.13</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>SOL_AWC</td>
<td>8</td>
<td>-0.12</td>
<td>-0.02</td>
<td>-0.02</td>
<td>0.06</td>
<td>-0.16</td>
<td>-0.08</td>
<td>-0.16</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>SOL_ALB</td>
<td>9</td>
<td>0.07</td>
<td>0.12</td>
<td>0.01</td>
<td>0.04</td>
<td>0.02</td>
<td>0.05</td>
<td>0.01</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>ESCO</td>
<td>10</td>
<td>0.98</td>
<td>0.82</td>
<td>0.84</td>
<td>0.83</td>
<td>0.82</td>
<td>0.99</td>
<td>0.82</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>SHALLST</td>
<td>11</td>
<td>27085</td>
<td>35829</td>
<td>22185</td>
<td>8315</td>
<td>25027</td>
<td>43568</td>
<td>8315</td>
<td>43568</td>
<td></td>
</tr>
</tbody>
</table>
hydraulic conductivity in the main channel (CH\textsubscript{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>
<thead>
<tr>
<th>Station</th>
<th>Calibration 1997-2005</th>
<th>Validation 2006-2013</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NSE</td>
<td>R\textsuperscript{2}</td>
</tr>
<tr>
<td>Ain Aicha</td>
<td>0.75</td>
<td>0.84</td>
</tr>
<tr>
<td>Bab Ouender</td>
<td>0.51</td>
<td>0.77</td>
</tr>
<tr>
<td>Tabouda</td>
<td>0.58</td>
<td>0.81</td>
</tr>
<tr>
<td>Khenichet</td>
<td>0.56</td>
<td>0.66</td>
</tr>
<tr>
<td>Barrage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barrage Sahla</td>
<td>0.62</td>
<td>0.64</td>
</tr>
<tr>
<td>Barrage Al Wahda</td>
<td>0.85</td>
<td>0.88</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Water balance components</th>
<th>Value</th>
<th>Percentage of contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall (mm)</td>
<td>807</td>
<td>100%</td>
</tr>
<tr>
<td>Runoff (mm)</td>
<td>231</td>
<td>29%</td>
</tr>
<tr>
<td>Lateral flow (mm)</td>
<td>81</td>
<td>10%</td>
</tr>
<tr>
<td>Infiltration and percolation (mm)</td>
<td>61</td>
<td>7%</td>
</tr>
<tr>
<td>Actual evapotranspiration (mm)</td>
<td>434</td>
<td>54%</td>
</tr>
<tr>
<td>Potential evapotranspiration (mm)</td>
<td>1642</td>
<td>–</td>
</tr>
</tbody>
</table>

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 (R²), 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<R²<0.89; 12.72<PBIAS<31.96) compared to the calibration period (0.51<NSE<0.85; 0.64<R²<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


