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Article

Application of the SWAT model for water budgeting and water resource planning in Oued Cherraa basin (northeastern Morocco)

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Abstract: This study focuses on the use of the Soil and Water Assessment Tool (SWAT) model for water budgeting and resource planning in Oued Cherraa basin. The combination of hydrological models such as SWAT with reliable meteorological data makes it possible to simulate water availability and manage water resources. In this study, the SWAT model was employed to estimate hydrological parameters in the Oued Cherra basin, utilizing meteorological data (2012–2020) sourced from the Moulouya Hydraulic Basin Agency (ABHM). The hydrology of the basin is therefore represented by point data from the Tazarhine hydrological station for the 2009–2020 period. In order to optimize the accuracy of a specific model, namely SWAT-CUP, a calibration and validation process was carried out on the aforementioned model using observed flow data. The SUFI-2 algorithm was utilized in this process, with the aim of enhancing its precision. The performance of the model was then evaluated using statistical parameters, with particular attention being given to Nash-Sutcliffe efficiency (NSE) and coefficient of determination (R^2). The NSE values for the study were 0.58 for calibration and 0.60 for validation, while the corresponding R^2 values were 0.66 and 0.63. The study examined 16 hydrological parameters for Oued Cherra, determining that evapotranspiration accounted for 89% of the annual rainfall, while surface runoff constituted only 6%. It also showed that groundwater recharge was pretty much negligible. This emphasized how important it is to manage water resources effectively. The calibrated SWAT model replicated flow patterns pretty well, which gave us some valuable insights into the water balance and availability. The study's primary conclusions were that surface water is limited and that shallow aquifers are a really important source of water storage, especially for irrigation during droughts.

Keywords: SWAT model; water budgeting; Oued Cherraa watershed; evapotranspiration; groundwater recharge; sustainable water management

1. Introduction

Although it is not a luxury, water is essential to all living things. The survival of all living things depends heavily on it. Additionally, both require comparatively large amounts of water to function well; therefore, understanding the water demand is particularly crucial [1]. The amount of food available, economic prosperity, human and animal habitats, local and international ties, and population displacement are all impacted by water availability. The relationship between groundwater-dependent irrigation system water supply and availability has recently been discussed in a number of ways [2]. Particularly in arid, semiarid, and water-scarce regions [3], the rapid economic development, population growth, and global climate change are all placing a great deal of strain on the water resources [4,5]. Land use, the predominant cropping pattern, the sites of water applications, and the time of water usage all have an impact on the regional and season-wise distribution of water throughout the basins [6]. The prospective demand for water resources is influenced by the restricted supply in many arid and semi-arid locations. The estimation, comprehension, and sustainable management of water metrics are essential in the 21st century. According to Dovie and Kasei [2], climate change has an impact on the majority of water resource projects. Thus, scholars are focusing on water budgeting by quantifying water resources all around the world. The water by considering various water users, including public, industrial, agricultural, and residential uses [7,8]. When used with correct data sets, hydrologic models such as SWAT [9], MODFLOW [10,11] MIKE [12], and HEC-RAS prove to be highly effective.

In order to calculate the amount of water in the study basin, these GIS-based agro-hydrological models needed the following data as inputs: agricultural information, infrastructure and technology data, socioeconomic data, and meteorological data. One sector's cropping pattern and water use have an impact on another sector's water consumption and outputs; for example, irrigation in river basins reduces water discharge downstream of the river. However, despite the fact that climate change and excessive demand from such small-scale methods will support the sustainable growth of water resources for various water users [13]. To better comprehend and model the changes in water use brought on by anthropogenic activities [14], developed heuristic rainfall-runoff models. The computer capacity of those models enables users to better understand and predict the features of water resources through numerical simulations and testing of various management scenarios [13]. These numerical models, which integrate a number of empirical equations and scientific principles, allow users to assess the hydrological interactions in river basins [15]. Using hydrologic models is the most accurate and useful method for forecasting water availability and distribution in the study basin under different operating and demand scenarios. The semi-distributed, process-based, agro-hydrological SWAT model is used to depict both processes that generate runoff and how they affect the hydrology of the research area. To determine the long-term impact of an environmental change on the hydrologic response of a basin, authors have attempted to connect water availability and consumption using these models [15,16].

The primary novelty of this study is the application of the Soil and Water Assessment Tool (SWAT) to Oued Cherraa basin in north-eastern Morocco. This basin, renowned for its natural attractions, including the celebrated Camel and Pigeon Caves, has not previously been studied using this model. This study represents a pioneering application of the SWAT model to the region, offering a novel perspective on the hydrological system. Oued Cherraa basin faces intricate challenges related to water management, agriculture, and tourism. A distinguishing feature of this study is its capacity to adapt the SWAT model to a region characterized by limited and unreliable data availability. Our study decisively overcomes the challenge posed by scarce data. We demonstrate that the SWAT model's efficacy is unparalleled, even in regions with incomplete data. This model is invaluable for areas worldwide that face similar limitations.

The SWAT model is the best choice for our study because it has many advantages. SWAT is very good at modeling hydrological processes in complicated and varied watersheds like Oued Cherraa basin. It can simulate water flow, water quality, soil erosion and the impact of farming, which are all important for managing water sustainably in this area. Furthermore, the model's capacity to accommodate diverse climate scenarios and identify optimal management strategies is of paramount importance in the context of anticipating the repercussions of climate change on water resources.

The present study is distinguished by its practical application, offering critical insights into the management of water resources in the region, with particular reference to agriculture, drinking water supplies for Berkane, and tourism. The research provides a plan for making important decisions, including building dams, using better irrigation techniques, and other ways to make the most of water. This shows how important it is to manage water in a way that doesn't use up too much, especially in a place where there is a lot of pressure on water resources.

It also adds to our understanding of how climate change affects water availability and why it's important to have plans to deal with it. The study provides important information for people who make decisions about water management in Oued Cherraa and other places with similar water and climate issues. This research is very important because it uses new ways of collecting data and can be used in places where there is not much data about water management.

2. Materials and methodology

2.1. Study area

Oued Cherraa watershed is located in the northeastern region of Morocco, spanning a range of longitudes between 2°15'25" and 2°27'24" W and latitudes between 34°46'51" and 34°57'30" N. It encompasses an area of 267.29 km^2 (see **Figure 1**). The area is comprised of three deep, narrow valleys situated in the Beni-Snassene region, located upstream from the town of Berkane [17]. Oued Cherraa river flows in a straight line for approximately 12 km, with its primary tributary, the Oued Beni-Ouklane, joining before the river ultimately merges with the Moulouya River. Approximately 4 km downstream from Berkane, the river contributes to the recharge of the local water table, which then flows into the Moulouya River. The region's topography is characterized by a diverse range of mountain ranges, exhibiting considerable elevation differences. The ranges in question rise from 800 m (Jbel Aghil, located downstream) to 1532 m (Jbel Foughal, at the basin's easternmost point). The majority of the area lies between 700 and 1000 m above sea level, with steep slopes ranging from 20% to 80%. These slopes often feature vertical cliffs that overhang the rivers.

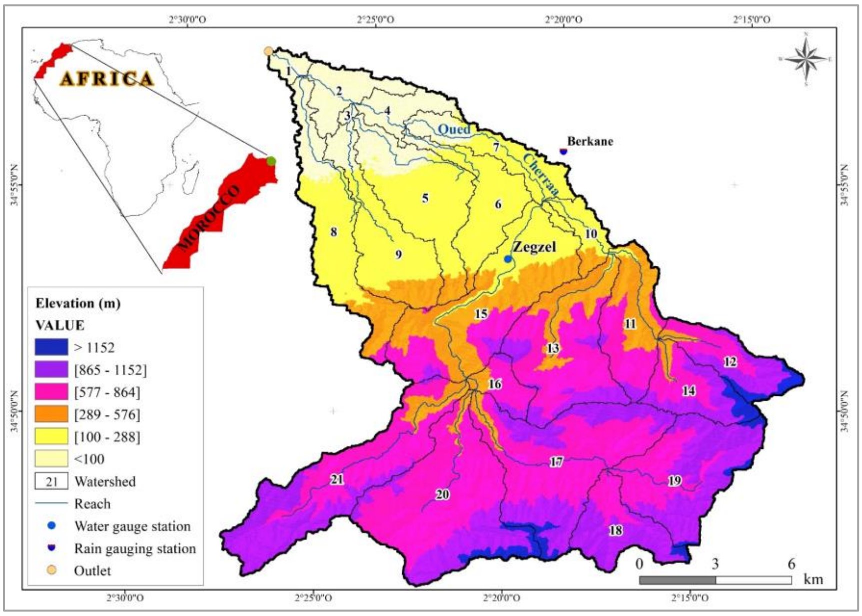


Figure 1. Site of the study area.

Geologically, the Beni Snassen region forms part of a SW-ENE-oriented Jurassic limestone massif, closely associated with the Atlas domain [18]. The highest peaks dominate the Triffa plain and the lower Moulouya valley to the north. The region is marked by deep gorges, such as the Zegzel gorges. The region's geological structure is primarily composed of Jurassic limestone and dolomite, which are underlain by impermeable substrata, typically Hercynian basement rocks such as schists and granites. The region's limestone is fissured and full of underground water. This water table is important for the local area.

Agriculture is a key economic activity in the region, particularly in the Trifa plain, where citrus farming is a dominant feature. Berkane province, located at the heart of the region, accounts for over 86% of the total area dedicated to citrus cultivation. Although citrus crops occupy only 3% of the region's agricultural land (SAU), which is 0.3% of Morocco's total agricultural land, this sector is of immense strategic importance to both the local and national economy. The province produces more than 88% of the region's citrus output, contributing 15% of Morocco's national citrus production. The cultivation of citrus fruits, particularly species such as oranges, lemons, and mandarins, plays a pivotal role in the region's export economy. In addition to enhancing local food security, this sector plays a pivotal role in bolstering the region's economic vitality. It's really important to be able to access groundwater from Oued Cherraa basin's aquifer system if we want to keep growing citrus fruits in this semi-arid region. So, having good irrigation systems that use these groundwater resources is really important for the success and sustainability of this agricultural industry.

2.2. Input data

The accuracy of the input data significantly improves the operational, realistic, and effective SWAT model when sub-basin-scale hydrological simulations are conducted using the ArcSWAT interface (GIS interface for the SWAT model). Oued

Cherraa watershed was the specific focus of this study. To meet certain input requirements, soil and land-use maps were superimposed on top of five slope categories (0%–5%, 5%–10%, 10%–15%, 15%–20%, and >20%) [19]. 21 sub-catchments, totaling 696 hydrological response units (HRUs), were created (**Figure 2A**). Depending on the objectives of the study, the number of HRUs may vary. In this case, we used a method that balanced a number of factors, such as computation time, spatial resolution, available data, model complexity, and calibration.

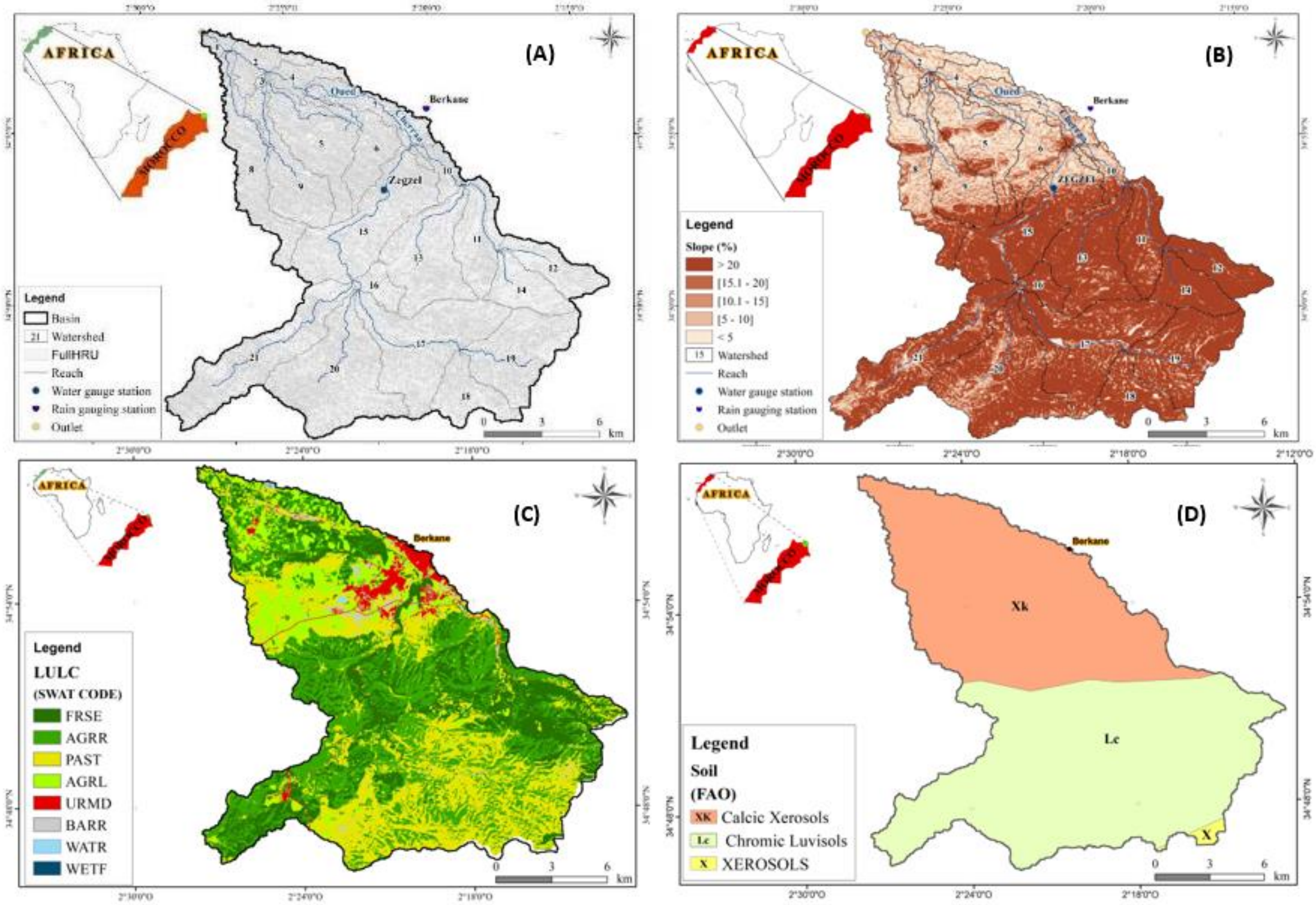


Figure 2. Input data for the SWAT: **(A)** watershed delimitation; **(B)** slope; **(C)** land cover; **(D)** Soil map.

2.2.1. Digital terrain model (DEM)

To define Oued Cherraa watershed and its drainage system, we used the digital terrain model (DEM) from the Shuttle Radar Topography Mission (SRTM). Areas between 60° North and 56° South are included in these data [20], which were first processed to a spatial resolution of 30 m. SRTM data from the United States Geological Survey (USGS) is available on the Earth Explorer website (accessed 29 January 2023). Oued Cherraa's altimetry, as determined by SRTM, is shown in **Figure 2A**, while the slope is shown in **Figure 2B**.

2.2.2. Land use

Land use and land cover maps (LULC) are important tools for determining various hydrological processes, such as surface erosion, evapotranspiration, and runoff, within a watershed. These maps provide a thorough illustration of how land was distributed and used during a specific time period. The LULC maps were meticulously created for the sake of this study using a Sentinel-2 satellite image, which was obtained on 18 June 2021, and had an impressive resolution of 10 m. High-resolution satellite images can be downloaded for free from the Copernicus Open Access Hub, which is managed by the European Space Agency (ESA) [19]. It is important to highlight the efforts made during the development process in order to ensure the accuracy and reliability of the maps. Suitable for the classification and detection of several land use categories, such as vegetation, water, bare soil, and urban areas, the satellite image bands used in this study are band 2 (blue—490 nm), band 3 (green—560 nm), and band 4 (red—665 nm). Satellite photos were processed and LULC maps were created using the ENVI 5.3 software. The software program ENVI 5.3, which is well-known for processing remote sensing data, was used to classify satellite photos and create the final land use map. Using the generic land use code and the terminology from the SWAT database, **Figure 2C** displays the LULC classes. This classification identified seven different land use types in the study area: forests (20.9%), orchards (34.4%), bare soil (1.7%), water bodies (0.1%), cropland (9.0%), built-up areas (3.0%), and grassland (30.8%). In addition to providing useful information on land use trends within the basin, this thorough classification provides an overview of the hydrological dynamics and behavior of the watershed.

2.2.3. Soil

It is vital to note that soil maps are challenging to find, particularly in underdeveloped nations [21]. To create a soil map, two sources of data were combined: 250 m resolution data from ISRIC’s SoilGrids and data from the United Nations Food and Agriculture Organization (FAO). It should be noted that only physical and chemical features are covered by the data that is currently available. The raster that was supplied into SWAT has an attribute table pinned to it with the data arranged in it. To represent the true breadth, all of the data that was downloaded from ISRIC’s SoilGrids has been updated. Different soil classifications with differing percentages of occupancy are found within the watershed [19]. These consist of Xersolos, Chromic Luvisols, and Calcic Xerosols; the first two classes are the most common (**Figure 2D**).

2.2.4. Climate data

The meteorological data utilized in this study was gathered at the Berkane meteorological station, which is managed by the Hydraulic Basin Agency of Moulouya (ABHM). The eight-year data collection period, which runs from 2012 to 2020, includes observations of rainfall and other meteorological parameters. Due to the lack of reliable meteorological data in semi-arid regions, it was essential to guarantee the accuracy and completeness of the time series. In accordance with the 1990 recommendations of Sharpley and Williams, the study filled in the data gaps using the ArcSWAT model and the WXGEN weather generator. This method produces thorough climate data that incorporates variables including sun radiation, wind speed, temperature, and relative humidity [22]. The goal of the study was to increase the quality and consistency of the meteorological data used in order to increase the reliability of the ArcSWAT model’s output.

2.2.5. Hydrological data

Using daily flow observations collected from the Tazarhine (on Oued Zegzel) station over a four-year period, from 2012 to 2016, the hydrological model was verified and calibrated. Since initial conditions are so important in ensuring simulation accuracy, model initialization was finished for the first two years of the study, or 2012–2013. Carefully calibrating the model and modifying parameters to achieve the highest possible agreement with the received data took place in 2014 and 2015. As a result of certain gaps in the available data for this time frame, the validation process focused on only one year of data, from 1 January to August 2016.

This strategic approach aimed to assess the SWAT model's ability to reliably and precisely reproduce observed flow, which is essential for guaranteeing the precision and dependability of the model's hydrological forecasts.

2.3. Methodology adopted

The semi-distributed SWAT model, created by the US Agriculture Research department [15,23,24], was employed in this study. The SWAT is a semi-distributed, GIS-based physical model that forecasts hydrological parameters and models the rainfall-runoff process [25]. The SWAT model can operate for a long time and is quite efficient. The model processes GIS-based data, such as digital elevation, the study area's land use and land cover (LULC), climate data, and soil data, to produce simulated outcomes in terms of water availability, loss of water, pesticide and nutrition transfer, etc. The following is the fundamental idea that underpins the SWAT model (Equation (1)) [15,23].

$$Wt = SW0 + \sum_{i=1}^{t} (Rday - Qsurf - Wseep - Ea - Qgw) \tag{1}$$

Based on the initial soil water content (SW0) on day (i), the amount of precipitation (Rday) on day (i) in mm H2O, the amount of surface runoff (Qsurf) on day (i), and the amount of water entering the vadose zone from the soil profile (Wseep) on day (i), the following formula provides the final soil water content (SWt) in millimeters of water (mm H2O). In addition, Ea denotes the amount of evapotranspiration on day (i) and Qgw denotes the return flow quantity (in milliliters of H2O) on day (i). Time is represented in days by the variable t [15,23]. Following this calculation, the model simulates the conveyance phase processes, which include the dispersion of chemicals, water, sediment, and nutrients down the channels and out of the watershed.

2.3.1. Configuring the SWAT model framework

We used SWAT 2012 with ArcGIS 10.4 for our modeling. First, we identified 21 sub-basins by delineating watershed boundaries and the drainage network using the digital terrain model (DEM). Hydrological response units (HRUs) were then created on the basis of soil type, land use and land cover (LULC) and slope (**Figure 2C**). In order to guarantee the precision and dependability of the data, the ArcSWAT extension was employed to categorize the watershed into sub-watersheds, slopes and drainage areas utilizing DEM data. Subsequently, the watershed was partitioned into homogeneous sections (HRU) in accordance with land use, soil and slope data. Input data for each sub-basin included soil type, weather conditions, land use and management practices, taking into account the impacts of physical processes on hydrology, river flow, runoff, sediment, nutrient and pesticide loading. Finally, meteorological data were verified and calibrated using the methods described in **Figure 3**.

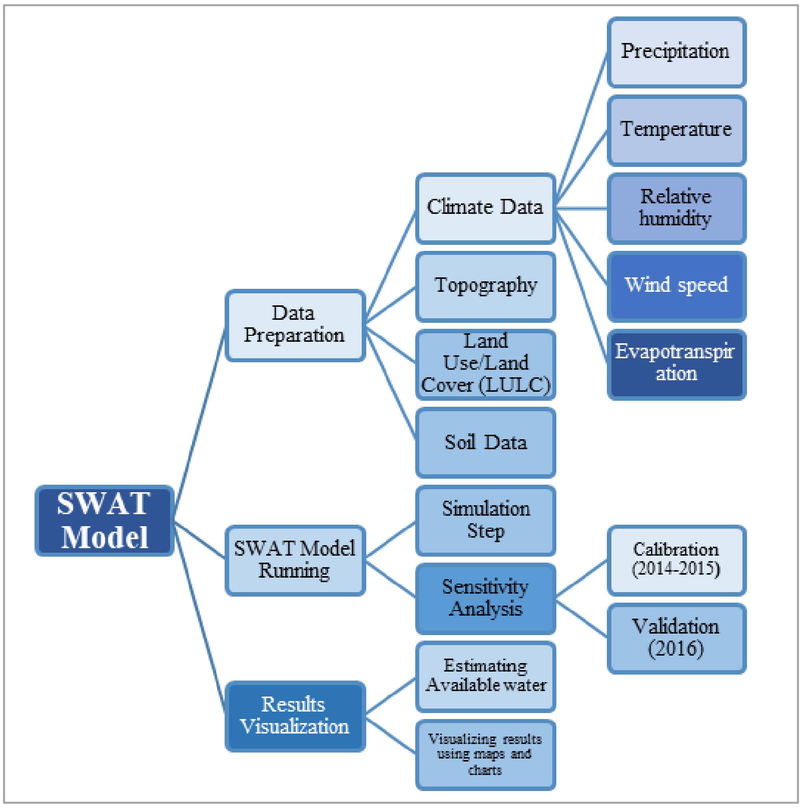


Figure 3. Working methodology.

2.3.2. Model calibration

Model calibration entails the adjustment of parameters until the model output aligns with the observed data [26]. In his publication [27], Beven outlines the calibration procedure for hydrological models as follows:

$$Q(x,t) = M(\theta,x,t) + \varepsilon(x,t) \tag{2}$$

M(θ,x,t) represents the estimated streamflow based on parameters θ and ε(x, t) is the error during the time interval. Q(x, t) is the flow at point x and time t. The model parameters are fine-tuned through both manual and automatic methods, with SWAT-CUP used for automatic calibration via the SUFI-2 algorithm. The model was calibrated for the years 2014–2015, with results compared to observed river flows during the same period.

2.3.3. Model validation

Validation serves to guarantee the precision of the model by means of a comparison between forecasts and field observations, without any alteration to the input parameters. In order to assess the model’s performance, the validation process employed flow data from 2016, which had not been included in the calibration phase.

2.3.4. Model performance evaluation

The SWAT-SUFI 2 version of the model uses several objective functions to assess performance, such as the Nash-Sutcliffe Efficiency (NSE) and the Coefficient of Determination (R^2). The NSE compares the variance in observed data with the variance in the model's predictions [28]:

$$\mathrm{NSE} = 1 - \left[\frac{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{mean})^2}\right] \quad (3)$$

where Y^{mean} is the mean of observed data, Y^{obs} and Y^{sim} are the observed and simulated values, respectively.

The R^2 value represents the proportion of the observed data variance that can be explained by the model. As stated by Santhi [29], an R^2 value exceeding 0.5 is deemed acceptable. Equation (4):

$$R^2 = \frac{\left[\sum_{i=1}^{j}(Oi - \bar{O})(Pi - \bar{P})\right]^2}{\sum_{i=1}^{j}(Oi - \bar{O})^2 \sum_{i=1}^{j}(Pi - \bar{P})^2} \quad (4)$$

where Oi and Pi are the observed and predicted values, and $\bar{O}$ and $\bar{P}$ are their respective means.

Following calibration, the model's performance was validated using independent data from 2016. The calibration and validation of daily flow were evaluated using statistical metrics outlined by Moriasi [30], as illustrated in **Table 1**.

Table 1. A statistical evaluation of the SWAT model [30].

Model performance	PBIAS	NS	RSR
Excellent	PBIAS < ±10	0.75 < NS ≤ 1.00	0.00 ≤ RSR ≤ 0.50
Good	±10 ≤ PBIAS < ±15	0.65 < NS ≤ 0.75	0.50 ≤ RSR ≤ 0.60
Acceptable	±15 ≤ PBIAS < ±25	0.50 < NS ≤ 0.65	0.60 ≤ RSR ≤ 0.70
Insufficient	PBIAS ≥ ±25	NS ≤ 0.50	RSR ≤ 0.70

3. Results and discussions

3.1. Assessment of sensitivity

During the sensitivity analysis for model calibration, several parameters were identified as highly sensitive. These include the deep aquifer percolation fraction (RCHRG DP), the curve number (CN2), the base flow alpha factor (ALPHA_BF), the groundwater evaporation coefficient (GW_REVAP), the storage time constant for normal flow (MSK CO1) and the compensation factors for soil evaporation (ESCO) and plant uptake (EPCO). These parameters have a significant influence on flow dynamics. **Table 2** shows the fitted values for these sensitive parameters.

While curve number (CN2) is generally the most sensitive flow parameter in most Moroccan basins, in Oued Cherraa basin it is the RCHRG DP parameter that is the most sensitive. This difference highlights the unique hydrological characteristics of Oued Cherraa basin compared with other Moroccan basins.

Table 2. Parameter overview.

Parameter name	Full name and units	Parameter Range	Sensitivity Rank	Optimized Value
1: V_ALPHA_BF	Baseflow recession constant (days)	0.05–0.65	4	0.0013
2: r_CN2.mgt	Runoff curve number	−0.15–0.48	3	−0.4
3: v_SHALLST.gw	Initial depth of water in the shallow aquifer (mm)	500–10000	13	6870.8
4: v_EPCO.hru	Plant uptake compensation factor	0.29–0.82	6	0.53
5: v_FFCB.bsn	Initial soil water storage expressed as a fraction of field capacity water content	0.12–0.69	10	0.06
6: v_CH_K2.rte	Effective hydraulic conductivity in main channel alluvium	2.14–185.82	11	96.66
7: v_CH_N2.rte	Manning's "n" value for the main channel	0.25–0.76	12	0.92
8: v_MSK_CO1.bsn	Calibration coefficient used to control impact of the storage time constant for normal flow	1.33–8.15	2	3.39
9: v_ESCO.bsn	Soil evaporation compensation factor	0.11–0.94	9	0.57
10: v_REVAPMN.gw	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	122–3670	8	1937.84
11: v_SURLAG.bsn	Surface runoff lag time	0.98–21.77	7	8.91
12: v_GW_REVAP.gw	Groundwater "revap" coefficient	0.014–0.30	5	0.25
13: v_RCHRG_DP.gw	Deep aquifer percolation fraction	0.01–0.51	1	0.019

3.2. Calibration and validation

After identifying the most sensitive parameters, we refined their values through multiple calibration cycles in order to align the simulated flow with the observed data. Model calibration and validation were carried out using flow data collected from the gauging station near the outlet of Oued Cherraa basin. Compliance with the exacting calibration and validation standards established by SWAT-CUP necessitated the meticulous daily recording of measurements. The data has been thoroughly investigated to ensure effective calibration and validation of the SWAT model. A comparison of the calibrated and observed flow patterns is shown in **Figure 4**, which illustrates a high degree of agreement.

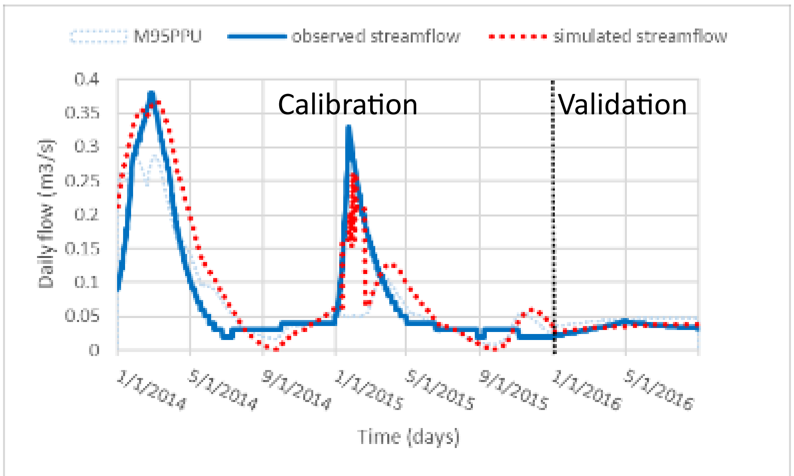


Figure 4. Hydrographs for assessing model calibration and validation.

Table 3 summarizes the additional performance. It should be noted that the Nash-Sutcliffe efficiency (NSE) values were very consistent, with NSE = 0.58 for calibration and 0.60 for validation. Furthermore, the correlation between observed and simulated flows remained consistent, with $R^2 = 0.66$ for calibration and $R^2 = 0.63$ for validation, as shown in **Figure 5**. These results demonstrate that the model performs adequately and provides a reliable simulation of flow dynamics in Oued Cherraa basin.

Table 3. Statistical summary for evaluating model performance.

Statistical parameter	**Calibration**	**Validation**
Nash-Sutcliffe (NSE)	0.58	0.60
Coefficient of determination (R^2)	0.66	0.63

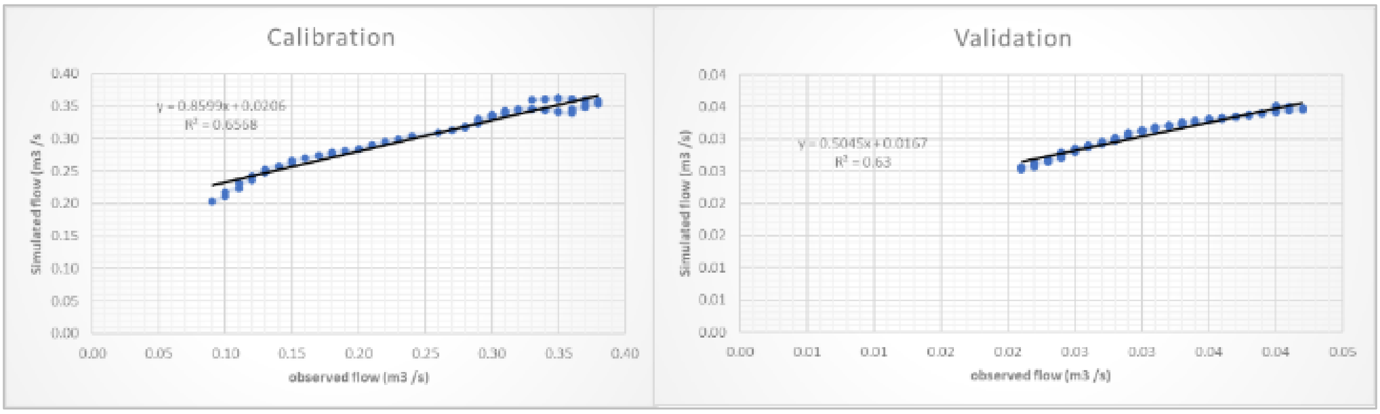


Figure 5. Scatter diagrams of the calibrated and validated models.

The feasibility and effectiveness of the model were demonstrated by its successful application in Oued Cherraa catchment. After examination, the model provided accurate results that corresponded well to the objectives of the study. Although the SWAT model generally underestimates flows, particularly during summer low-flow periods, the results remain acceptable, as confirmed by data from the Tazarhine station (on the Oued Zegzel).

3.3. Water budget

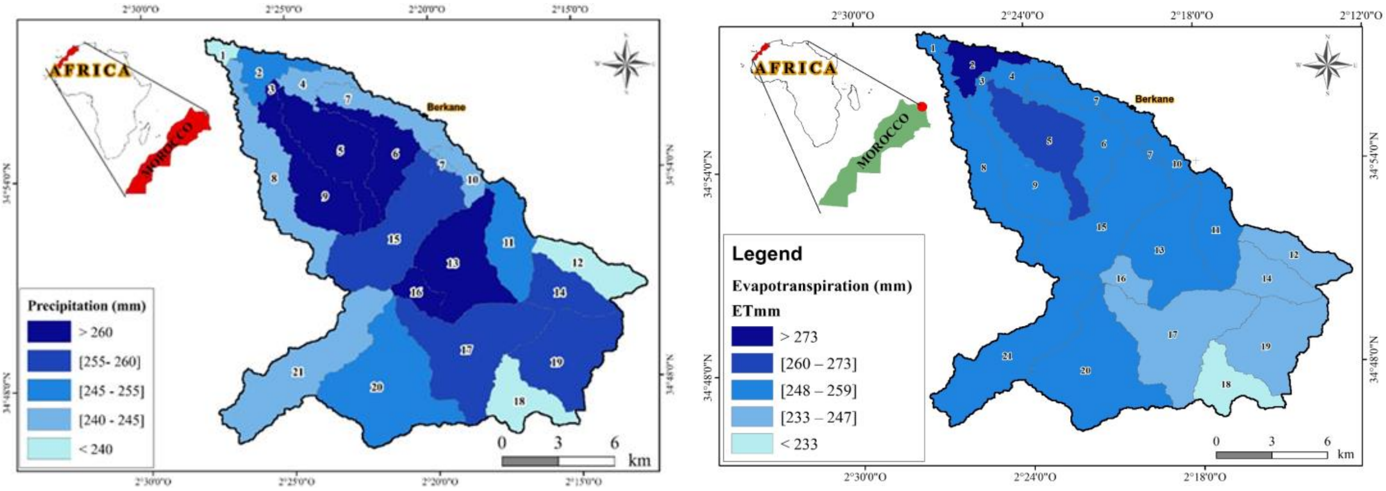
In order to conduct an accurate hydrological analysis of Oued Cherraa catchment, it was essential to develop models that had been calibrated and validated to the greatest extent possible. The calibration process enabled the parameters and input data to be refined in a manner that was consistent with real-world observations, thereby enhancing the overall performance of the model. Subsequently, the models underwent a validation process utilizing independent datasets to ascertain their precision and dependability in anticipating diverse scenarios. Model performance was modified through a comparison of the model outcomes with the observed data, identifying and rectifying discrepancies.

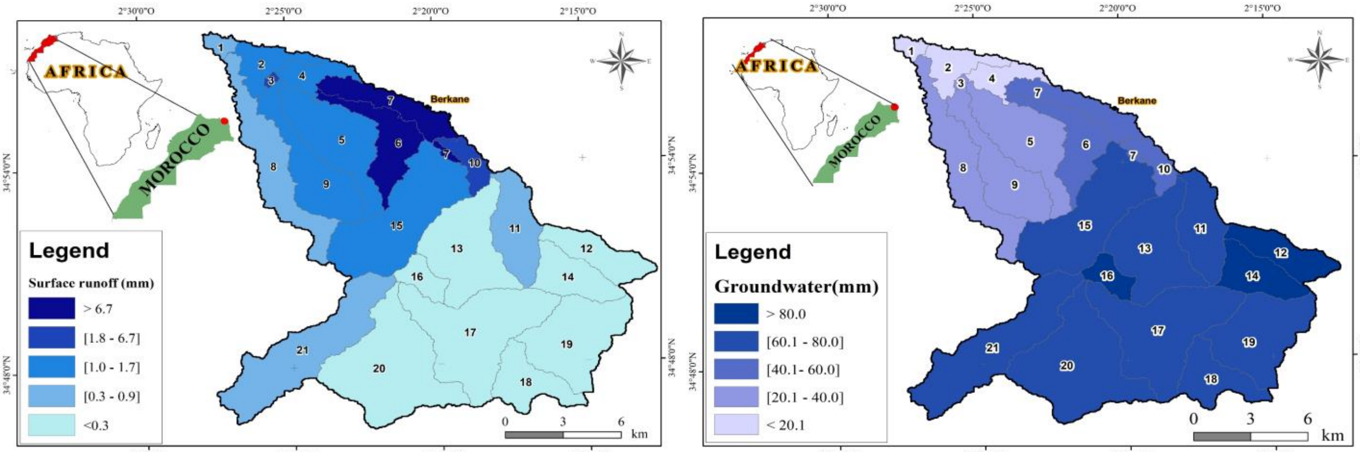
The components of the water balance, outlined in **Table 4**, facilitated a more comprehensive understanding of the hydrological dynamics within the catchment, encompassing runoff, evapotranspiration, precipitation and groundwater recharge. The calibration and validation phases generated coherent outcomes, thereby confirming the reliability of the models in simulating hydrological processes.

Table 4. Assessment of hydrological parameters.

Hydrological Components	**Calibration Average (mm)**	**%**	**Validation Average (mm)**	**%**
Precipitation	267.2	100	267.2	100
Surface flow	1.30	0.48	1.56	0.58
Lateral flow	15.45	5.78	12.8	4.79
Return flow	0.2	0.07	0.01	0.003
Recharging deep aquifers	0.89	0.33	0.76	0.28
Shallow aquifer storage	14.6	5.46	12.2	4.55
Evapotranspiration	234.66	87.88	239.92	89.79

These consistent results have served to reinforce the ability of the models to accurately represent the hydrological processes occurring within the catchment area, a fact that had previously been demonstrated by research [31]. This research emphasized the significance of calibrated and validated models for the assurance of reliable hydrological assessments. The average amount of rain that falls in Oued Cherraa catchment area is 267 mm (see **Figure 6A**). About 89% of this, or 239 mm, is lost through evaporation and transpiration. This shows just how important this is for the water balance. **Figure 6B** shows that there’s more evaporation and plant transpiration in farmland than in forests. This is probably because of the weather, like temperature and humidity, as shown in **Figure 6**. As you can see in **Figure 6C**, runoff accounts for just 6% (15 mm) of annual rainfall. Surface runoff and base runoff are relatively minor compared to evapotranspiration. The study also showed that shallow aquifers get a higher proportion of rainfall (12.2 mm, 4.55%) than deep aquifers (0.76 mm, 0.28%). **Figure 6D** illustrates that groundwater levels in irrigated areas exhibit a decrease of less than 60 mm, whereas mountainous regions demonstrate an increase of over 80 mm. This phenomenon is shaped by irrigation practices and the distinctive characteristics of the soil. These findings highlight the necessity for close monitoring of groundwater levels to ensure the sustainable management of water resources and the prevention of over-exploitation of aquifers.




(A) (B)

(C) (D)

Figure 6. Spatial variation of water balance components: **(A)** Precipitation; **(B)** Evapotranspiration; **(C)** Surface runoff; **(D)** Water table.

3.4. Available water

The study shows that around 89% of the water in Oued Cherraa catchment is lost through evaporation and transpiration. The rest is shared between the percolation reservoir (made up of the shallow aquifer, deep aquifer and unsaturated zone) and the runoff components (surface runoff, lateral runoff and return flow). Surface runoff accounts for only 5% of total runoff (see **Table 4**). The rainy season peaks in January, February, March, April, November and December, causing soil saturation and potential flooding, particularly in sub-catchment 7 (**Figure 6C**). Reservoirs rely heavily on runoff for water storage during the dry season, and during periods of low rainfall farmers often rely on stored soil moisture for irrigation, which can adversely affect late crops. Infiltration data indicates that 5.61% of annual rainfall (**Figure 7**) contributes to the percolation reservoir, with minimal loss in the form of return flow. The recharge rate of the deep aquifer is approximately 0.3%, while the shallow aquifer retains the majority of the water.

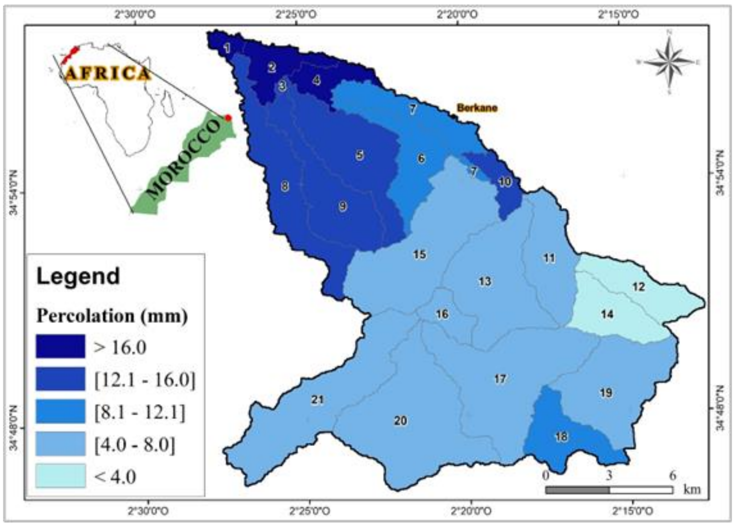


Figure 7. Distribution of infiltration within the Oued Cherraa watershed.

The watershed can store enough water in shallow aquifers to support irrigation during the dry season. Looking at the seasonal changes in the hydrological components (**Figure 8**), we can see that evapotranspiration goes up during dry periods and that there's a moderate water reserve in the catchment. This means there's potential for soil water storage in deep aquifers.

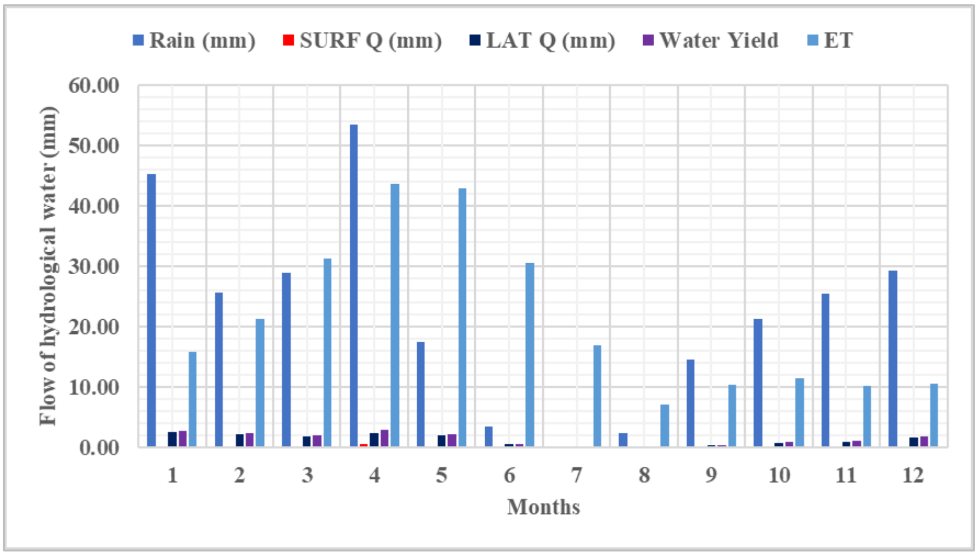


Figure 8. Seasonal fluctuations in the hydrological components of the Oued Cherraa catchment (SURF Q denotes surface runoff, WYLD represents water yield, ET refers to evapotranspiration, and rain signifies mean annual precipitation).

3.5. Discussion

The SWAT (Soil and Water Assessment Tool) model has proven to be an invaluable resource in Morocco, facilitating the assessment of the water balance and supporting the sustainable management of water resources. Prior research has demonstrated that evapotranspiration represents a significant component of the water balance in numerous Moroccan catchments. The estimated evapotranspiration rate for the R'dom catchment is approximately 72%, as reported by Alitane et al. [32]. By contrast, the M'dez catchment exhibits a higher evapotranspiration rate of 79.9%, as documented by Boufala et al. [33]. The results for Oued Cherraa catchment are in line with the aforementioned conclusions. It should be noted that the majority of precipitation is lost through evaporation and transpiration, representing approximately 89% of the total. It is essential to consider this factor when calculating regional water balances. It is essential that we prioritize the reduction of these losses in our water management strategies, particularly in arid and semi-arid zones.

Surface runoff in Morocco's watersheds has been shown to vary; for example, in the R'dom watershed, it accounts for 12.04% of the water balance [32], while in the M'dez watershed, it amounts to 13.83 mm [33]. Our study revealed that surface runoff in Oued Cherraa basin accounted for only 6% of annual rainfall, which is less than what we observed in other regions. This difference could be due to the different types of land, topography and soil that influence the amount of runoff generated. The limited runoff in our results suggests that the catchment relies more on groundwater recharge and evapotranspiration for its water budget, which has a big impact on how we manage water resources, especially during dry periods.

Groundwater recharge, an essential aspect of hydrological studies, was found to contribute minimally to the water balance in other Moroccan basins, such as 4.14% in R'dom [32] and 8% in the Ouergha basin [34]. The way in which we utilize the land and the impact of climate change on water movement are of great consequence. In the Oued Fez basin, there has been a notable increase in the amount of land dedicated to urban expansion and irrigation, which has resulted in a 55% surge in surface runoff and a 7.4% uptick in evapotranspiration [35]. While our study didn't look at the impact of land use changes, the results for Oued Cherraa catchment seem to indicate that the region might have similar issues. With all this variability in evapotranspiration and reduced runoff, it's clear we need integrated water management strategies to account for land use and climate conditions. These will help us to manage water stress and make sure we have enough water in the long term.

In summary, the comparison of our results with previous studies highlights both consistencies and unique features of Oued Cherraa catchment. Evapotranspiration plays a big part in the water balance, as we've seen in other parts of Morocco [32,33]. However, our study shows that surface runoff and groundwater recharge play a smaller role than we expected. This shows how important it is to have management strategies tailored to the particular hydrological features of the catchment area [13,34]. What's more, while our study didn't focus on land use and climate change, the data suggest we should consider these factors when planning water supplies in the region [35].

4. Conclusion

This study highlights the value of a comprehensive and context-specific approach to hydrological modelling and water resource management in Oued Cherraa catchment. A comprehensive sensitivity analysis allowed us to identify key parameters that significantly influence the simulation of flow dynamics. In particular, the deep aquifer percolation fraction (RCHRG DP) was demonstrated to be a crucial factor for this basin. This parameter represents the portion of water that percolates from the surface to the deep aquifer, significantly influencing the basin's groundwater recharge rates. It is clear that variations in the RCHRG DP directly affect the replenishment of deep groundwater reserves. These are essential for maintaining baseflow during dry periods. We must therefore accurately estimate them to understand subsurface water movement and ensure the reliability of hydrological models in predicting water availability over time. The calibration and validation phases showed that the SWAT model is an accurate tool for replicating observed hydrological patterns, with satisfactory performance metrics, including Nash-Sutcliffe efficiencies of 0.58 and 0.60 for calibration and validation, respectively.

The results show that evapotranspiration is the main factor, accounting for 89% of annual rainfall. This is in line with what we've seen in other Moroccan basins. By comparison, there's not much surface runoff or groundwater recharge, which is in line with the unique hydrological characteristics of Oued Cherraa basin. This points to the significance of tailored water management strategies that prioritize sustainable practices, especially considering the area's reliance on groundwater storage, which supports irrigation during dry periods.

The study also demonstrates the critical need for ongoing monitoring and strategic water management in light of potential challenges posed by land use changes and climate variability. Although this research didn't look at these factors directly, the insights gained show that we need to manage water more holistically, taking into account how land use, climate and hydrological responses affect each other. This is going to be really important for making sure there's enough water and that resources are used sustainably in arid and semi-arid areas like Oued Cherraa.

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References

1. Singh A. Conjunctive use of water resources for sustainable irrigated agriculture. Journal of Hydrology. 2014; 519: 1688-1697. doi: 10.1016/j.jhydrol.2014.09.049
2. Dovie DBK, Kasei RA. Hydro-climatic stress, shallow groundwater wells and coping in Ghana's White Volta basin. Science of The Total Environment. 2018; 636: 1268-1278. doi: 10.1016/j.scitotenv.2018.04.416
3. Prabhanjan A, Rao EP, Eldho TI. Application of SWAT Model and Geospatial Techniques for Sediment-Yield Modeling in Ungauged Watersheds. Journal of Hydrologic Engineering. 2015.
4. Samimi M, Mirchi A, Moriasi D, et al. Modeling arid/semi-arid irrigated agricultural watersheds with SWAT: Applications, challenges, and solution strategies. Journal of Hydrology. 2020; 590: 125418. doi: 10.1016/j.jhydrol.2020.125418
5. Ross A. Speeding the transition towards integrated groundwater and surface water management in Australia. Journal of Hydrology. 2018; 567: e1-e10. doi: 10.1016/j.jhydrol.2017.01.037
6. Du E, Tian Y, Cai X, et al. Evaluating Distributed Policies for Conjunctive Surface Water-Groundwater Management in Large River Basins: Water Uses Versus Hydrological Impacts. Water Resources Research. 2022; 58(1). doi: 10.1029/2021wr031352
7. Ridoutt BG, Eady SJ, Sellahewa J, et al. Water footprinting at the product brand level: case study and future challenges. Journal of Cleaner Production. 2009; 17(13): 1228-1235. doi: 10.1016/j.jclepro.2009.03.002
8. Vairavamoorthy K, Gorantiwar SD, Pathirana A. Managing urban water supplies in developing countries—Climate change and water scarcity scenarios. Physics and Chemistry of the Earth, Parts A/B/C. 2008; 33(5): 330-339. doi: 10.1016/j.pce.2008.02.008
9. Sabale R, Venkatesh B, Jose M. Sustainable water resource management through conjunctive use of groundwater and surface water: a review. Innovative Infrastructure Solutions. 2022; 8(1). doi: 10.1007/s41062-022-00992-9
10. Abdalla OAE. Groundwater modeling in semiarid Central Sudan: adequacy and long-term abstraction. Arabian Journal of Geosciences. 2009; 2(4): 321-335. doi: 10.1007/s12517-009-0042-4
11. Baalousha HM. Development of a groundwater flow model for the highly parameterized Qatar aquifers. Modeling Earth Systems and Environment. 2016; 2(2). doi: 10.1007/s40808-016-0124-8
12. Kaleris V, Langousis A. Comparison of two rainfall–runoff models: effects of conceptualization on water budget components. Hydrological Sciences Journal. 2016; 62(5): 729-748. doi: 10.1080/02626667.2016.1250899
13. Sabale RS, Bobade SS, Venkatesh B, et al. Application of Arc-SWAT Model for Water Budgeting and Water Resource Planning at the Yeralwadi Catchment of Khatav, India. Nature Environment and Pollution Technology; 2024.
14. Oki T, Agata Y, Kanae S, et al. Global assessment of current water resources using total runoff integrating pathways. Hydrological Sciences Journal. 2001; 46(6): 983-995. doi: 10.1080/02626660109492890

15. Neitsch SL, Arnold J, Kiniry J, et al. Soil & Water Assessment Tool Theoretical Documentation Version 2009. Texas Water Resour; 2009.
16. Liu L, Cui Y, Luo Y. Integrated Modeling of Conjunctive Water Use in a Canal-Well Irrigation District in the Lower Yellow River Basin, China. Journal of Irrigation and Drainage Engineering. 2013.
17. Carlier P. Triffa Plain: Water Resources of Morocco: 1. Domains of the Rif and Eastern Morocco, Notes&Mém (French). Serv. Géol; 1971.
18. Laouina, A. Le Maroc nord-oriental: reliefs, modelés et dynamique du calcaire. [Master's thesis]. Univ. Paris I, Paris; 1990.
19. Laaboudi M, Mezrhab A, Alioua ZE, et al. Analyzing Water Availability Via the SWAT Hydrological Model in Oued Cherraa Basin (Northeastern Morocco). Water Conservation Science and Engineering. 2024; 9(2). doi: 10.1007/s41101-024-00290-8
20. Farr TG, Rosen PA, Caro E, et al. The Shuttle Radar Topography Mission. Reviews of Geophysics. 2007; 45(2). doi: 10.1029/2005rg000183
21. Rafik A, Ait Brahim Y, Amazirh A, et al. Groundwater level forecasting in a data-scarce region through remote sensing data downscaling, hydrological modeling, and machine learning: A case study from Morocco. Journal of Hydrology: Regional Studies. 2023; 50: 101569. doi: 10.1016/j.ejrh.2023.101569
22. Sharpley AN, Williams JR. EPIC, erosion/productivity impact calculator. Tech. Bull; 1990.
23. Arnold JG, Srinivasan R, Muttiah RS, et al. Large Area Hydrologic Modeling and Assessment Part I: Model Development1. Jawra Journal of the American Water Resources Association. 1998; 34(1): 73-89. doi: 10.1111/j.1752-1688.1998.tb05961.x
24. Kim NW, Chung IM, Won YS, et al. Development and application of the integrated SWAT–MODFLOW model. Journal of Hydrology. 2008; 356(1-2): 1-16. doi: 10.1016/j.jhydrol.2008.02.024
25. Eini MR, Massari C, Piniewski M. Satellite-based soil moisture enhances the reliability of agro-hydrological modeling in large transboundary river basins. Science of The Total Environment. 2023; 873: 162396. doi: 10.1016/j.scitotenv.2023.162396
26. Gupta HV, Sorooshian S, Yapo PO. Status of Automatic Calibration for Hydrologic Models: Comparison with Multilevel Expert Calibration. Journal of Hydrologic Engineering. 1999.
27. Beven K. A manifesto for the equifinality thesis. Journal of Hydrology. 2006; 320(1-2): 18-36. doi: 10.1016/j.jhydrol.2005.07.007
28. Nash JE, Sutcliffe JV. River flow forecasting through conceptual models part I—A discussion of principles. Journal of Hydrology. 1970.
29. Santhi C, Arnold JG, Williams JR, et al. Validation of The Swat Model On A Large Rwer Basin With Point And Nonpoint Sources1. Jawra Journal of the American Water Resources Association. 2001; 37(5): 1169-1188. doi: 10.1111/j.1752-1688.2001.tb03630.x
30. Moriasi DN, Arnold JG, Van Liew MW, et al. Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. Transactions of the ASABE. 2007; 50(3): 885-900. doi: 10.13031/2013.23153
31. Obuobie E. Estimation of groundwater recharge in the context of future climate change in the White Volta River Basin, West Africa. Available online: https://bonndoc.ulb.uni-bonn.de/xmlui/handle/20.500.11811/3712 (accessed on 7 November 2024).
32. Alitane A, Essahlaoui A, Van Griensven A, et al. Towards a Decision-Making Approach of Sustainable Water Resources Management Based on Hydrological Modeling: A Case Study in Central Morocco. Sustainability. 2022; 14(17): 10848. doi: 10.3390/su141710848
33. Boufala M, El Hmaidi A, Essahlaoui A, et al. Assessment of the best management practices under a semi-arid basin using SWAT model (case of M'dez watershed, Morocco). Modeling Earth Systems and Environment. 2021; 8(1): 713-731. doi: 10.1007/s40808-021-01123-6
34. Lamia E, Soufiane T, Souad H, et al. Semi-Distributed Modeling of a Large Scale Hydrological System Using SWAT Model. In: Proceedings of the 2020 IEEE 2nd International Conference on Electronics, Control, Optimization and Computer Science (ICECOCS); 2020.
35. EL Garouani A, Nabunya V. Analysis of Climate Trend and Effect of Land Cover Change on Streamflow in Oued Fez Basin, Morocco. SSRN; 2023.