

Modeling the flow of Oued Cherraa Basin (northeastern Morocco) using the SWAT model and evaluating model performance

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Abstract. River flow modeling is essential for water resource management, particularly in poorly gauged basins such as the Oued Cherraa in eastern Morocco. In these areas, modeling serves as an alternative to direct monitoring, helping to understand hydrological responses to water challenges such as floods, droughts and irrigation needs. The study used the SWAT model (ArcSWAT 2012 version) to simulate river flow in the Oued Cherraa basin. A sensitivity analysis, calibration and validation process were carried out using the sequential uncertainty adjustment method (SUFI-2), which optimized model parameters and ensured accurate reproduction of flows. The model was refined to better capture the basin's complex hydrological processes, providing critical data for water management and planning. Key parameters analyzed include the deep aquifer percolation fraction (RCHRG_DP), the calibration coefficient for normal flow, and the curve number (CN2). The results showed a strong correlation between observed and simulated flow data. The mean monthly flow at Tazarhine (on Oued Zegzel) was 0.99 m³/s, with a simulated value of 1.076 m³/s during calibration and validation.

Keywords: Hydrological modeling, ArcSWAT, Oued Cherraa watershed.

1. Introduction

The accessibility of water is an indispensable factor in supporting life, particularly in arid regions where river resources are scarce. This poses major challenges for maintaining agriculture, industry and human consumption. In regions such as Morocco, where water scarcity is a major challenge, effective management of water resources is of paramount importance for the sustainability of livelihoods and the promotion of economic development [1], [2]. Rivers are a primary source of freshwater, but the challenges of effectively managing river systems are becoming increasingly evident due to rising demand, climate change and poor water quality [3], [4].

Morocco is facing increasing pressure on its water resources due to population growth, industrialisation and agricultural expansion, which have led to overall higher consumption and pollution [5]. Morocco is currently facing a water shortage, with people using 606 litres of water per person each year. This is set to drop to just 500 litres by 2030, which will make it even harder to meet the growing demand for water in rural and urban areas [5]. Even though Morocco has introduced sustainable water management practices, it still lacks data on how water is distributed and available.

Although efforts have been made to implement sustainable water management practices, Morocco still faces gaps in data relating to the distribution and availability of water resources. This is particularly evident in areas such as the Oued Cherraa basin, where there is a lack of comprehensive data on streamflow, groundwater recharge and runoff patterns, which are essential for informed decision-making and effective water resource management.

This study addresses challenges in the Oued Cherraa basin using river flow modelling with the ArcSWAT 2012 model. The model has been calibrated and validated using the SWAT-CUP 2012 interface.

The objective is to provide more accurate data on water distribution in the basin. This will help guide the planning and management of water resources in the region, ensuring more efficient water use, improving irrigation practices and supporting policies that promote sustainable water use for future generations. The modelling results will provide a better understanding of the hydrological compartment of the basin, including flow variability, groundwater recharge and the impact of land use and climate change on water availability.

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2. Materials and methodology

2.1 Study area description

Oued Cherraa catchment, located in north-east Morocco and covering an area of 267.29 km² (Fig.1), is characterised by three distinct valleys, in particular Oued Zegzel and Oued Cherraa, which play an essential role in recharging the water table and converging with Moulouya river [6].

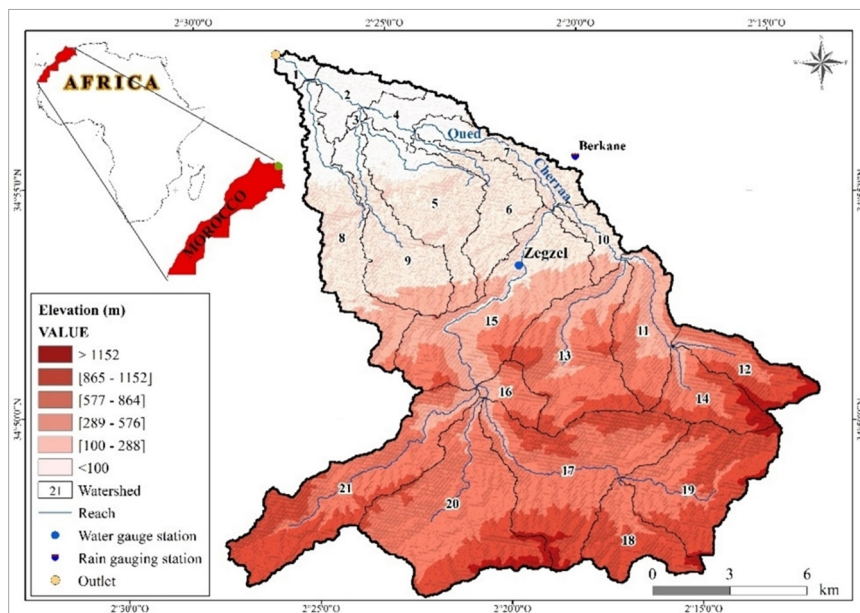


Fig. 1. The study area

The basin is divided into two geomorphological sectors: an upstream mountainous region composed mainly of ancient rocks such as Paleozoic schists and secondary carbonate rocks, and a downstream plain dominated by superficial Quaternary deposits. From a hydrogeological point of view, two superimposed water tables are present: the deep-water table of the Lias with considerable water reserves and the superficial water table of the plio-quaternary with a more limited volume of water [7], in decline due to exploitation in the irrigated areas of the Triffa plain.

2.2 Method adopted

The study used the SWAT model, in particular the 2012 version of ArcSWAT, to simulate the flow in the Oued Cherraa basin. The sensitivity, calibration and validation steps were carried out using the SUFI-2 algorithm via SWAT-CUP2012, allowing the model parameters to be fine-tuned to ensure accurate reproduction of the flow patterns. Furthermore, 696 hydrological response units (HRUs) were identified and adjusted in accordance with the research objectives and technical constraints across 21 sub-catchments [8]. The SUFI-2 algorithm, in particular, facilitated the parameter sensitivity analysis, thereby contributing to the identification of the most influential parameters for the hydrological modelling of the Oued Cherraa basin.

2.2.1 Input data

The study used a range of data sources to develop a model of the hydrological processes occurring in the Oued Cherraa catchment. Meteorological data from the Berkane station (2012-2022) were used, with missing data for temperature, humidity, wind speed and solar radiation supplemented by the WXGEN weather generator [9]. The hydrological data were based on daily flow observations from the Tazarhine station (2012-2016). This made sure the model's flow simulations were precise.

The ArcSWAT model also needs spatial data. We used a 30-metre resolution DEM to identify slopes and define catchment areas. We also created a LULC map from a high-resolution Sentinel-2 satellite image. This classified the land into seven categories, which gave us a good overview of runoff and other hydrological processes [8]. Soil data, including attributes such as bulk density and hydraulic conductivity, was obtained from FAO SoilGrids and ISRIC. This enabled the identification of the predominant soil types, including chromic luvisols and xerosols, which are essential for accurate modelling of water retention and infiltration. All of the above data was used in a comprehensive hydrological analysis.

2.2.2 SWAT Model Calibration and Validation

The SWAT model for the Oued Cherraa watershed was calibrated and validated using sensitivity analysis and key parameter adjustments. The sensitivity of flow parameters was assessed using the SWAT-CUP2012 software and the Sufi-2 method. This included Latin hypercube sampling to identify the most influential factors [10]. The model was calibrated for 2014-2015, with parameter adjustments to match observed and simulated data. The model was validated using flow data up to August 2016 because there was no data for the rest of the year. We used statistical metrics like Nash-Sutcliffe Efficiency (NSE) (equation 1) and the coefficient of determination (R^2) to evaluate performance.

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

Y_{sim} and Y_{obs} represent the simulated and observed flows, respectively, while Y_{mean} represents the average of the observed data. The NSE looks at how accurate the model predictions are. The higher the value, the better the performance (Abbaspour, 2013). R^2 shows how well the observed and simulated flow match up (equation 2).

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

The simulated or evaluated data are denoted by " O_i " while a variable (such the flow rate) is represented by " \bar{O} ". R^2 is an indicator of the coefficient of determination. The closer the value is to 1, the better the model fits. We used Latin hypercube sampling [11] to calculate the 95% prediction uncertainty (95PPU) to make sure the model was reliable even though there were gaps in the data during the validation phase.

3. Results and discussions

3.1 Analysis of sensitivity

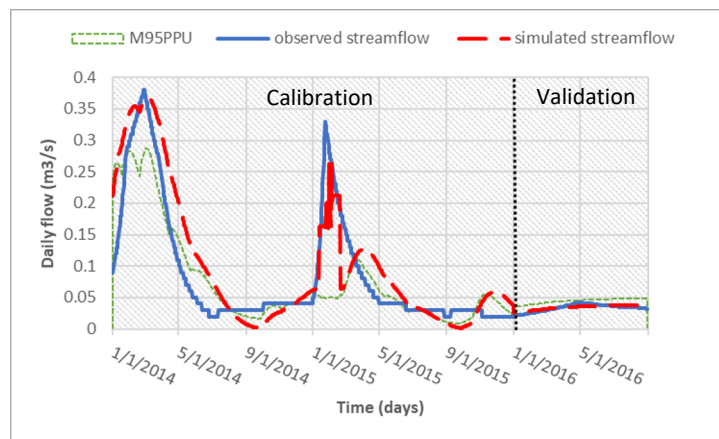
The sensitivity analysis for the model calibration revealed a number of sensitive parameters. Some of the most important parameters are the deep aquifer percolation fraction (RCHRG DP), curve number (CN2), base flow alpha factor (ALPHA_BF), groundwater evaporation coefficient (GW_REVAP), calibration coefficient controlling the storage time constant for normal flow (MSK CO1), and compensation factors for soil evaporation (ESCO) and plant uptake (EPCO). The parameters we've provided are really sensitive and have a big impact on the streamflow dynamics. Table 1 gives you all the details you need about the adjusted values for the sensitive parameters in the calibration process. In most Moroccan watersheds, the number of curves parameter (CN2) is the flow parameter that's most sensitive. However, in the case of the Oued Cherraa basin, it's the RCHRG DP parameter that's the most sensitive. This shows what makes the Oued Cherraa basin so different from other Moroccan basins in terms of hydrology.

Table 1. Overview of Key Parameters

Parameter name	Full name and units	Initial value	Rank	Adjusted 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

Following the identification of the most sensitive parameters, adjustments were made with a view to refining the values through several calibration cycles. This was done with the objective of matching the observed and simulated flow patterns. The flow data obtained from the gauging station situated at the outlet of the Oued Cherraa basin were employed for the purposes of calibration and validation of the model, which had been meticulously prepared in accordance with the requirements set out by SWAT-CUP. This approach enabled us to ensure the model's functionality and validate the pertinent data. As illustrated in Fig. 2, the calibrated and observed flow patterns exhibited near-identical characteristics. Table 2 presents a summary of the model's performance.

*Fig. 2 Hydrographs for model calibration and validation*

The deployment of the SWAT model in Oued Cherraa catchment area has demonstrated its viability and effectiveness, with results that are accurate and align with the study objectives. It is important to note, however, that the model tends to underestimate flows, particularly during low-flow periods, as observed at the Tazarhine station.

Table 2. Statistical summary to assess model performance

Paramètre statistique	Calibration	Validation
Nash-Sutcliffe (NSE)	0.58	0.60
Coefficient of regression (R ²)	0.66	0.63

3.3 Hydrological parameters simulated

3.3.1 Simulation of river flow

Table 3 provides a comparison between the simulated and observed mean monthly flows at the Zegzel gauging station. The SWAT model consistently produced lower estimates of flow, with discrepancies of 3.3% during calibration and 1% during validation. Notwithstanding the aforementioned discrepancies, the simulated discharge exhibited a high degree of correlation with the observed data, which serves to reinforce the reliability of the model. The mean flow rate at the station was 0.99 m³/s during the calibration phase and 1.076 m³/s during the validation phase. The model's performance at Tazarhine (oued Zegzel) was also evaluated, with a close match between simulated and observed flow, particularly during periods of low flow. It should be noted, however, that the model produced slightly higher estimates during these periods, which requires a cautious interpretation of the results.

Table 3. Comparison of monthly measured and simulated flows

Period	Average monthly flow (m ³ /s)	
	Observed	Simulated
Calibration	1.023	0.99
Validation	1.054	1.076

3.3.2 Simulation of hydrological parameters

The SWAT model was used to simulate surface runoff in Oued Cherraa catchment, with the result that an annual runoff of 15.51 mm was revealed, with a monthly maximum in April of 3.01 mm (**fig. 3**). A comparison of the simulated and observed runoff hydrographs indicates a slight discrepancy during the winter and spring months, which may be attributed to a lag in groundwater and surface water inputs. For the summer and autumn months, however, both types of hydrograph show comparable monthly trends.

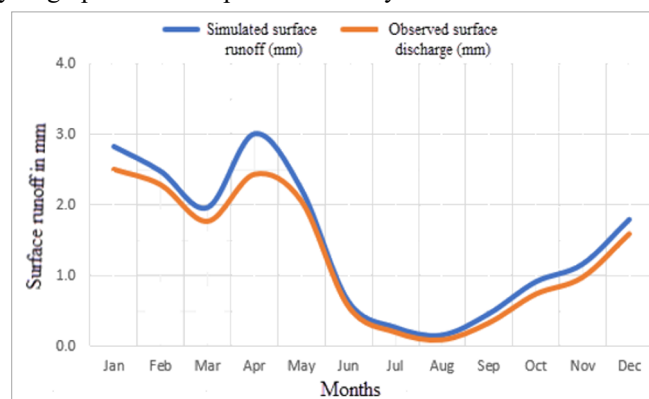


Fig. 3 Surface runoff hydrograph at the Tazarhine station

The results of the sensitivity analysis indicate that groundwater lag is the parameter with the greatest impact. **Table 4** provides a full breakdown of the simulated hydrological parameters, offering pointers for further analysis. According to the model, average water production from January to May exceeds 12.47 mm, suggesting the possibility of storing excess water to alleviate periods of summer drought. Mountainous sub-basins have higher inputs than those in lowland areas, probably due to factors such as topography and climate (**fig.4a**). Monthly potential evapotranspiration peaks in summer, while it remains relatively low in winter and autumn. The variations between sub-basins highlight the complexity of the relationship between environmental factors and the dynamics of evapotranspiration (**fig.5b**).

Table 4. Hydrological parameters simulated

Month	Pluie (mm)	Water yield (mm)	Evapotranspiration (mm)	Average lateral flow	Potential evapotranspiration (mm)
January	45.27	2.82	15.77	2.51	28.70
February	25.66	2.47	21.27	2.29	50.42
March	28.94	1.96	31.34	1.77	85.85
April	53.44	3.00	43.58	2.44	111.57
May	17.53	2.22	42.80	2.06	159.87
June	3.54	0.64	30.46	0.56	180.69

July	0.29	0.27	16.99	0.19	195.08
August	2.37	0.16	7.08	0.08	175.78
September	14.63	0.46	10.46	0.32	125.94
October	21.33	0.91	11.54	0.73	79.35
November	25.49	1.16	10.12	0.97	39.34
December	29.34	1.79	10.54	1.59	24.08

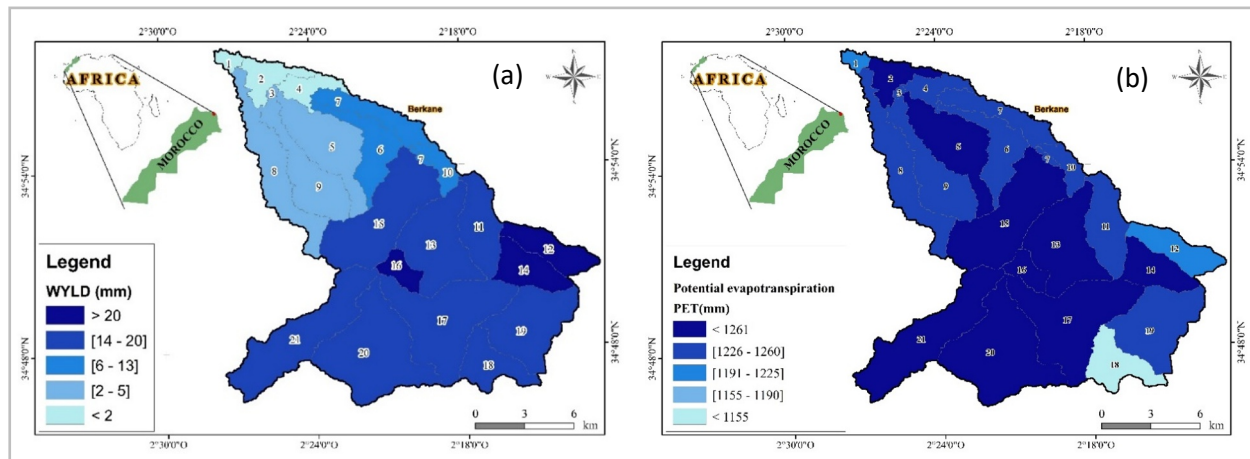


Fig. 4 Spatial distribution of water production (a) and Spatial distribution of potential evapotranspiration (b)

4. Conclusion

In order to model the hydrology of Oued Cherraa, the ArcSWAT tool was utilised. The basin was modelled using daily flow data, with the SUFI-2 algorithm employed for the purpose of calibration. The percolation fraction of the deep aquifer was identified as the parameter exerting the greatest influence on the model output. The performance of the model, assessed by the correlation coefficient by the correlation coefficient (R^2) and the Nash-Sutcliffe efficiency (NSE), showed good agreement between recorded and simulated data for daily flows, with R^2 values of 0.66 and 0.63, and NSE values of 0.58 and 0.60 respectively. The monthly simulations also demonstrated the model's effectiveness. During calibration, the recorded volumes were $0.99 \text{ m}^3/\text{s}$, and during validation, $1.076 \text{ m}^3/\text{s}$. These results emphasise the significance of river flow modelling for the management of water resources and highlight the potential of the SWAT model for hydrological analysis of Oued Cherraa basin in eastern Morocco.

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Author Contribution

Mohammed Laaboudi, Abdelhamid Mezrhab and Zahar Elkheir Alioua: Conceptualization, Investigation, Methodology, Software, Validation, Formal analysis, Resources and writing-original draft preparation. Mohammed Laaboudi, Ali Achebour, Wadii Snaibi and Mohammed Sahil: Writing-reviewing and editing. Abdelhamid Mezrhab: Supervision. All the authors have read and agreed to the published version of the manuscript.

Ethics approval and consent to participate

Notably, no studies involving human participants have been conducted by any of the authors.

Consent for publication

All the authors have agreed to publish this article.

Competing Interests

The authors assert that there are no personal or financial ties to individuals or groups that could improperly influence this work. The viewpoint expressed in the manuscript titled " Modeling the flow of Oued Cherraa Basin (northeastern Morocco) using the SWAT model and evaluating model performance" was not influenced by any professional or personal interest of any kind in any company, product, or service.

Data Availability statement

This article is published and contains all of the data generated or analyzed during the study.

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