

Original scientific paper

UDC 332.2:556(65)
https://doi.org/to_be_assigned

Received: January 10, 2026

Corrected: May 30, 2026

Accepted: June 17, 2026

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ASSESSMENT OF LAND USE AND LAND COVER CHANGE ON THE HYDROLOGICAL RESPONSE OF SAIDA WATERSHED USING SWAT MODEL

Abstract: The aim of this research is to analyze the impact of three decades of land use and land cover (LULC) changes on the hydrological response of Saida watershed located in North-west of Algeria. To achieve this goal, the Soil and Water Assessment Tool (SWAT) was applied to simulate the monthly streamflow of Saida watershed during the period 1985-2014. The thematic layers of digital elevation model, soil map, LULC maps and weather data were initialized to set up SWAT model. The model was calibrated during the period 1985-2004 and validated during 2005-2014 with the SUFI-2 algorithm. The results of model performance statistics indicated a good agreement between the observed and simulated streamflows at Sidi Boubakeur gauging station, as verified by coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NSE) which are 0.92 and 0.86 during the calibration and 0.68, 0.67 during the validation period, respectively. LULC dynamics derived through satellite image classification for the years 1985, 2000 and 2014 revealed a significant land degradation, with barren land increasing by 38.5% and agricultural land decreasing by 31.7%. Consequently, average streamflow increased significantly from 3.42 m³/s in 1985 to 19 m³/s in 2014 with respect of observed LULC dynamics. The soil type and the groundwater-surface water interaction of Saida watershed have an important role to the water abundance. The findings will help the management and planning of water resources to ensure environmental sustainability of Saida watershed.

Keywords: LULC change, streamflow, SWAT, simulation, hydrological response, Saida watershed, Algeria

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Introduction

Water is a vital natural resource, essential for sustaining life and supporting socio-economic development. In Northwestern Algeria, the scarcity of perennial rivers and aquifers makes water resources management more challenging especially under increasing climatic and anthropogenic pressures (Hachemaoui et al., 2022; Mahcer et al., 2024a; Souza et al., 2016). At the watershed scale, hydrological response is governed by the combined effects of natural factors such as soil, topography and human induced changes in land use and land cover (LULC). LULC refers to both natural ecosystem and human land use practices; and its dynamic have a significant impact for environmental change such as hydrological response, vegetation trends and land degradation (Abbas et al., 2022; Mahcer et al., 2024a).

Moreover, in the recent decades, LULC has been significantly modified in many semi-arid and Mediterranean regions due to climate change and various human drivers such as urbanization, deforestation, and changing agricultural practices, often leading to increased erosion, altered flow regimes and reduced ecosystem resilience. In this context, remote sensing and Geographic Information System (GIS) have become powerful tools for monitoring LULC dynamics and supporting land and water management.

Moreover, multi-temporal satellite imagery allows for regular LULC classes mapping and detection of change patterns, while GIS facilitates the integration of these data with environmental layers for spatial analysis (Ahmad et al., 2023; Mahcer et al., 2024b). In addition, the integration of hydrological models which link the meteorological factors with land-surface processes permits the simulation of complex interactions within a watershed and evaluation of the hydrological consequences of LULC changes (Abbas et al., 2021). Among a large range of hydrological models, the Soil Water Assessment Tool (SWAT) is a useful model to simulate hydrological response under varying LULC and climatic scenarios (Abdelkebir et al., 2023; Akoko et al., 2021; Neitsch et al., 2011). It is an open source model, which integrates easily with remote sensing data and GIS platforms. The model divides a basin into hydrological response units (HRUs) that represent unique combination of land use, soil and slope; thereby capturing the spatial heterogeneity that controls the hydrological response. The Saida watershed, located in the Macta basin in North West Algeria, is an important agricultural area, particularly for cereal production, and plays a key role in regional development. However, the watershed has experienced substantial LULC changes over the past decades, including land degradation and expansion of barren and built-up areas, which may threaten agricultural lands, modify hydrological processes and increase environmental risks.

While several studies have applied SWAT and remote sensing to assess LULC and hydrology in semi-arid and Mediterranean environments, comprehensive analyses that explicitly quantify the impacts of multi-decadal LULC change on the hydrological response of the Saida watershed remain limited. This lack of site-specific knowledge constrains the design of effective land and water management strategies in the region.

The present study integrates multi-temporal satellite-derived LULC maps with the SWAT model to evaluate how three decades of LULC change have affected the hydrological response of the Saida watershed over the period 1985–2014. The specific objectives are to Calibrate and validate the SWAT model to simulate the hydrological response of the Saida watershed using observed hydro-meteorological data for 1985–2014; and assess the impact of observed LULC changes between 1985, 2000 and 2014 on key hydrological components,

with a focus on streamflow and water yield. By clarifying the links between LULC dynamics and hydrological response, this study provides insights that can support sustainable watershed management and adaptation strategies in semi-arid regions of North-West Algeria.

Material and methods

Study area

The study area is the Saida watershed, part of one of the largest western basin in Algeria which is the Macta basin (Fig 1). The geographical extent of the studied watershed lies between 0.04°W and 0.26°E longitude and to 34.70°N and 35.1°N latitude, covering a drainage area of almost 597 km² (Fig 1).

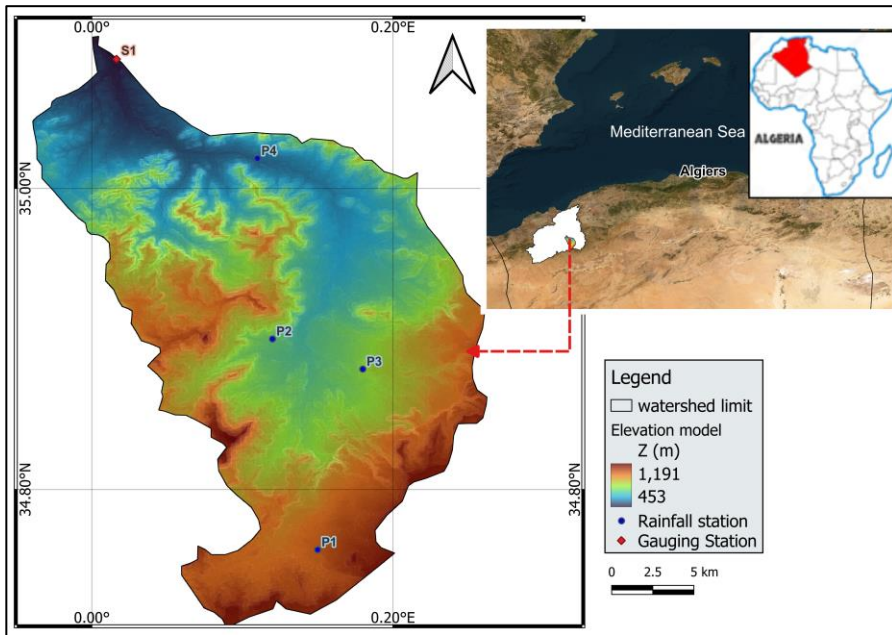


Fig. 1. Location and digital elevation model of Saida watershed

Saida watershed is surrounded by mountains of Tellien Atlas such as Daia in the West and highlands of Saida (Tifferit) in the South East. The elevation ranges from 460 m to 1191 m above sea level (Table 1). The western and the South-Eastern part of the watershed is extremely rugged with an average elevation of 1000 m; the central part is covered with hills with elevation ranges from 800m to 460m altitude at the outlet. The average slope index of Saida watershed is about 10.92m/km (Table 1). The climate of the studied watershed is semiarid with maximum and a minimum temperature of about 36°C and 3°C in the month of July and January, respectively. It receives 330mm of the mean annual rainfall recorded between (1985-2016). The intense precipitation during the wet season (November - january) is peaked in January and low precipitation during the dry season (summer). Saida wadis is a non perenial stream, it is one of the tributaries of the Macta basin, it extends from Saida city crossing many towns with a lengh of 35 km to join Taria wadis in Mascara. Saida wadis discharges yearly a streamflow of about 0.85m³/s. Saida watershed has a good hierarchical channels of the hydrographic network with high branches but low density. The hydrological characteristics of Saida watershed are summarized in Table 1.

Table 1. Hydrological characteristics of the Saida watershed

Parameters	Notation	Unit	Value
Area	A	km ²	597
Perimeter	P	km	130
Compactness coefficient	K _c	/	1.49
Lenght of the main wadis	lp	km	35
Average slope index	I _m	m/km	10.92
Maximum altitude	H _{max}	m	1191
Minimum altitude	H _{min}	m	460
Drainage Density	Dd	km ⁻¹	2.91

Methodology

In this study to assess the impact of LULC on water resources in the Saida watershed, the SWAT hydrological model was used. The methodology of this study consists of two parts: 1) Streamflow modelling using SWAT model. 2) Effects of past LULC changes on streamflow LULC maps were acquired from the reference years 1985, 2000 and 2014. The LULC maps were generated using an unsupervised classification method which identified various classes based on the spectral properties of the pixels and they were compared to the simulated streamflow to assess its effects on hydrological response. The proposed methodology is presented in Figure 2.

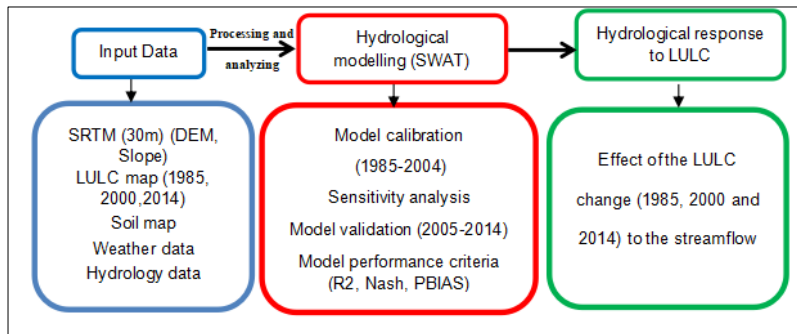


Fig. 2. Flowchart for the proposed methodology using SWAT model

The soil and water assessment tool (SWAT) is a semi-distributed, continuous time step hydrological model widely used to assess the influence of environmental and ecological alterations on hydrological responses at different watershed scales (Abdelkebir et al., 2023; Akoko et al., 2021). SWAT was developed by the United States Department of Agriculture (USDA) (Arnold et al., 1998), divides a large basin into several number of small sub-basins and each sub-basin is further sub-divided into multiple Hydrological Response Units (HRUs). Each HRU represents unique combination of land use/management/slope/soil attributes (Neitsch et al., 2011) and it is considered as the building block of SWAT model which is more sensitive to HRU definition thresholds than to sub-basin discretization (van Griensven et al., 2012). SWAT model simulates flow from HRUs generation which is routed to sub-basin and basin outlet through stream networks.

Data requirements and analysis

SWAT model requires various data types such as: topography, weather and hydrological data, land use and land cover and soil map. Below is the description of all input datasets.

Topography

The altitude of any point of the earth's surface at specific resolution is given by the digital elevation model (DEM). In the study area of Saida watershed, a DEM with spatial resolution of 30 m was downloaded from the United States Geological Survey (USGS Earth Explorer) (<https://earthexplorer.usgs.gov/>). Much information was derived from DEM for model simulation, such as, slope (Fig 3.a) and stream network which are processed using QGIS3.34. Accordingly, The Saida watershed is characterized by slopes values ranging from 0% to 39.4%. the highest values are found in the Eastern Daia mountains, western Djbel BelHadj and Southern Doui Thabet. While lower values indicate flat to very gently terrain along Saida wadis boundaries. The largest part of the area is marked by a moderate slope terrain.

Soil map

Soil data map of the study area were obtained from the Digital Soil Map of the World (DSMW) database (<https://www.fao.org/>). Accordingly, the soil map of the Saida watershed consists of two textural classes (Fig 3.b): loam classified in Calcaric Cambisols (Bk) type soil, dominates all through the watershed (Bentabet et al., 2019; Zouidi et al., 2019). The loamy-clay soil of the calcaric fluvisol (Jc) is limited on the Northeastern side of the watershed.

LULC

The historical LULC maps for the three reference years (1985, 2000 and 2014) were prepared from classified satellite images. However, multi-temporal satellite images from different sensors were used (Table 2) with similar spatial (30m) and spectral characteristics (spectral bands in visible, infrared, shortwave infrared). The season images selected are mainly associated with cloud free atmosphere. The image objects were classified using unsupervised classification based on natural groupings of the spectral properties of the pixels. Consequently, five classes of LULC were selected for image classification such as agricultural land, built up area, forest cover, barren lands and water bodies (Fig 3c). The LULC, Soil maps and DEM were overlaid in GIS environment and incorporated into SWAT database. Moreover, The LULC of each reference year is considered as a scenario, which is integrated in SWAT to compare how streamflow responds to LULC dynamics.

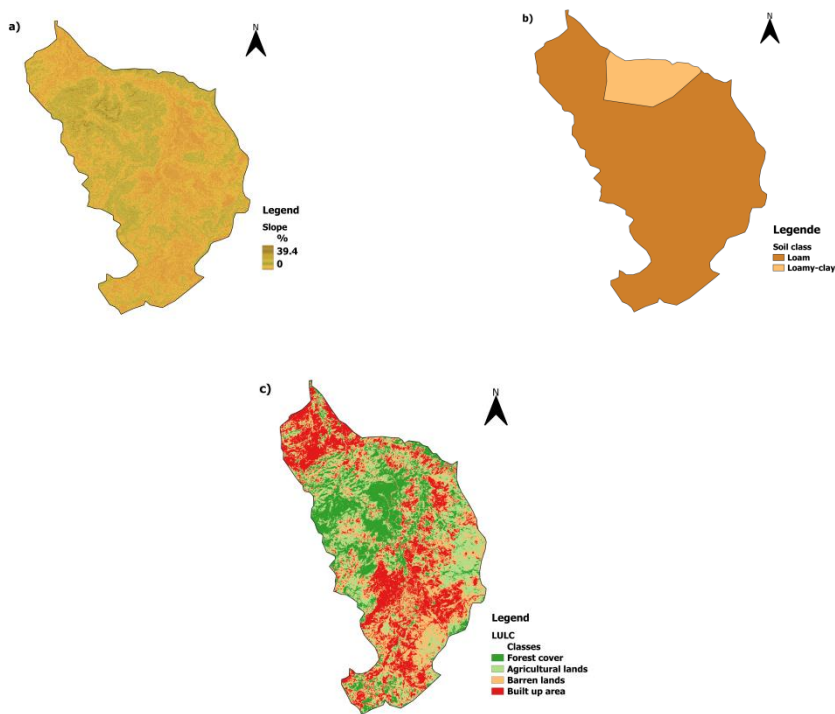


Fig. 3. Saida watershed characteristics a) slope, b) soil types, c) LULC classes

Table 2. Characteristics of the satellite images used for LULC map in Saida watershed

Date	Type of imagery	Satellite	Path row
28/10/1985	TM	Landsat4-5	197/36
29/10/2000	ETM+	Landsat-7	197/36
13/11/2014	Oli/TIRS	Landsat 8-9	197/36

Consequently, for HRUs generation, the whole study watershed was divided into 28 sub-watersheds, based on stream network, soil types, slope and dominant land use classes for 1985, 2000 and 2014 LULC, respectively. The size of sub-watersheds are ranged from 1.28 km² to 54.51 km². These sub-watersheds are spatially connected, where the outlet that controls runoff generation and water yield is located in sub-watershed 12. Many studies have highlighted that the number of sub-watersheds divided may not improve in model prediction if the spatial variability of weather parameters are rightly captured (Arnold et al., 2012; Muleta, 2012; Samal and Gedam, 2021). The model generated different HRUs due to change in LULC types. The slope data derived from the DEM were also reclassified to correspond with the SWAT database requirement.

Weather data

SWAT requires daily weather data for streamflow simulation in a watershed such as rainfall, maximum and minimum temperature, relative humidity, solar radiation and wind speed. However, SWAT modelling can be helpful even with limited data (Wang et al., 2018). In the present study, daily rainfall records from rain gauge stations (P) inside the Saida watershed

(Table 3) during the period (1985- 2014) were used. These data were collected from the National Agency for water Resources (ANRH) (<https://anrh.dz/>). Temperature data (maximum and minimum) were downloaded from the climate forecasting system analysis (0.5*0.5 degree grid interval) global data set (<https://power.larc.nasa.gov/data-access-viewer/>). The spatial variation of the rainfall in the basin was captured by interpolating the daily rainfall for each sub-basin in SWAT. The available weather data were converted into the usable format to be applied in SWAT calibration and uncertainty analysis (SWAT-CUP).

Runoff data

Monthly streamflow data measured at Sidi Boubaker gauging station (S1) were used (Table3). The historical observed streamflow records between the year 1985 to 2014 were collected from the National Center of Water Resources (ANRH). These data were used for model calibration and validation.

Table 3. Characteristics of hydrological gauging in Saida watershed

Rainfall gauging					Streamflow gauging			
Code	Symbol	X	Y	Z (m)	code	Symbol	X	Y
111103	P1	0.15°E	34.76°N	1000	111129	S1	0.016°E	35.08°N
111113	P2	0.12°E	34.90°N	950				
111114	P3	0.18°E	34.88°N	920				
111116	P4	0.11°E	35.02°N	590				

The quality of times-series data and its outliers were checked. Then, weather time series data were organized and converted into usable format for SWAT calibration.

Performance measures

SWAT streamflow simulation of Saida watershed covers calibration, and validation. The model performance was computed using the following criteria: Coefficient of determination (R^2), Nash-Sutcliffe efficiency (NSE) and Percent BIAS (PBIAS). The coefficient of determination (R^2) (Eq. (1)) measures the proportional variation in the simulated variable explained by the measured variable and indicates the linear relationship between the estimated and measured variables. The value of NSE (Eq.(2)) shows the relative magnitude of the residual variance compared to the observed data (Santhi et al., 2001). it ranges from (-∞ to 1) with 1 representing a perfect agreement between the simulated and measured values. PBIAS measures the percentage of the overestimation or underestimation of the simulated variables (Eq. (3)). The optimized model parameters were obtained from calibration/validation and transferred to the model setup with 1985, 2000 and 2014 LULC map to study the impacts of LULC change on water resources in the study basin.

$$R^2 = \left[\frac{\sum_{i=1}^N (X_{obs\ i} - \bar{X}_{obs}) \cdot (X_{sim\ i} - \bar{X}_{sim})}{\sqrt{\sum_{i=1}^N (X_{obs\ i} - \bar{X}_{obs})^2} \sqrt{\sum_{i=1}^N (X_{sim\ i} - \bar{X}_{sim})^2}} \right]^2 \quad (1)$$

$$NSE = 1 - \frac{\sum_{i=1}^N (X_{obs\ i} - X_{sim\ i})^2}{\sum_{i=1}^N (X_{obs\ i} - \bar{X}_{obs})^2} \quad (2)$$

$$PBIAS = 100 \times \frac{\sum_{i=1}^N (X_{obs\ i} - X_{sim\ i})}{\sum_{i=1}^N X_{obs\ i}} \quad (3)$$

Where: $X_{obs\ i}$ and $X_{sim\ i}$ are observed and simulated variable at specific time i respectively.
 $\overline{X_{obs}}$: Average observed variable during the time series period (N).

The model performance is satisfactory if the $NSE > 0.5$, and $R^2 > 0.5$ (Liew et al., 2003; Santhi et al., 2001). While $PBIAS < 25\%$ (Moriassi et al., 2015; Santhi et al., 2001)

Results and discussion

SWAT simulation

Sensitivity Analysis

Sensitivity analysis is an essential preliminary step to model calibration, enabling the identification of parameters that exert the greatest influence on watershed hydrological response. In this study, four parameters exhibited high sensitivity: The Soil Conservation Service (SCS) Curve Number for moisture condition (CN2), the Baseflow Alpha Factor (ALPHA_BF), Groundwater Delay (GW_DELAY), and the threshold depth of water in the shallow aquifer for return flow (GWQMN) (Table 4).

Table 4. Parameters sensitivity analysis and fitted value in SWAT model after calibration

N°	Parameter name	Fitted value	Min value	Max value
1	R__CN2.mgt	-0.151	-0.2	0.2
2	V__ALPHA_BF.gw	0.334	0	1
3	V__GW_DELAY.gw	73.21	30	450
4	V__GWQMN.gw	1.306	0	2

The CN2 parameter emerged as the most influential, underscoring the pivotal role of soil properties and land cover in governing infiltration and surface runoff generation. The negative fitted coefficient for CN2 (-0.151) is consistent with moderately loamy soils that enhance infiltration (Abraham et al., 2020), while the presence of calcium carbonates may delay surface runoff initiation by locally limiting vertical percolation. The calibrated ALPHA_BF value of 0.334 suggests moderate baseflow response, suggesting that groundwater contributes to sustaining baseflow during dry period. While the estimated groundwater delay of 73.21 days reflects a substantial lag time between percolation and groundwater contribution to streamflow, which is compatible with semi-arid basins underlain by comparatively deep aquifers (Abbaspour, 2015; Arnold et al., 2012). The calibrated GWQMN value (1.306 mm) further highlights the importance of shallow aquifer storage in maintaining baseflow, particularly during low flow seasons.

These parameter sensitivity are in line with previous SWAT applications in Mediterranean and semi-arid environments, where CN2 and groundwater related parameters emerge as key controls on basin hydrological response (Abdelkebir et al., 2023; Zaibak and Meddi, 2022; Zettam et al., 2017). Collectively, these results validate a hydrological regime of the Saida watershed marked by the presence of calcium carbonates which increase runoff through saturation excess. Additionally, the groundwater contributes steadily to streamflow of Saida wadis at the outlet but not immediately, and sustain baseflow in the stream during dry periods.

SWAT Model Calibration and Validation

The SWAT model was calibrated for the period 1985–2004 and validated for 2005–2014 using monthly streamflow at Sidi Boubaker gauging station (S1) with the SUFI-2 algorithm implemented in SWAT-CUP (Figs. 5 and 6). Model performance was evaluated using the coefficient of determination (R^2), Nash–Sutcliffe efficiency (NSE), and percent bias (PBIAS) (Table 5).

Table 5. Performance of simulated versus observed flow for calibration and validation periods

Statistical parameter	R^2	NSE	PBIAS (%)
Calibration period 1985_2004	0.92	0.76	41
Validation period 2005_2014	0.68	0.67	8.4

During calibration, the model reproduced a large part of the variability in observed monthly flows with $R^2 = 0.92$, $NSE = 0.76$, but with a positive PBIAS value of 41%, indicating a systematic underestimation of total streamflow volume in this period. In the validation phase, performance metrics decreased to $R^2 = 0.68$ and $NSE = 0.67$, while PBIAS improved to 8.4%, suggesting a closer match in terms of overall water balance but with reduced correlation in the timing and magnitude of monthly flows.

The calibration PBIAS exceeds the recommended bias limits, which is linked to the complex behavior of calcaric cambisols under semi-arid conditions. However, their loamy texture justifies a high initial infiltration capacity reflected by lower value of CN2. Furthermore, the calcaric nature of these soils often facilitates surface crusting and the development of shallow limit vertical percolation and produce rapid runoff.

Visual comparison of observed and simulated hydrographs (Fig. 4a) shows that the model reproduces the general seasonal pattern and several peak events, although, some high flows in February 2007 and February 2012 are underestimated and certain high flows after, April 2012 are overestimated. These results affect the concordance between observed and simulated flows ($R^2 = 0.68$) shown in the Scatter plot (Fig 4b) for validation phase.

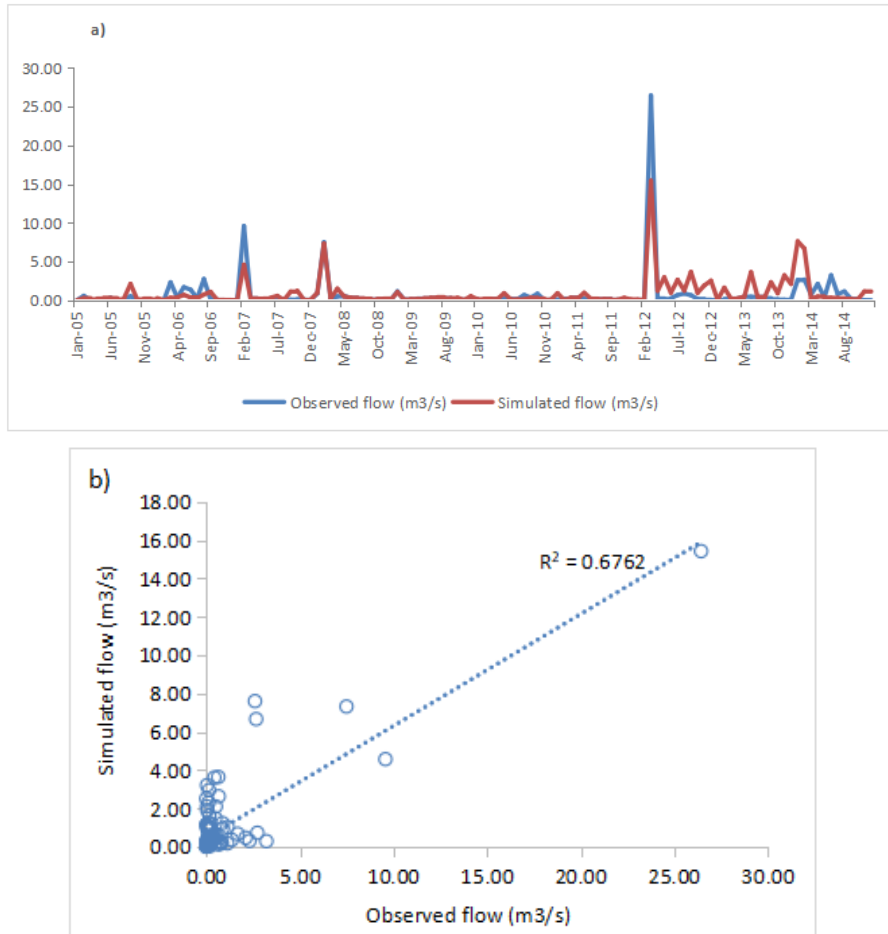


Fig. 4. SWAT model flow simulation during validation (2005-2014) at monthly scale: a) Time series plot; b) Scatter

Consequently, The SWAT model performance can be classified as reasonable in capturing the hydrological rhythm of the Saida watershed but the quantitative results should be interpreted with caution, especially for the earlier period. Moreover, data scarcity and climatic variability pose challenges to hydrological simulations in semi-arid area (Abbaspour, 2015; Khaleghi and Hosseini, 2024; Ouallali et al., 2020). In addition, the calibrated model therefore provides a satisfactory basis for exploring the direction and relative magnitude of LULC induced changes in hydrological response. but the quantitative results should be viewed in light of the documented bias and structural uncertainties. Uncertainties also arise from the limited density of rainfall stations (four gauges) and the use of interpolated gridded temperature data, as well as from errors potentially introduced by DEM processing and land-cover classification. These factors may affect both the timing and magnitude of simulated flows, and they constrain the confidence with which the model can represent extreme events and small-scale spatial variability within the watershed.

LULC change analysis

Analysis of LULC dynamics for the years 1985, 2000, and 2014 revealed pronounced changes in land-use composition (Fig. 5; Table 6). Built-up areas increased progressively from 96.66 km² (1985) to 115.31 km² (2014), indicating mounting urbanization pressures proximal to Saida city and the migration of the rural populations to the neighboring towns such as Sidi Amar and Sidi Boubaker.

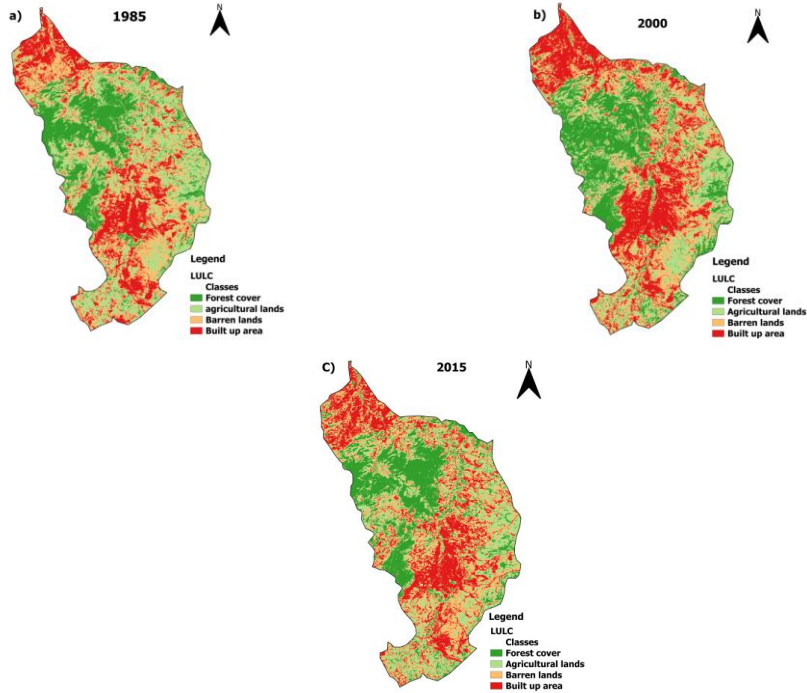


Fig. 5. LULC for the reference years of 1985, 2000 and 2014

The most substantial expansion was observed in barren land, which increased by 58.42 km², driven by deforestation and agricultural abandonment processes that favour erosion and land degradation. Contrastingly, agricultural lands decreased considerably from 143.85 km² to 98.18 km², while vegetative cover declined moderately from 224.5 km² to 193.1 km².

Table 6. Areas classes change from year 1985-2014

LULC Classes	Scenario 1985	Scenario 2000	Scenario 2014
	Area (km ²)		
Built up land	96.66	100.95	115.31
Barren land	151.54	158.92	209.96
Vegetation cover	224.5	223.66	193.1
Agriculture land	143.85	133.02	98.18

These transitions signify a shift from vegetated and agricultural land toward more barren and urban surfaces, a pattern widely documented in semi-arid Mediterranean environments (Belay and Mengistu, 2019; Dinka and Chaka, 2019; Jahanshahi et al., 2025). Such land cover changes typically alter evapotranspiration regimes and increase runoff volumes.

The sharp decline in cropland is especially significant since agricultural areas function as infiltration buffers; their conversion to barren or built-up land increases imperviousness, reduces soil moisture retention, and intensifies runoff generation (Peng and Wang, 2012).

Impact of LULC on water yield

Using the calibrated SWAT model, water yield, defined here as the sum of surface runoff, lateral flow, and groundwater contribution to the stream, was simulated for LULC conditions representative of 1985, 2000, and 2014. The results of the water yield simulation under different scenarios of LULC at a monthly scale are given in Figure 6.

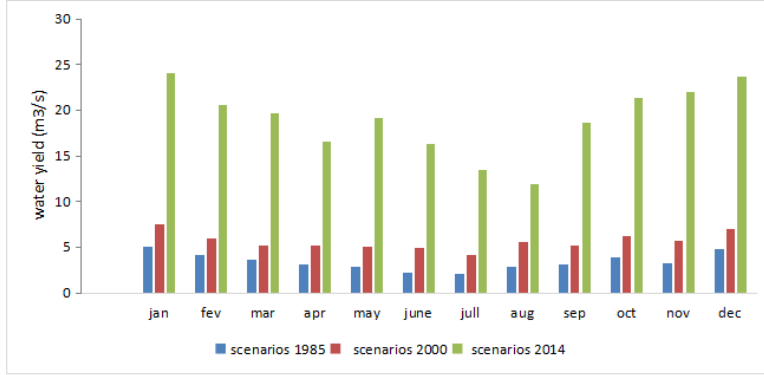


Fig. 6. Monthly average water yield over the years 1985, 2000 and 2014

The simulations indicate an overall increase in monthly water yield over the study period. The 2014 scenario produced higher simulated flows compared to the 1985 scenario in most months (Fig.6). For example, the average water yield in January increased from 5.12 m³/s for the 1985 LULC scenario to 24.11 m³/s for the 2014 LULC scenario, while May values rose from 2.81 m³/s to 19.21 m³/s under the same scenarios.

These differences reflect the expansion of barren and built-up areas while agricultural and vegetated lands are declined. This lead to more runoff and less evapotranspiration. However, because the model also incorporates temporal climatic data inputs, the increase in water yield is due to both land cover changes and interannual variability in precipitation and temperature. Given the positive bias during calibration, the magnitude of the simulated increase in water yield should be interpreted cautiously, focusing on trends rather than absolute values.

The model also shows that moderately permeable soils with carbonate layers favor initial infiltration, but can slow deeper percolation, causing perched water and more runoff during intense events. This is shown in simulated peaks during events such as February 2007, January 2008, and February 2012 (Figure 6). Groundwater parameters indicate a delayed but persistent contribution to streamflow, which supports sustaining baseflow during dry periods across all scenarios. Thus, these results highlight the complex trade-off of LULC change in semi-arid watersheds: immediate gains in water yield are counterbalanced by potential long-term vulnerabilities related to aquifer depletion and decreased hydrological resilience (Aragaw and Kura, 2024; Hachemaoui et al., 2022).

Overall, the findings indicate that the evolution of barren and urban surfaces tends to increase runoff-driven water yield in the Saida watershed. These outcomes align with previous

findings from Mediterranean semi-arid catchments, where deforestation and urban development result in heightened runoff and peak flow magnitudes (Khaleghi, 2017; Yan et al., 2018).

The results are most robust when used for comparing scenarios and identifying general trends, rather than for exact planning for water resources or flood risk assessment.

Conclusion

This study used the SWAT model to examine how three decades of LULC change have influenced the hydrological response of the Saida watershed between 1985 and 2014. The model was calibrated and validated using monthly streamflow data and performance metrics (R^2 , NSE, PBIAS) that indicate an acceptable reproduction of overall variability, but also reveal a notable positive bias during the calibration period, that must be considered when interpreting absolute flow values. The LULC analysis showed a pronounced shift from agricultural and vegetated areas toward increased barren and built-up land, which the simulations associate with higher runoff-dominated water yield and modified seasonal flow patterns. These results support the view that LULC change is an important driver of hydrological behaviour in this semi-arid basin; however, the magnitude of simulated changes reflects the combined effects of land-cover evolution, climatic variability, and model uncertainties. Uncertainties arise from the limited density of hydro-meteorological observations, the use of interpolated climatic data, and potential classification errors in the multi-sensor LULC maps, as well as from the structural and parametric limitations of SWAT. Consequently, the findings are most robust for assessing the direction and relative magnitude of hydrological changes between LULC scenarios, rather than for providing precise design values. From a management perspective, the results highlight the need to consider both land degradation (expansion of barren areas) and urban growth when planning water resources and soil conservation measures in the Saida watershed, and they suggest that scenario-based analyses combining LULC and climate projections would be a useful next step to support long-term adaptation strategies.

Conflicts of Interest: The authors declare no conflict of interest.

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