Water Balance Estimation in Semiarid Mediterranean Watersheds Using SWAT Model

Yassine Bouslihim, Aicha Rochdi, and Namira El Amrani Pazza

Abstract The objective of this paper is to test the feasibility of using the SWAT model with limited availability of data. We also aim to estimate the water balance in two adjacent watersheds, Mazer is gauged and El Himer is ungauged, measuring an area of 179.2 km^2 and 177.7 km^2, respectively. The SWAT model was calibrated and validated at the gauged watershed and all calibrated parameters were adopted for the ungauged watershed. The obtained values for NSE and R^2 show the presence of a significant correlation and results of calibration and validation period can be considered acceptable. Water balance results show a significant contribution of surface runoff in water yield and demonstrate that evapotranspiration causes significant losses in this type of climate.

Keywords Water balance · SWAT model · Ungauged watershed

1 Introduction

Water plays a crucial role in every community, given the socio-economic and environmental importance of water resources. Therefore, it is very important to preserve it. Scientific research plays a major role in the provision of useful information to water-related decision-making.

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Nowadays, hydrological models have become indispensable tools to water estimation and management sector [6].

These models require a large number of data input, especially to operate highly parameterized models such as SWAT, thus making it difficult to carry out of hydrological studies under certain conditions of limited data availability. Thus, it is urgent to deal with cases of limited data.

In this paper, we present the case of an ungauged watershed (El Himer) with limited availability of runoff and rainfall data and the relevant soil information. To overcome these limitations, we used a regionalization method and adopted data from the neighboring Mazer watershed.

The model was calibrated and validated at Mazer watershed and all calibrated parameters were used to estimate the different components of the hydrologic cycles.

2 Materials and Methods

2.1 Study Area

Mazer (179.2 km^2) and El Himer (177.7 km^2) watersheds belong to Settat-Ben Ahmed plateau, Chaouia Morocco (Fig. 1). The climate is Mediterranean semiarid,

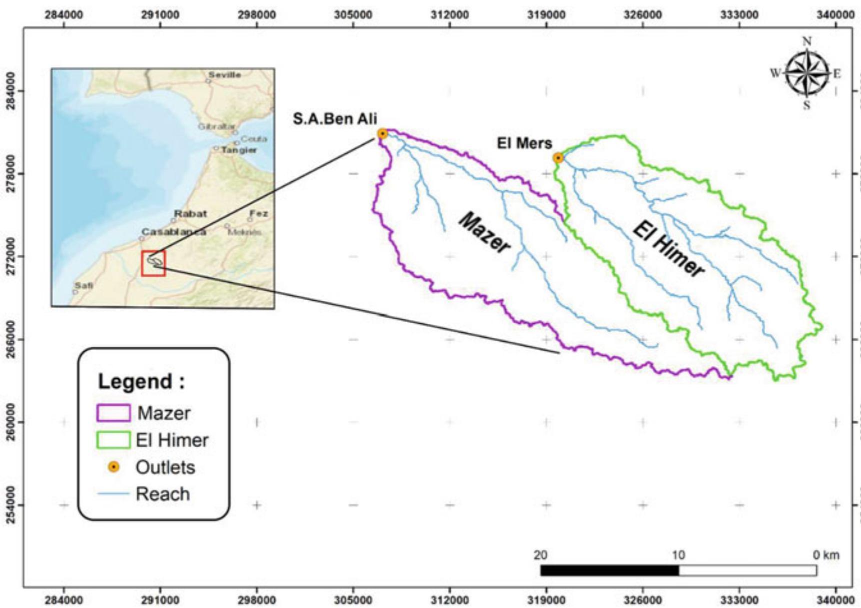

Fig. 1 Location of El Himer and Mazer watersheds

with low precipitation (280–320 mm/year) and a mean annual temperature of around 17 °C [1].

2.2 Required Data for SWAT Model

SWAT (Soil and Water Assessment Tool) is a physically based and semi-distributed parameter. It's a watershed and continuous scale developed for the USDA Agricultural Research Service (ARS) [4]. It has a simple, easy-to-use GIS interface. For a model setup such as The DEM (Digital elevation model), a wide diversity of data about soil, land use, and climate, are required.

The DEM was obtained from ASTER-GDEM2 with a resolution of 30 m.

Land use was generated from Landsat-6 satellite image using the supervised classification with ArcGIS software.

Soil map: SWAT model requires several soil parameters (Table 1). Thus, several soil analyses were carried out in order to complete the soil database by combining them with soil map produced by the Ministry of Agriculture and the Hassan II Agricultural and Veterinary Institute (IAV) in 1985.

Daily runoff and rainfall for Mazer watershed were obtained from the Hydraulic Basin Agency of Bouregreg and Chaouia (ABHBC). All other parameters such as temperature, wind speed, relative humidity, and solar radiation were extracted from the NCEP Climate Forecast System Reanalysis (CFSR) [2]

Table 1 Soil input parameters for SWAT Model

Parameter	Description	Unit
HYDGRP	Soil hydrological group	–
SOL-Z	Depth from the soil surface to bottom of layer	mm
SOL_BD	Moist bulk density	$g \cdot cm^{-3}$
SOL_AWC	Available water capacity of the soil layer	mm $H_2O \cdot mm^{-1}$ sol
SOL_K	Saturated hydraulic conductivity	$mm \cdot hr^{-1}$
SOL_CBN	Organic carbon content	% of soil weight
SOL_CLAY	Clay content	% of soil weight
SOL_SILT	Silt content	% of soil weight
SOL_SAND	Sand content	% of soil weight
ROCK	Rock fragment content	% of total weight
SAL_ALB	Moist soil albedo	–
USLE_K	USLE equation soil erodibility (K) factor	0.013 metric ton m^2 hr/ (m^3—metric ton cm)
SOL_EC	Electrical conductivity	$dS \cdot m^{-1}$

2.3 Methodology and Simulation Information

After the configuration of the model, the watershed delimitation and the insertion of various data are necessary to create the HRUs. The model was calibrated over a three-year period (1998–2000) and prior to that a 3-year period was used as a warm-up (1995–1997) and the subsequent 2 years were a validation period (2001–2002) at the Mazer watershed.

The SWAT-CUP was used to select the most sensitive parameters which were used for model calibration at Mazer watershed and to predict the runoff at the ungauged watershed (El Himer). This method is known as regionalization. More specifically, the physical proximity approach was selected in the current study. The concept of this approach is to transfer hydrological model parameters from the gauged basin (Mazer) to the ungauged basin (El Himer) according to the similarity of their physical attributes, the rationale being that catchments with similar attributes should behave similarly [5].

The performance of calibration and validation periods of SWAT model was evaluated using the coefficient of determination (R^2, Eq. (1)) and Nash–Sutcliffe Efficiency (NSE, Eq. (2)) [3].

$$R^2 = \left[\frac{n \sum Q_{obs(i)} Q_{sim(i)} - \left(\sum Q_{obs(i)}\right)\left(\sum Q_{sim(i)}\right)}{\sqrt{\left[n(\sum Q_{obs(i)}{}^2) - (\sum Q_{obs(i)}{}^2)\right]\left[n(\sum Q_{sim(i)}{}^2) - (\sum Q_{sim(i)}{}^2)\right]}} \right]^2 \quad (1)$$

$$NSE = 1 - \frac{\sum_{i=1}^{n} (Q_{obs(i)} - Q_{sim(i)})^2}{\sum_{i=1}^{n} (Q_{obs(i)} - \bar{Q}_{obs(i)})^2} \quad (2)$$

3 Results and Discussion

3.1 Sensitivity Analysis

The SUFI-2 tool included in SWAT-CUP was used for sensitivity analysis and for model calibration at Mazer watershed. Seven parameters were found to be the most sensitive and all these parameters are given in Table 2 with their initial and fitted value.

Table 2 The sensitivity parameters and their fitted value

Parameter Names	Rank	Initial range	Fitted value
R__SOL_AWC	1	(−0.5, 0.5)	0.45
V__DEP_IMP	2	(0, 6000)	3319.25
V_LAT_TIME	3	(0, 180)	59.03
V__DDRAIN_BSN	4	(0, 3000)	2090.12
R_CN2	5	(−0.5, 0.5)	0.016
V__SLSUBBSN	6	(10, 150)	76.11
V_ALPHA_BF	7	(0, 1)	0.14

3.2 Calibration and Validation of SWAT Model for Mazer Watershed

The most sensitive parameters were used to calibrate the SWAT model on a monthly time step at Mazer watershed. Figure 2 shows the monthly comparisons of measured and simulated streamflow for the calibration and validation periods. Table 3 summa-

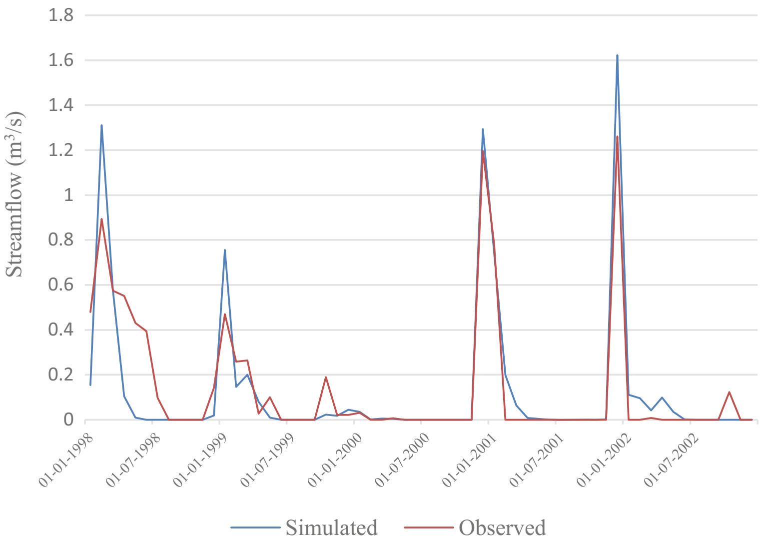

Fig. 2 Observed and simulated monthly streamflow for model calibration (1998–2000) and validation (2001–2002) at Mazer watershed

Table 3 The values of statistical indicators in the calibration period 1998–2000 and the validation period 2001–2002

	R^2	NSE
Calibration	0.75	0.65
Validation	0.95	0.89

Table 4 Average annual water balance components for the entire watershed

Water balance component (mm)	Mazer	El Himer
Precipitation	198.8	219.2
Surface runoff	14.2	20.7
Lateral flow	2.8	2.2
Return flow	6.3	18
Evaporation	155.6	145.2

rizes the results of statistical comparison between the simulated and the observed streamflow. The analysis shows the presence of a significant correlation and the results of calibration and validation period can be considered acceptable, with values of over 0.65 and 0.75 for NSE and R^2, respectively.

3.3 Water Yield and Water Balance

The comparison between Mazer and El Himer watersheds shows that their characteristics are nearly similar. Their outlets are very close to each other, with a distance that does not exceed 12 km, with the same dominant types of soil and land cover. Consequently, the seven sensitive parameters can be used to simulate the water balance at El Himer watershed, considering that both watersheds respond in the same way.

The model was simulated for a period of 5 years (the calibration and validation periods) to estimate the average annual basin values for the different water balance components. All results are reported in Table 4. In both watersheds, the contribution of surface runoff in water yield simulation was more significant than that of lateral flow and return flow. Therefore, evapotranspiration played an important role in causing water loss.

4 Conclusions

This study concentrates on the estimation of water yield and water balance in an ungauged watershed using regionalization method and SWAT model, based on the information of a neighbor-gauged watershed. The model was calibrated and validated at the gauged watershed (Mazer) and all their calibrated parameters were transferred to the ungauged watershed (El Himer). Unfortunately, the data needed to confirm the obtained results of hydrologic cycle are not available, that is why we can consider the model as a prospective tool for hydrological simulation on ungauged watersheds. Future research must thus focus on climate change studies, in order to use these results to assess the reliability of different projections of climate change impacts in the ungauged watershed.

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