



Modelling the impact of soil and water conservation structures at various scales in Tunisian semi-arid region

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Abstract

In central-northern Tunisia, a combination of dryness, erratic rainfalls, and the undulating terrain create an erosion-prone environment. Soil and water conservation (SWC) measures have been widely applied to reduce the losses of water and top-soil from agricultural fields and thereby increase crop-production and the rural communities' livelihoods. However, the impacts of various SWC interventions are interrelated and difficult to predict. The objective of this study is to evaluate the impacts of Bench Terraces (BTs), in combination with small scale reservoirs (Hill Lakes (HLs)), on runoff and erosion using the Soil and Water Assessment Tool (SWAT) across semi-arid environments of Tunisia. Development and testing of the BT parameter set was performed using monthly surface runoff and multiple bathymetric sediment measurements obtained from the HLs of small BT-treated catchments (< 20 km²). The established Bench Terraces (BTs) parameter set was applied to the Rmel watershed (675 km²) to eventually test the parameters' performance at the integrated landscape level. SWAT simulation using the defined BT parameter set and 'pond' approaches for the scattered HLs across Rmel produced a 'good' modelling performance indicated by NSE values of 0.89 and 0.91 during calibration and validation. A combination of BTs and HLs overall reduced runoff and sediment yield by 33% and 17% respectively. The Rmel case study demonstrates the robustness of the BT parameter-set obtained from small and quasi-homogeneous training catchments. The enhanced knowledge about SWC impacts, and its consideration in modelling (across scales), will eventually support planning and management in Tunisia's dry and degradation-prone landscapes.

Keywords Watershed · SWAT · Surface runoff · Erosion · Dry areas

Introduction

Around two-thirds of Tunisia is exposed to arid and semi-arid climatic conditions with a distinct winter-rainy season and an erratic Mediterranean rainfall regime. Tunisia's water

resources are both scarce and vulnerable to degradation through natural and anthropogenic causes including climate change. Water scarcity and droughts challenge the country's agricultural production; at the same time, the declining water retention and infiltration capacities of degraded soils speed up surface runoff and the occurrence of flash floods (de la Paix et al. 2013). The evolving surface erosion features (e.g. gullies) create drainage networks, which abruptly concentrate and route the excess rainwater from the watersheds (Strohmeier et al. 2017; Oweis 2017). The consequential erosion and loss of arable lands (Verner et al. 2018), overlaid with the increasing dryness, threaten the rural farming communities' production base.

A wide range of location-specific sustainable land management (SLM) practices, including soil and water conservation (SWC) measures, have been established across the global drylands that increase the resilience of rural farmers to degradation and climate change (Mirzabaev et al. 2019). Since millennia, terracing is among the most common interventions aiming at conserving soil and water in agriculture

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(Hooke 2006). In Tunisia, the so-called Bench Terraces (BTs) and small-scale reservoirs, specified as ‘Hill Lakes’ (HLs), are widely applied practices to retain surface runoff and sediments in the semi-arid landscapes and thereby enhance the agricultural production. Important large-scale SWC implementation initiatives in Tunisia were launched in the 1990s (Boufaroua et al. 2013; Ministry of Agriculture 2014); various positive implications of both Bench Terraces and Hill Lakes have been intensively elaborated and discussed through the research conducted by e.g. Talineau et al. (1994), Cherif et al. (1995), and Nasri (2007). Among other initiatives, Ben Khelifa et al. (2017, 2021) established small to medium scale catchment (hydrological) models evaluating the impacts of Bench Terraces on soil and water dynamics. However, the application of spatially distributed and diverse SWC interventions within the heterogeneous landscape ($> 10^2\text{km}^2$) is complex and hard to predict.

A proper parameterization of different SWC interventions and their consistent implementation and consideration in large scale models are key for sustainable land management planning. Sound hydrological modelling supports the ex ante impact assessment of water harvesting techniques prior implementation which allows e.g. the conduction of cost–benefit analyses and large-scale trade-off assessment of planned interventions, eventually serving the proper decision making.

Bench Terraces have been well studied in the field (Roose 2002; Nasri 2007) and through modelling (Al Ali et al. 2008; Ben Khelifa et al. 2017). However, their outscaling is still challenging because of the heterogeneity of the rugged Tunisian watersheds (Ben Khelifa et al. 2021) and the superposition and interrelation with other landscape assets (e.g. forests and rangelands) and according management-interventions. The present research follows the modelling methodology applied in previous studies by Ben Khelifa et al. (2017) and Ben Khelifa et al. (2021), particularly verifying the applicability of an obtained and robust Bench Terrace parameter set (BTPS). The Soil and Water Assessment Tool (SWAT) (Arnold et al. 1998, 2012) was applied to align with the previous studies pursued in similar context and environment (Ben Khelifa et al. 2021; Mosbahi and Benabdallah 2020; Ben Khelifa et al. 2017) and, thus, to further build on and benefit from the acknowledged SWAT modelling routines and parameter sets developed. This research particularly facilitates and combines the knowledge gained from a small and quasi-homogenously Bench Terraced sub-watershed (Sbaihia sub-watershed study; Ben Khelifa et al. 2017) and a medium-large sub-watershed (El Gouazine).

This research eventually tackles both (i) the performance evaluation of the BTPS developed through previous studies at enhanced scale and landscape complexity level and (ii) the assessment of BT impacts in space and time distributed

across a representative and heterogenic watershed in semi-arid Tunisia.

Material and methods

Scaling methodology and target sites description

Scaling methodology

This research tests the readiness of SWC parameterization for scaling through modelling, from small and quasi-homogeneous catchments to the integrated watershed level. The study primarily targets the 675 km² Rmel watershed, located within Tunisia’s north-eastern semi-arid region, including several sub-watersheds with various extent Bench Terraces (BTs) treatment and Hill Lakes (HLs) at their individual outlets. In previous research, conducted by Ben Khelifa et al. (2017), the small and quasi-homogeneous Sbaihia catchment was used to develop and calibrate a Bench Terrace parameter set (BTPS); secondly, a satellite sub-watershed (El Gouazine) with similar context but larger spatial heterogeneity (Fig. 1) was used for validation (Ben Khelifa et al. 2021). The present study’s target watershed (Rmel) hydrological model is based on—and tests—the BTPS transferred from previous studies. The study’s target watershed (Rmel), as well as the reference sub-watersheds (Sbaihia; El Gouazine), are representatively located within the semi-arid rainfed agricultural production zone of Tunisia and thus reflect on the potential out-scale ability of BTs within the concerned production system.

Target watershed description

Rmel watershed The Rmel watershed is located in the north-east of Tunisia between 36° 32.0.9' and 36° 14.20' Latitude North and between 10° 13.47' and 10° 13.4' Longitude East. It has a rugged and irregular terrain ranging from 20 to 1235 m above sea level (Fig. 1). The watershed covers an area of 675 km² and drains into the Rmel dam, established in 1998 (Ben Khelifa et al. 2017). The maximum monthly temperature, recorded during July and August months, exceeds 35 °C, while the minimum monthly temperatures (January and February) are around 7 °C. Average annual evaporation from the Rmel dam (time period: 1999 to 2019) is 1710 mm. The spatial variability of rainfall indicates an irregular distribution of rainfall across the Rmel watershed (Fig. 2). The north-eastern part (upstream) receives the largest average annual rainfall amounts (490 to 513 mm), whereas the south (downstream) is drier with an average annual rainfall below 400 mm.

Research conducted by Ben Ayed (1966) and Attia et al. (2004) identified ten soil types across the Rmel study area

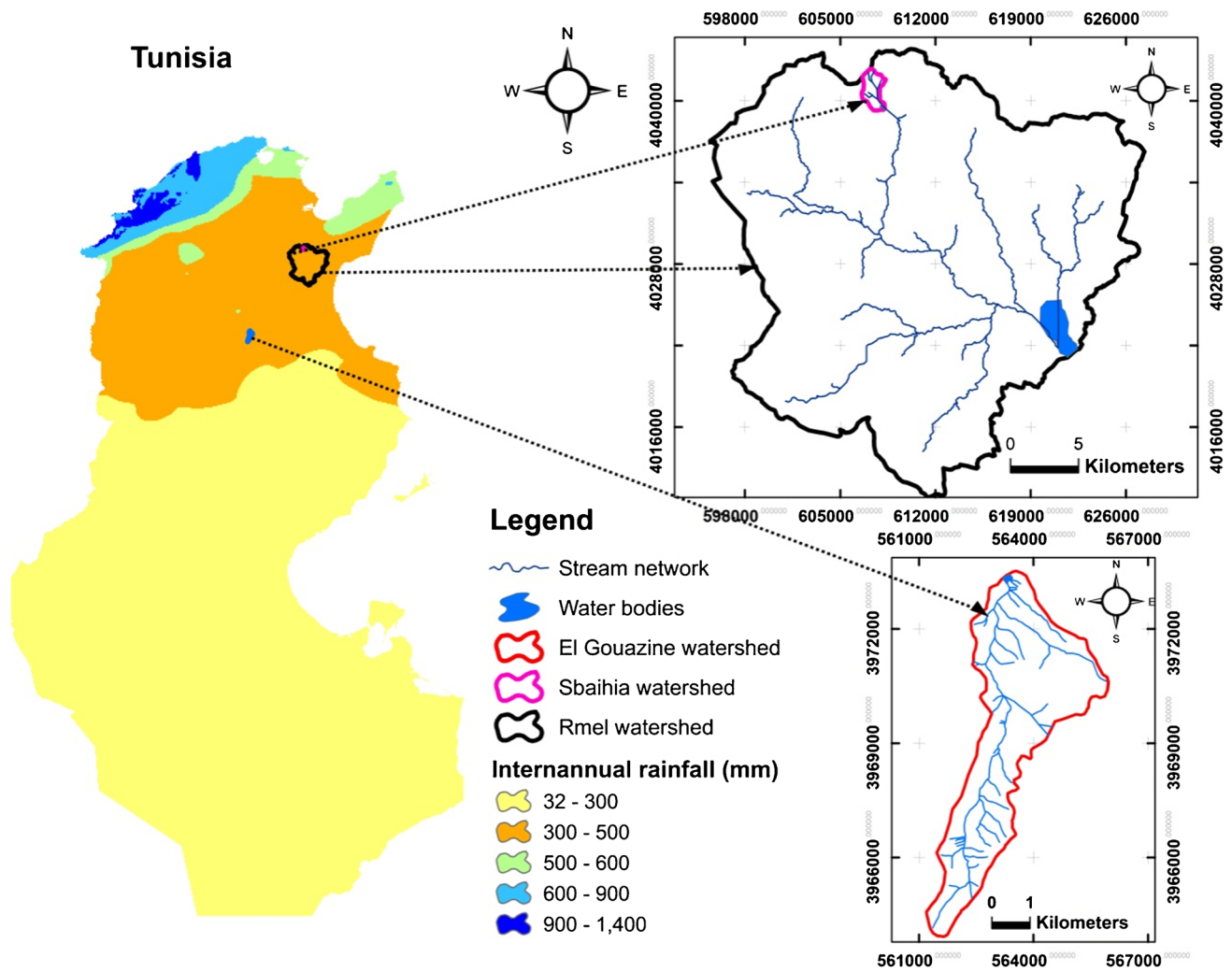


Fig. 1 Location of the studies area

using the Commission de Pédologie et de Cartographie des Sols (CPCS) (1967) classification system; the soils have slow infiltration rate characteristics which are assigned to dual hydrologic soil groups C and D (USDA-SCS 1972).

The Rmel watershed’s surface cover and land use characteristics, shown in Fig. 3, were investigated for the target time-period of the modelling study (1997–2011); Google Earth satellite images from 2005 and several field visits concluded that agricultural areas (predominately wheat and olives groves) cover around 62%. Forest with a varying degree of degradation covers around 20% of the watershed, predominately in the mountainous areas. The remaining areas are shrubland (12%) and barren (2.5%) as well as minor urban and water covered areas (3.5%).

Sbaihia sub-watershed Sbaihia is a sub-watershed located in the upper north-eastern part of the Rmel watershed, with a catchment area of 3.2 km² (Fig. 3). Its altitude ranges

between 227 and 426 m above sea level. The catchments’ surface runoff and sediment yield have been monitored since 1993. Sbaihia is largely treated by Bench Terraces (> 50% of the total area).

El Gouazine watershed El Gouazine catchment is a satellite study site to Rmel watershed (Fig. 1). El Gouazine catchment is 16.5 km², and its elevation ranges from 378 to 571 m above sea level. The outlet (Hill Lake) is part of the hydrological and bathymetric survey network established in 1993. Between July 1996 and July 1997 a large extent of El Gouazine watershed area (36%) was treated by Bench Terraces (Ben Khelifa et al. 2021).

SWC interventions

Since the 1980s, the Rmel watershed has been treated by several SWC practices including the most dominant Bench

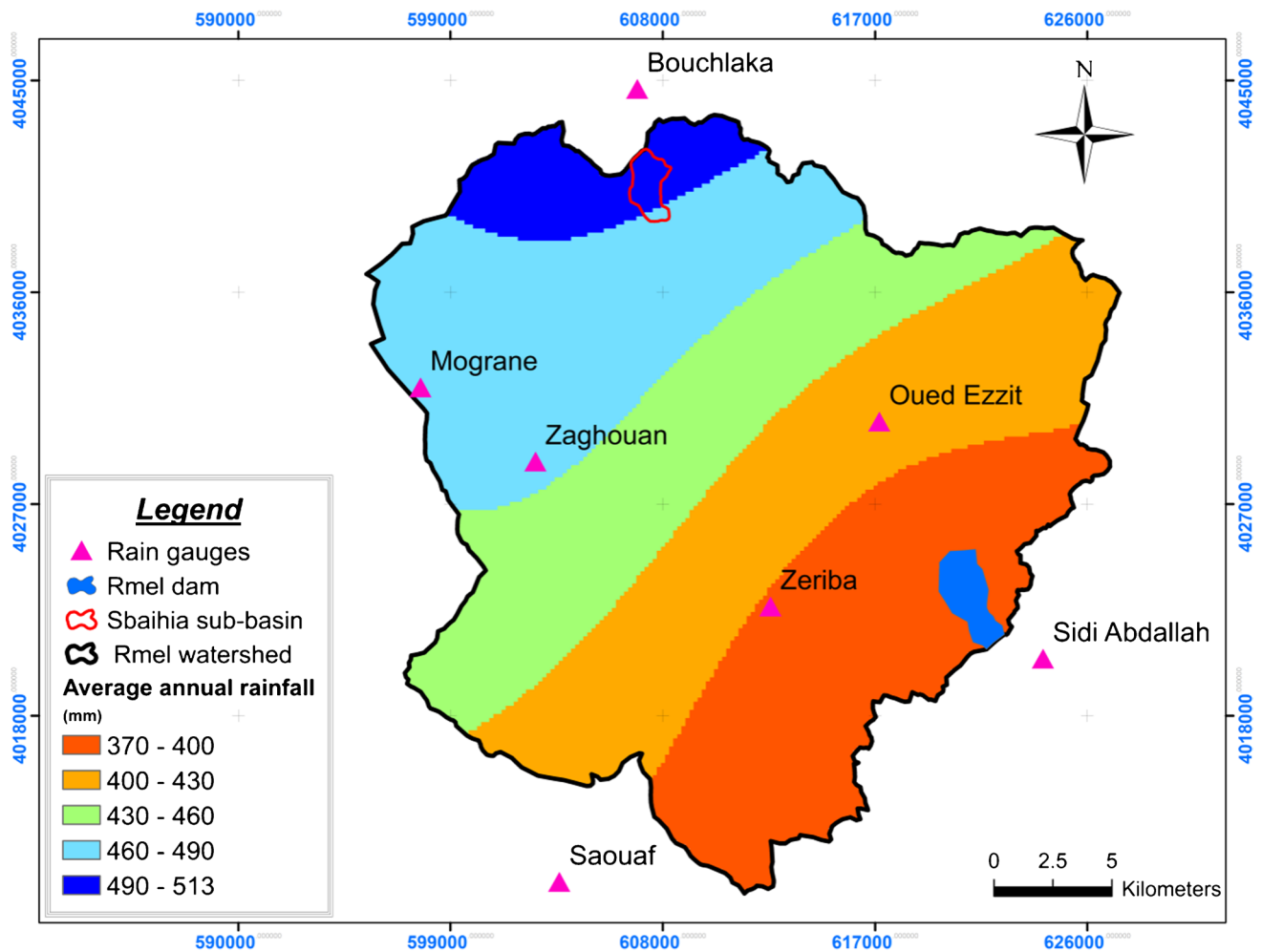


Fig. 2 Spatial distribution of rainfall in the Rmel watershed

Terraces and Hill Lakes. In total, 25 HLs were implemented across Rmel watershed storing around 2.8 million m³ of surface water. In the meantime, around 34% of their initial capacities are lost due to sedimentation (ONAGRI 2019). HLs are designed to serve for surface water collection for subsequent (supplemental) irrigation in proximate areas as described by Boufaroua et al. (2013). In the sloping uplands, Benches Terraces were implemented in the agricultural areas mostly covered by wheat and olives orchards. BTs are earth embankments along the contour lines of a terrain with the aim to intercept, store, and foster the infiltration of runoff (Ben Khelifa et al. 2017). Other techniques, i.e. the dry Stone Cords, are implemented to a minor/local extent and have comparable functionality as the Bench Terraces; they consist of low dry stone walls in one, two, or three rows along the contour of the slope. They are often applied in steep upstream areas of the watershed where the vegetation cover is sparse or absent and runoff concentration is rapid. Their essential role is to decelerate runoff generation and its

erosion capability. However, their areal coverage and potential impact on Rmel watershed hydrology is minor.

Hydrological modelling using SWAT

SWAT model description

SWAT (Arnold et al. 1998, 2012) is a semi-distributed model with a daily time step computation, capable to simulate the hydrological cycle processes at various spatial scales. SWAT requires spatially referenced input data on terrain, soil, land cover, and land use as well as spatio-temporal weather information. In this study, the following inputs were used:

- Daily precipitation obtained from local rain gauge stations during the period 1997–2011 (DGRE).
- Climatic data including relative humidity, air temperature, solar radiation, and wind speed, provided by the

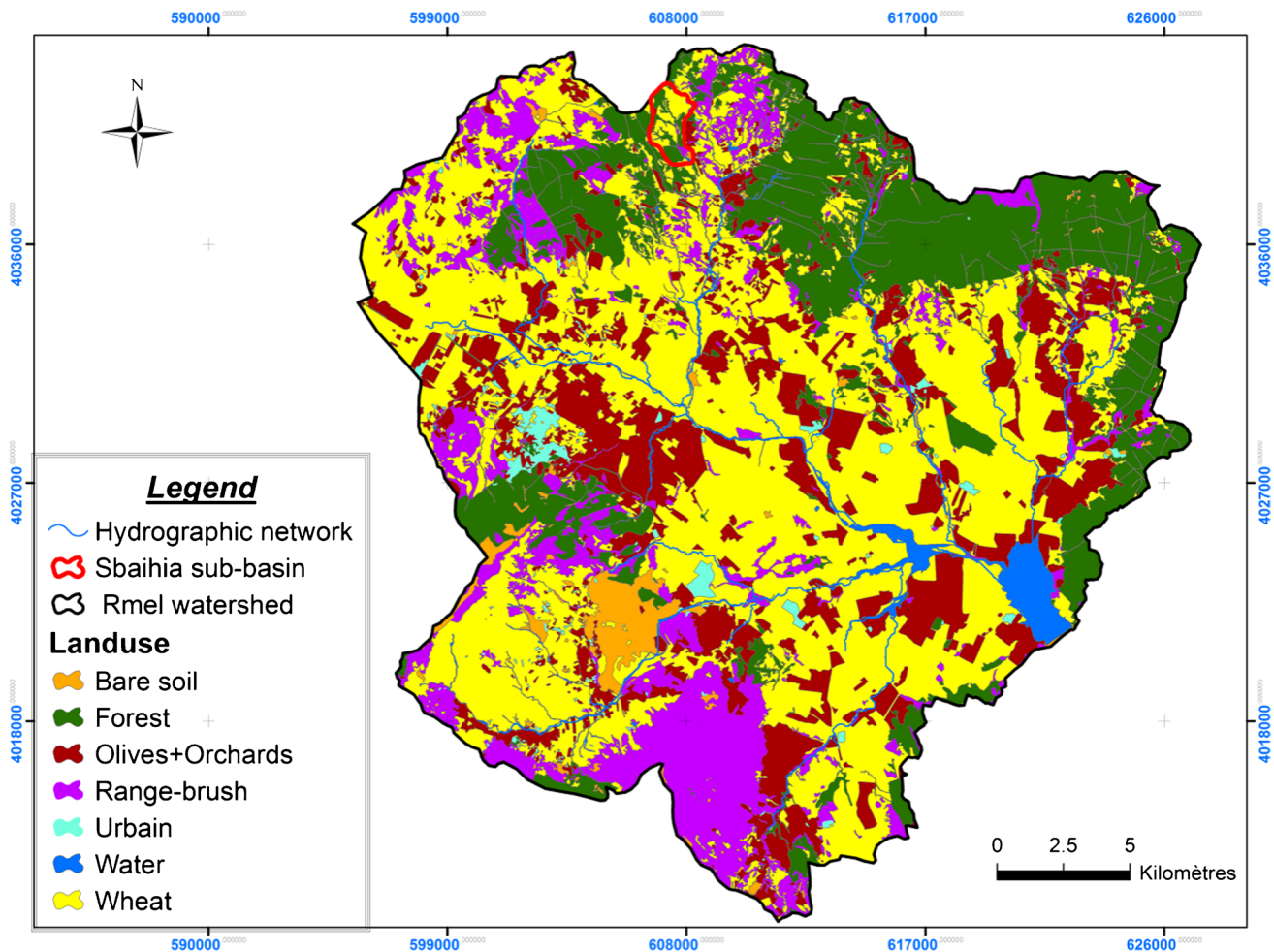


Fig. 3 Land use map of Rmel watershed in 2005

National Environmental Prediction Center (NCEP) for the period 1979–2014 (National Environmental Prediction Center (NCEP) 2014).

- Digital Elevation Model of the Aster (Advanced Spaceborne Thermal Emission and Reflection Radiometer) GDEM (Global Digital Elevation Model) with a 30 m spatial resolution.
- Soil map was deduced from the local agriculture map and existing soil profiles.
- Land cover map was created using Google Earth satellite imagery (year 2005) and field visits. The validation of the Google Earth images classification led to satisfactory results with an overall accuracy of 94% and a Kappa index of 0.93; land use/management was defined based on local knowledge (e.g. conventional agricultural operations).

Watershed boundaries, stream network, and sub-watershed creation are controlled by the GDEM input. The SWAT project was set up considering the subdivision into

sub-watersheds that are further sub-divided into Hydrologic Response Units (HRUs), representing homogeneous slope steepness and land use and soil characteristics. In this research, the Soil Conservation Service (SCS) Curve Number (CN) method (USDA-SCS 1972) was used for surface runoff computation. The simulated runoff is routed through the channel network using variable storage routing method (Williams 1969). Sediment yield is calculated at the HRU level using the Modified Universal Soil Loss Equation (MUSLE; Williams and Berndt 1977).

The SWAT-CUP algorithm (SWAT Calibration and Uncertainty Procedures) developed by Abbaspour et al. (2007) was set up for the calibration and validation processes based on the SUFI-II calibration algorithm (Abbaspour et al. 2007) to assure consistency with the modelling procedure used by Ben Khelifa et al. (2017, 2021). This study used two common statistical parameters for model performance assessment (Moriassi et al. 2015) of monthly runoff values obtained from the Rmel outlet (dam) gauging station: (i) Nash–Sutcliffe efficiency (NSE) (NSE; Nash and Sutcliffe

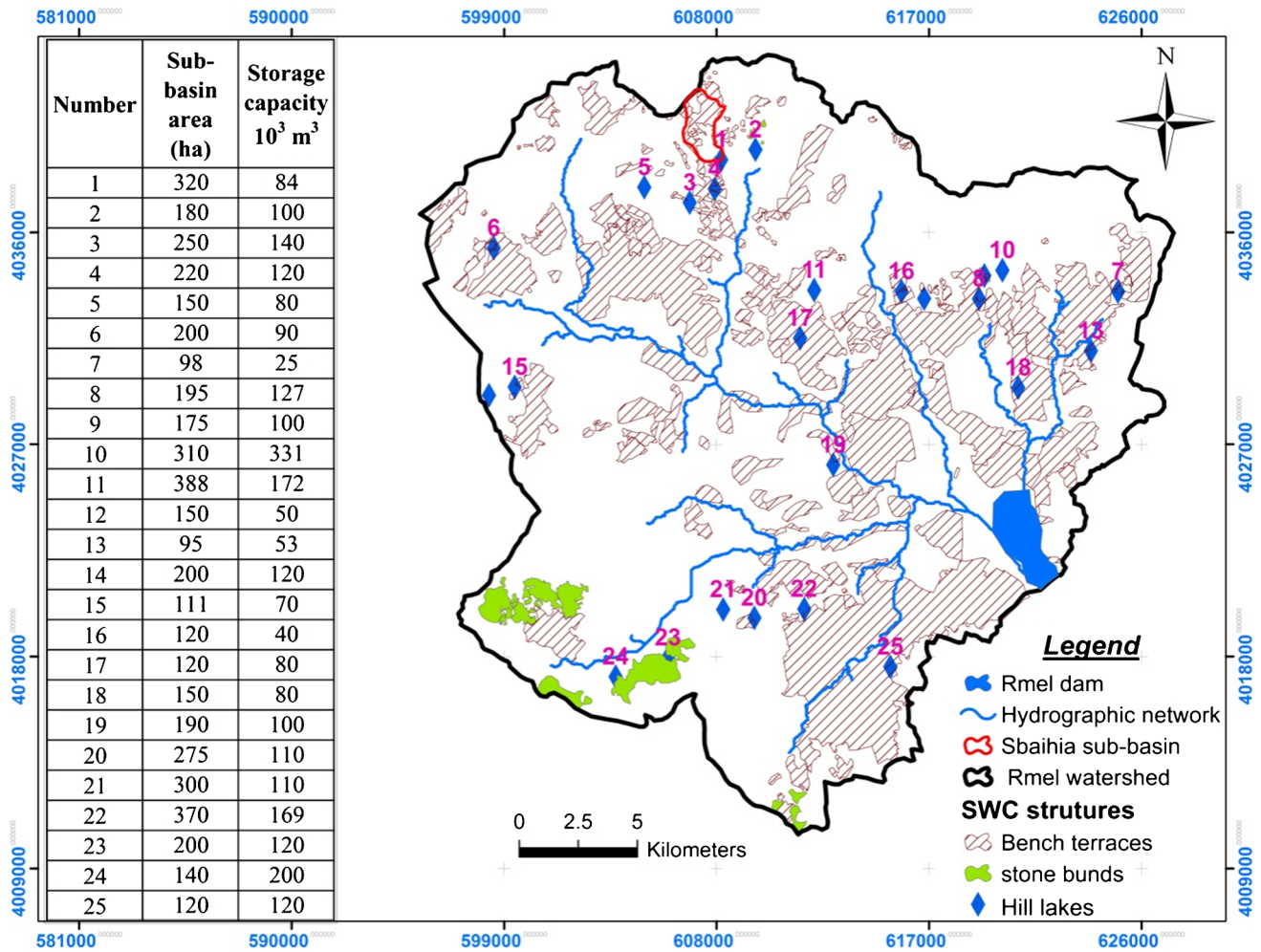


Fig. 4 Spatial distribution of Soil and Water conservation structures in Rmel watershed

1970), considered a robust indicator to evaluate the simulation’s ‘goodness of fit’, and (ii) PBIAS, for identifying the simulation’s bias.

$$NSE = 1 - \frac{\frac{1}{N} \sum (Q_{sim}(t) - Q_{obs}(t))^2}{\sum (Q_{obs}(t) - \bar{Q}_{obs}(t))^2} \tag{1}$$

where NSE is a Nash–Sutcliffe Efficiency; Q_{sim} is simulated discharge (m^3s^{-1}); Q_{obs} is observed discharge; \bar{Q}_{obs} average observed discharge is the number of values; t is the time step; and N is the number of observations.

$$PBIAS = \left[\frac{\sum_{i=1}^n (Q_{sim}(t) - Q_{obs}(t))}{\sum_{i=1}^n Q_{obs}(t)} * 100 \right] \tag{2}$$

SWC considerations in SWAT

A robust BTPS developed by Ben Khelifa et al. (2017; Sbaihia catchment modelling campaign) identifies the best-fit modifications of the curve number (CN), slope length (SL), and the support practice factor (P), to describe BT impacts on surface runoff and erosion. In this study, the calibrated ‘Sbaihia BTPS’ values (CN; SL; P) were directly transferred into the Rmel model using SWAT. Bench Terraces retain surface runoff, which directly affects the SCS-CN. Moreover, through intermitted structures along the contours of the hill slopes, BTs reduce slope length (SL) and retain sediments at the BTs (P_USLE). Besides the BT structure impacts, the vulnerability to soil erosion is also affected by the land cover factor (C_USLE; Collinet and Zante 2002) and the soil erodibility factor (K_USLE; Ben Ayed 1966).

Hill Lakes were considered ‘ponds’ in the SWAT model. The Tunisian HLs are usually not overflowed (they collect

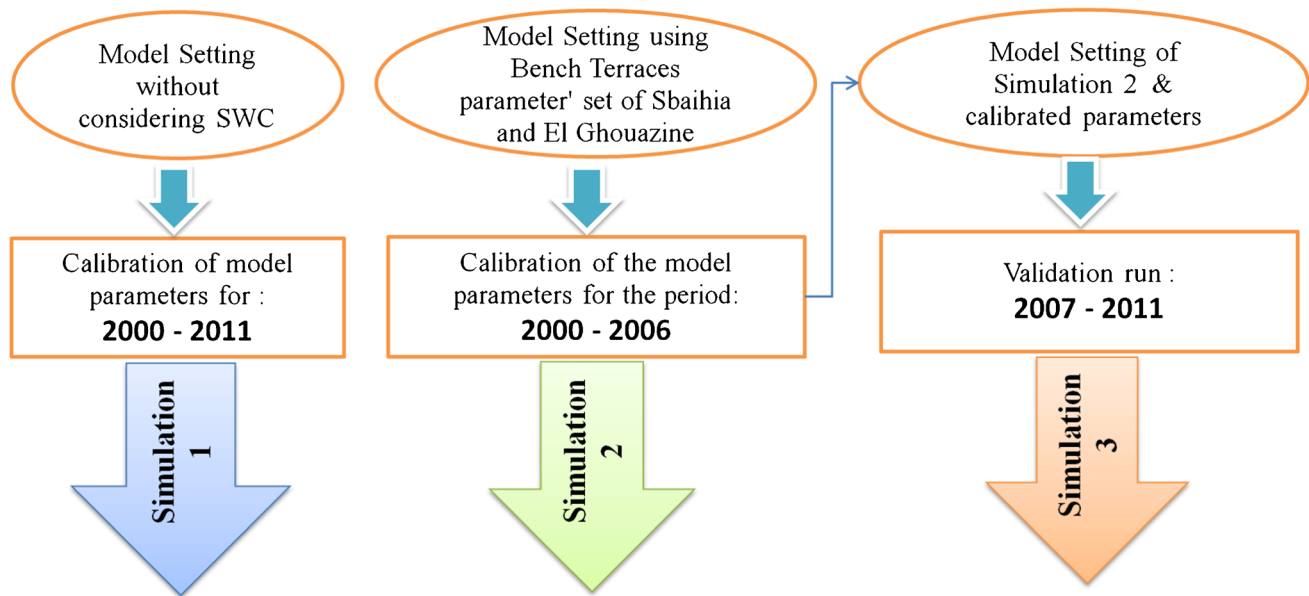


Fig. 5 Model runs for the Rmel watershed to assess the impact of SWC structures

entire surface water). For each HL entry into the watershed model, the following information is needed:

- Identification of the sub-basin draining into the Hill Lake (pond)
- Fraction of sub-basin area that drains into the pond (PND_FR)
- Surface area of the pond when filled to principal spillway (PND_PSA) (ha)
- Volume of water stored in the pond when filled to spillway (PND_PVOL) (10^4 m^3)
- Surface area of the pond when filled to emergency spillway (PND_ESA) (ha)
- Volume of water stored in the pond when filled to emergency spillway (PND_EVOL) (10^4 m^3)
- Initial volume of water in the pond (PND_VOL) (10^4 m^3)
- Initial sediment concentration in pond volume (PND_SED) (mg/l)

SWAT scenarios and performance assessment

SWAT simulations were performed at the daily time step for entire modelling period ranging from 1997 to 2011. However, modelling performance was assessed at the monthly time step matching the temporal resolution of the most accurate observation datasets available. Model calibration was conducted from 2000 to 2006, and the validation period ranged from 2007 to 2011, considering a 3-year warm-up period for model set up and initialization (1997–1999). Sediment yield observation data from bathymetric surveys

conducted at multi-annual time step in the Rmel outlet reservoir and was used for manual verification purposes only.

As an initial simulation, the Rmel watershed hydrology was simulated for the period 2000–2011 without considering any of the SWC interventions (BTs & HLs) shown in Fig. 4. This scenario was set up using a variety of sensitive SWAT parameters derived from the previous El Gouazine study (Ben Khelifa et al. 2021), representing the untreated local environmental conditions. In a second step, the simulation time period was divided into a calibration period, from 2000 to 2006, and a validation period, from 2007 to 2011, respectively.

Best calibration simulation was identified using SWAT-CUP and SUFI-II algorithm (Abbaspour et al. 2007). Calibration parameter ranges were defined based on two indicators evaluating the simulation uncertainties: (i) the p-factor, which indicates the percentage of observation data covered through 95% of the simulations (95PPU) considering various calibration parameters combinations, and (ii) the r-factor, which describes the average width of the 95PPU band, divided by the standard deviation of the observation data. By theory, a simulation that exactly corresponds to measured data results in a p-factor of 1 and r-factor of zero. As an overview, the following three main simulation runs were performed (Fig. 5):

- Simulation 1: untreated conditions assuming no SWC implementation (suppressing BTs & HLs) in the Rmel watershed. Simulation 1 does not consider any reduction in surface runoff and erosion as an effect of the applied BTs and HLs.

Table 1 Parameters used for the calibration period

Model parameter	Description	Fitted value	Variation range of values		Land use	Slope %
CN2	Curve number for moisture condition II in garrigue area	81	59	89	Garrigue	
ALPHA_BF	Base flow alpha factor (days)	0.765	0,5	1		
GW_DELAY	Groundwater delay (days)	315.5	50	500		
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	8.5	0	10		
GW_REVAP	Groundwater 'revap' coefficient	0.19	0,15	0,2		
REVAPMN	Threshold depth of water in the shallow aquifer for 'revap' to occur (mm)	2.5	0	5		
SOL_AWC	Available water content in the soil layer	0.29	0,05	0,3		
SOL_K	Saturated hydraulic conductivity	0,09	0,05	0,6		
ESCO	Soil evaporation compensation factor	0,35	0,2	0,7		
SLSUBBSN	Average slope length (m) in wheat area having a slope 0–8%	57	50	65	Wheat	0–8
CN2	Curve number for moisture condition II in wheat area, having slope 0–8%	59	53	65	Wheat	0–8
CN2	Curve number for moisture condition II in wheat area having a slope 8–12%	61	55	67	Wheat	8–12
CN2	Curve number for moisture condition II in wheat area having a slope 12–16%	65	58	74	Wheat	12–16
CN2	Curve number for moisture condition II in wheat area having a slope > 16%	65	58	74	Wheat	> 16
CN2.mgt	Curve number for moisture condition II in forest area	72	53	79	Forest	
CN2.mgt	Curve number for moisture condition II in olives area, having a slope 0–8%	58	51	63	Olives	0–8
CN2.mgt	Curve number for moisture condition II in olives area having a slope 8–12%	60	53	65	Olives	8–12
CN2.mgt	Curve number for moisture condition II in olives area having a slope 12–16%	64	55	67	Olives	12–16
CN2.mgt	Curve number for moisture condition II in olives area having a slope > 16%	65	55	67	Olives	> 16
SLSUBBSN	Average slope length (m) in olives area having a slope 0–8%	71	65	75	Olives	0–8
SLSUBBSN	Average slope length (m) in wheat area having a slope 8–12%	41	40	60	Wheat	8–12
SLSUBBSN	Average slope length (m) in wheat area having a slope 12–16%	35	30	40	Wheat	12–16
SLSUBBSN	Average slope length (m) in wheat area having a slope > 16%	25	20	30	Wheat	> 16
SLSUBBSN	Average slope length (m) in olives area having a slope 8–12%	42	40	60	Olives	8–12
SLSUBBSN	Average slope length (m) in olives area having a slope 12–16%	48	40	50	Olives	12–16
SLSUBBSN	Average slope length (m) in olives area having a slope > 16%	23	20	30	Olives	> 16
RCHRG_DP	Deep aquifer percolation fraction	0,02	0	0,05		
CN2	Curve number for moisture condition II in degraded forest area	82	73	87	Degraded forest	

- Simulation2: application if the calibrated BTPS developed through the Sbaihia sub-watershed study (Ben Khelifa et al. 2017) and introduction of HLs as 'ponds' to the SWAT simulation 1. The soil available water capacity (AWC-SOL) parameters were set to those obtained from El Gouazine watershed study (Ben Khelifa et al. 2021); other selected SWAT parameters were slightly re-calibrated using SWAT-CUP SUFI-II algorithm (Table 1).
- Simulation 3: validation of simulation 2 for the time period from 2007 to 2011, to test the goodness of fit of the parameters.

Calibration and validation of surface runoff were conducted through 28 parameters (Table 1), including 16 parameters (CN, SL) which relate with the slope steepness classes as well as soil and land use types to consider the impact of BTs per environmental context. These parameters were chosen in accordance with the international literature (Malagò et al. 2015; Abbaspour et al. 2007, 2015; Ben Khelifa et al. 2017; Ben Khelifa et al. 2021), modelling experience, as well as sensitivity tests.

Sensitivity analysis was performed using two statistical parameters (*t*-test and *p* value) and its results identified the

Table 2 Sensitivity analysis of parameters

Parameter name	t-Stat	p Value	Land use	Slope
SLSUBBSN.hru	1.56	0.13	Wheat	12–16%
CN2.mgt	1.52	0.14	Wheat	12–16%
GWQMN.gw	1.37	0.16		
CN2.mgt	1.35	0.17	Olives	12–16%
CN2.mgt	1.23	0.18	Wheat	8–12%
CN2.mgt	0.81	0.19	Forest	
CN2.mgt	0.51	0.23	Degraded forest	
CN2.mgt	0.47	0.32	Olives	0–8%
CN2.mgt	0.44	0.41	Olives	> 16%
SOL_AWC(..).sol	0.43	0.43		
CN2.mgt	0.33	0.43	Garrigue	
SLSUBBSN.hru	0.24	0.43	Wheat	8–12%
GW_REVAP.gw	0.12	0.51		
ALPHA_BF.gw	-0.03	0.52		
SLSUBBSN.hru	-0.25	0.59	Wheat	0–8%
CN2.mgt	-0.25	0.61	Wheat	> 16%
RCHRG_DP.gw	-0.38	0.64		
REVAPMN.gw	-0.38	0.66		
SOL_K(..).sol	-0.41	0.67		
SLSUBBSN.hru	-0.54	0.69	Olives	> 16%
SLSUBBSN.hru	-0.66	0.70	Olives	8–12%
SLSUBBSN.hru	-0.67	0.71	Wheat	> 16%
GW_DELAY.gw	-0.80	0.74		
CN2.mgt	-0.80	0.81	Olives	8–12%
SLSUBBSN.hru	-0.84	0.81	Olives	0–8%
ESCO.hru	-1.02	0.81		
SLSUBBSN.hru	-1.43	0.90	Olives	12–16%
CN2.mgt	-1.47	0.97	Wheat	0–8%

Table 3 Performance criteria of the three scenarios adopted in Rmel watershed

Scenario	Performance criteria	Monthly time step
Simulation 1	NSE	0.07
	PBIAS	-69.5
Simulation 2	NSE	0.89
	PBIAS	17
Simulation 3	NSE	0.91
	PBIAS	7.7

most sensitive parameters illustrated in Table 2. Thus, the most sensitive parameters were the average slope length (SLSUBBSN), SCS curve number for moisture condition II (CN2) in wheat cropped areas with slope range between 12 and 16%, and threshold depth of water in the shallow aquifers required for return flow to occur (GWQMN).

Results and discussion

Observed surface runoff and sediment yield

Monthly time step runoff data were provided for the time period from 2000 to 2011, obtained at the gauging station located at the Rmel dam. At the annual basis, runoff varied between 5 and 71 mm, with an average of 27 mm annual runoff. The observed sediment yield deduced from bathymetric surveys performed in the Rmel reservoir in 2000 and 2011 concludes on an average annual sediment yield value of 5.7 t/ha/year.

Results of simulated scenarios

Validation of the simulation 1 (zero treatment) at the monthly time scale, from 2000 to 2011, yielded poor results (Table 3). Simulation 1 was set up using El Gouazine watershed parameters (representing local untreated conditions); the bad validation performance indicates the (i) potential impact of the SWC measures on surface runoff and (ii) the need for re-calibration of parameters beyond SWC impacts.

In contrast to simulation 1, the calibration and validation runs (simulation 2 and simulation 3) led to satisfactory results (Fig. 6). The NSEs obtained are 0.89 and 0.91 for calibration and validation respectively. PBIAS criterion revealed that the model tends to slightly underestimate the peak flows during calibration and validation periods. P-factor and r-factor were 0.73 and 0.5 respectively.

Figure 7 confirms the high goodness of fit between the observed and the simulated monthly flows during the calibration and the validation periods. The particular underestimation of runoff peak flows during the calibration period took place in 2000 and 2001, which correspond with very dry conditions (Fig. 6). The model correctly estimated sediment yield for the calibration period with a simulated value of 5.3 t/ha/year, compared to the observed value of 5.7 t/ha/year. The intercomparison of simulation 1 (untreated) with the simulations 2 and 3 (treated) indicates the potentially huge impact of SWC structures on runoff and sediment yield over the concerned period from 2000 to 2011 (Fig. 8). In average, SWC structures (BTs & HLs) reduced sediment yield by around 17% and decreased runoff by around 33%. Considering the spatial distribution of BTs, the largest effect of BTs on the reduction of surface runoff and erosion was achieved in slope steepness classes ranging between 2 and 16% dominated by cereal and olive orchard agriculture.

Bench Terraces and Hill Lakes are among the most important soil and water conservation practices applied in agricultural areas in central-northern Tunisia. The Rmel study reveals that the spatially distributed BTs and HLs effectively reduce sediment yield and surface

Fig. 6 Monthly simulated and observed hydrographs in the Rmel watershed during calibration and validation

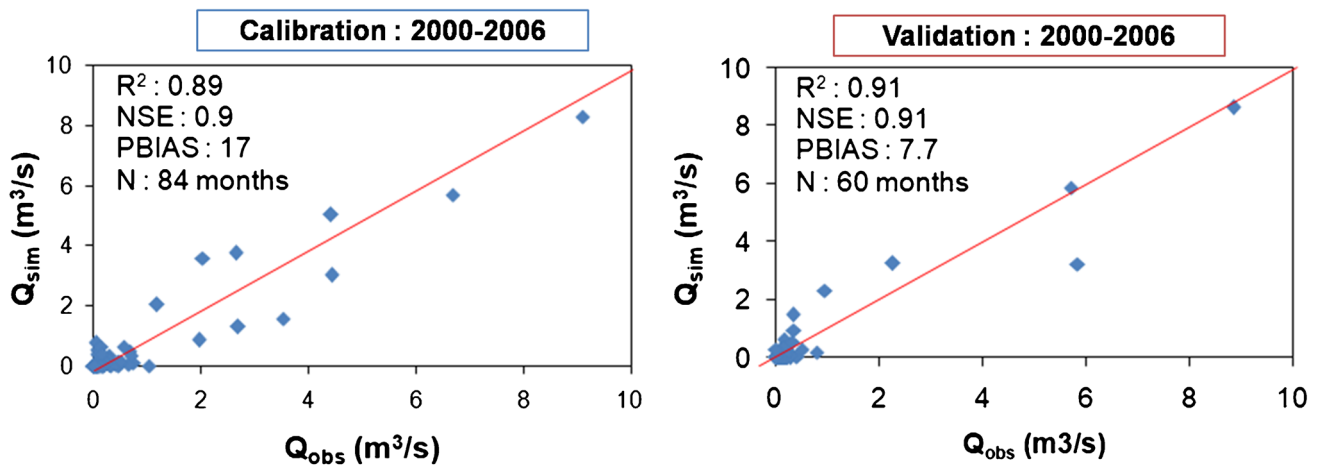
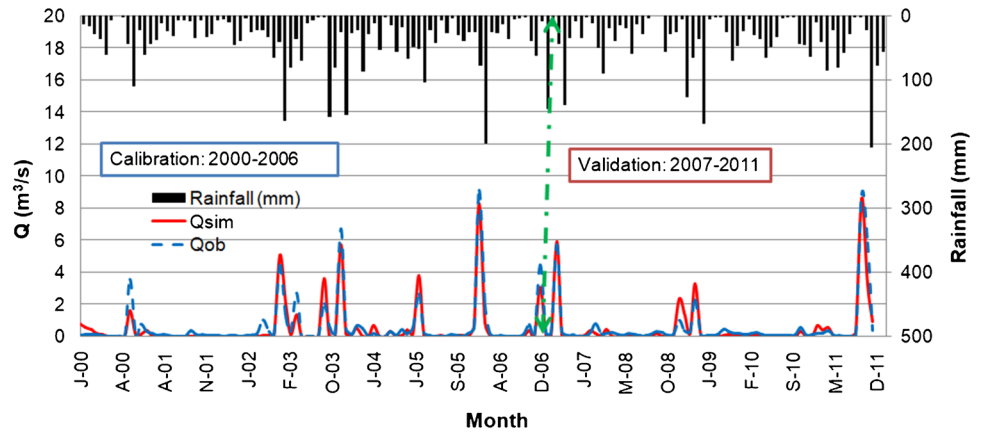


Fig. 7 Relationship between simulated and observed runoff during calibration and validation period

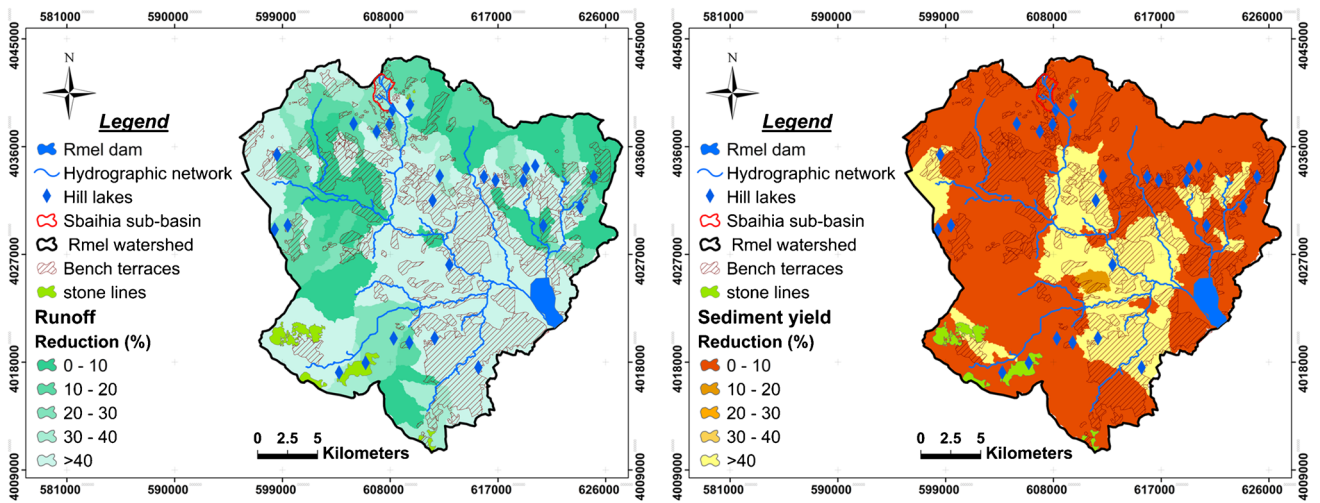


Fig. 8 Impact of SWC Structures on runoff and sediment yield in Rmel watershed

runoff—which consequentially slows down the degradation processes, helps to maintain soil health and enhances the local deep infiltration of water into the plants' root-zones prolonging the growing season and thereby increasing agricultural productivity. The conducted scaling approach of local BTPS confirms the importance of SWC practices at the large and integrated watershed level. In North Africa and Middle East (MENA) region, including Tunisia, a lack of high-quality in situ data often inhibits proper watershed model set up, calibration, and validation routines (Aouissi et al. 2018). However, the scattered and local availability of high-quality datasets (e.g. Sbaihia and El Gouazine in Tunisia) can help to set up and establish local models for the assessment of simplified and robust parameter sets. Testing these parameter sets through out-scaling to (i) other sub-watersheds and (ii) large and complex watersheds can shed light on the performance of such datasets and their feasibility for application in similar environmental context. Thus, to serve as an initialization for watershed modeling in data scarce areas and/or to reduce uncertainty in complex environments with interrelated hydrological processes including the simulation of SWC impacts. Furthermore, dynamic assessment approaches using scenario modelling advance from the development of 'static' SWC suitability maps. Thus, modelling can support the adaptation of management to environmental and climatic changes anticipated in the near future.

Conclusion

In the present research, a SWAT model was set up and used to evaluate the impacts of the implemented Bench Terraces (BT) and Hill Lakes (HLs) on the Rmel watershed's runoff and sediment yield dynamics. The pre-developed Bench Terrace parameter set (BTPS), established and verified through well-defined and small-scale sub-watershed studies (Sbaihia and El Gouazine), and the consideration of HLs through 'ponds' in SWAT, yielded plausible simulation results. Monthly runoff calibration and validation procedures suggest good simulation performance (using NSE and PBIAS), and the according sediment yield simulations approximated the bathymetric survey-based observation data. The good performance of the locally developed BTPS at the large and integrated landscape level—applied and tested in the 675 km² large Rmel watershed—reveals the robustness and out-scaling potential of the BTPS to similar environments and supports large and complex watershed management and sustainable land management (SLM) planning in data scarce areas.

However, further research and testing are required, especially to evaluate the boundaries of applicability of the developed BTPS. The pursued research forms a solid basis

for 'best-bet' parameter sets in the semi-arid rainfed zones of central-northern Tunisia—however, potential applicability could be much broader than that. Furthermore, climate change and according shifts in rainfall zones and aridity will likely impact the performance of BTs in Tunisia in the future. To achieve resilience and preparedness prior the arrival of change, further ex-ante assessment studies using changed environmental settings (including climate change) will be of high importance.

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Declarations

Conflict of interest The author(s) declare that they have no competing interests.

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