PARAMETERIZATION OF THE EFFECT OF BENCH TERRACES ON RUNOFF AND SEDIMENT YIELD BY SWAT MODELLING IN A SMALL SEMI-ARID WATERSHED IN NORTHERN TUNISIA

BENCH TERRACE EFFECTS ON RUNOFF AND EROSION USING SWAT MODELLING

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ABSTRACT

In Tunisia, Soil and Water Conservation (SWC) interventions are among the most practicable strategies to prevent and mitigate rainwater losses through surface runoff and consequential erosion of fertile soils. In this study, a small and terraced agricultural catchment (Sbaihia) was used as an experimental site to analyze and parameterize the effects of bench terraces on water and sediment yield using the Soil and Water Assessment Tool (SWAT). Model calibration and validation was performed taking advantage from high-quality daily runoff data from 1994 to 2000 and a high resolution bathymetric survey of the hill lake at the watershed outlet. SWAT indicated that the local terraces, established on approximately 50% of the watershed area, reduced surface runoff by around 19% and sediment yield by around 22%, decelerating the siltation of the hill lake. Targeted model calibration delivered concise parameter set describing bench terrace impacts on runoff (SCS Curve Number method) and sediment yield (MUSLE) crucial for outscaling of SWC impacts and suitable watershed management.

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1002/ldr.2685

KEY-WORDS: SWAT, SWC, erosion, semi-arid, Tunisia.

INTRODUCTION

Due to its scarcity, water is a bottleneck for the present and the future development of Tunisia. The country is among the least endowed with water resources worldwide and recent water stress forecasts are not positive (Maddocks et *al*., 2015). In 2014, the Tunisian Ministry of Agriculture estimated the availability of 440 m^3 of fresh water per capita per year, and that this ratio will likely decrease to 360 m^3 in 2030, with an estimated total population of 13 million people (Ministry of Agriculture, 2014). The African Development Bank reported an increased water shortage due to severe droughts or overexploitation of water resources during the 2030 to 2050 period (ADB, 2011). This is particularly worrying in view of the predicted climatic trends for the Mediterranean (IPCC, 2014).

On the other hand, water scarcity in Tunisia is inter-linked with substantial vulnerability to land degradation driven by the torrential rainfall pattern, a rugged terrain and intensively cultivated and overgrazed lands (Roose 1994; Cherif et *al*., 1995). Moreover, sparse vegetation, soil sealing and crusting decrease the potential infiltration capacity of the soils in many areas Belaid (2015) leading to a predominant surface runoff response and thus accelerating soil erosion. The high susceptibility to water erosion of the dry Mediterranean environments is well known (Raclot et *al*., 2009; Laudicina et *al*., 2014), and seems particularly valid for the Tunisian landscape (Hermassi et *al*., 2014; Ben Slimane et *al*., 2015).

From the 1990s Tunisian institutions adopted Soil and Water Conservation (SWC) strategies (Ministry of Agriculture, 2014) to tackle these problems in order to reduce surface runoff, enhance groundwater recharge, and decrease soil losses from the fields. Appropriate design of SWC structures varies according to the targeted landscape morphology. In the uplands contour structures, such as bench terraces, are used as effective measure to interrupt the hill slopes (Cherif et *al*., 1995; Nasri et *al*., 2004), whereas in the hydrographic network the construction of hill lakes is a frequently applied intervention strategy in Tunisia (Talineau et *al*., 1994). Well-designed SWC interventions, particularly in the upland, potentially prevent or mitigate soil erosion, and their impacts on water and soil has been the subject of many studies recently conducted in Tunisia (Nasri et *al*., 2004; Lacombe et *al*., 2007; Ouessar et *al*., 2008). The positive effect of the different measures is evident –after 25 years of adoption Tunisian SWC structures have reduced the land area threatened by erosion from 24.0% to 15.2% and reduced the siltation in dams from $28.10^6 m^3 year^{-1}$ to $17.\ 10^6\ m^3\ year^{-1}$as announced by the Ministry of Agriculture in 2014. However, out-scaling of these results is challenging due to the high variability of the Tunisian landscape.

Hydrological modeling is among the recently developed tools to assess water and land management strategies – including SWC measures -in complex watersheds. In the semi-arid Tunisian context, different authors applied the SWAT model (Arnold et *al.*, 1998; Arnold et *al.*, 2012) in order to respond to several management interventions including the impact assessment of climate change on water resource management (Sellami et *al*., 2015), while other researchers focused on the quantification of runoff and sediment transport (Bouraoui et *al*., 2005; Mosbahi et *al*, 2012) or water quality interrelations with agriculture as reported by Aouissi et *al*., (2014). Few Tunisian studies (Ouessar et *al*., 2004; Ouessar et *al*., 2008; Abouabdillah et *al*., 2014) targeted the impact of SWC structures on watershed hydrology and soil erosion. However, landscape pattern are variable and the overlay of several treatment and management effects in large watersheds complicate explicit conclusions on variable SWC impacts.

The objective of this research was the assessment of the impact of bench terraces on runoff and sediment yield in a small and quasi-homogeneously SWC-treated watershed in Tunisian semi-arid region using the SWAT model. More specifically, the research was aimed at achieving an effective parameterization of the effect of the bench terraces keeping into account varying slope and distance between terraces. The study area is the Sbaihia watershed (3.2 km^2), unique for its relatively uniform terracing treatment and the high quality runoff monitoring at the outlet – the Sbaihia hill lake. Best estimate of concise runoff and erosion related parameter set are supposed to support future large scale studies optimizing water management in northern Tunisia.

Comprehensive calibration and validation of runoff was undertaken based on daily water yield from the catchment. Bathymetric assessment of sediment accumulation in Sbaihia hill lake, carried out in several year time interval, was used for adjustment and verification of sediment yield simulation.

MATERIAL AND METHODS

Study area

The Sbaihia watershed is located in the Zaghouan Governorate (Northeastern Tunisia), between 36° 31.30’ and 36° 29.65’ Latitude North and between 10° 11.43’ and 10° 12.63’ Longitude East, ranging from 227 to 426 m.a.sl. (Figure 1). The watershed covers an area of around 3.2 km^2 and drains into the Sbaihia hill lake, selected in 1993 for surface runoff and siltation monitoring in the Tunisian semi-arid region (Albergel et *al*., 2004).

Average annual temperature and rainfall are 19.4°C (Bouficha station; 58 m.a.s.l; 1994-2008 data series) and 426 mm (rain gauge nearby the dam, 227 m.a.s.l; 1994-2008 data series) respectively. The coefficient of variation (CV) of the annual precipitation is 35 % which indicates considerable erratic rainfall pattern. The climate is classified as semi-arid according to the UNEP aridity index (UNEP, 1992). Average slope of Sbaihia watershed is 9% (Figure 2b), while 46% of the watershed has a gentle slope, less than 8%, and 90% has a slope from 0 to 16 %, which is within the slope range for terrace installation in Tunisian semi-arid regions according to the standards set by Roose (2002). The slope classes defined in this study (Figure 2) relate to the ranges used by Wischmeier & Smith (1978).

Land cover is mainly characterized by forest showing various degrees of degradation (34%), annual crops mainly constituted by winter wheat (49%), rangelands including degraded shrubland areas (10%), and by a limited extent of olive groves (1%). The remaining lands are bare soil (5%), water and urban area with 1%. Dominant forest tree species are *Pinus halepensis* (Mill.) and *Tetraclinis articulate* (Vahl.). In the understory, and in the open and or degraded forest and shrubland areas, *Rosmarinus officinalis* (L.), *Erica multiflora* (L.), *Phillyrea angustifolia* (L.), *Cistus salvifolius* (L.), *Artemisia herba-alba* (Asso.), and other shrub species are common, along with *Stipa tenacissima* (L.) as most frequent herbaceous species. The land cover map was drawn by the authors based on Google Earth images referred to 2004 (Figure 2c).

The study area is included in the BirMcherga (Castany et *al*., 1957) and Grombalia (Bujalka et *al*., 1971) sheets of the Geologic Map of Tunisia at the 1:50,000 scale. Six Cretaceous formations are represented in the watershed, which lithology is relatively homogeneous. Greyish-greenish marls span over most of the central and northern part of the area. Limestones (both marly and massive) outcrop only in the northernmost sector. In the Southern part of the catchment, grey marls outcrop with intercalated marly limestones, and with clayey limestones and quartzite around the water body.

According to the Agriculture map, two main soil types can be observed in the watershed, named as Rendzines and Sols bruns calcaires according to the CPCS (1967) classification system. More detailed information and data about the soils of the watershed are reported by Attia et *al*., (2004). Based on these information, on field observations, and on the analysis of remote sensing images that allowed for the identification of areas characterized by severe erosion and dense vegetation cover, the soil layer of the Agriculture map was modified

(Figure 2d) and the soil units were defined as shown in Table 1. A tentative and indicative designation according to IUSS Working Group WRB (2014) is also proposed in Table 1.

Soil and water conservation (SWC) structures

During the 1980s, agricultural areas of Sbaihia watershed have been intensively treated with Soil and Water Conservation (SWC) interventions, predominately through the establishment of bench terraces (Figure 3). The local terraces are earth embankments following the contour lines with the aim to intercept, store and foster the infiltration of runoff water. Thus, contributing to an increase of soils moisture and preventing a rapid siltation of the downstream hill lake (Cherif et *al*., 1995).

Around 50% of the entire watershed has been treated by terraces (Figure 4) which was evaluated based on satellite image analysis and field investigations. The terraces mainly cover the areas used for cereal production (spring wheat) and partly olive orchards. The earth dams create minor ponding areas in certain downhill spacing, laterally interrupted by spill ways, without impacting the native hill slope topography besides the marginal sediment accumulation at the structures.

The inter-terrace spacing is directly related with the hill slope: the distance (E) between terraces in meter is determined by the Bugeat formula established by Cherif et *al.* (1995); Hill slope p is expressed as decimal fraction:

$$E = 2.2 / p + 8$$ Equation: 1

Modeling and parameterization

SWAT model

SWAT (Arnold et *al*., 1998; Arnold et *al*., 2012) is a basin-scale continuous-time model that operates on a daily time step and is designed to predict the impact of management operation on water, sediment, and agricultural chemical yields (Gassman et *al*., 2007; Arnold et *al*., 2012). A watershed is divided into multiple sub-watersheds, which are further subdivided into hydrologic response units (HRUs) representing homogeneous slope steepness, land use and soil characteristics. The water balance of each HRU is represented by following equation (Neitsch et *al*., 2011):

$$SW_t = SW_0 + \Sigma P_i - Q_{sup.i} - Q_{lat.i} - ET_i - Q_{sub.i})$$ Equation: 2

Where SW_t is the final water content of the soil (mm), SW_0 is the initial soil water content (mm), P_i is the precipitation (mm), Q_{supi} is the surface runoff (mm), Q_{lati} is the lateral flow (mm), E_{Ti} is the evapotranspiration (mm), and Q_{subi} is the groundwater flow (mm).

In SWAT, surface runoff can be computed by two methods: the Soil Conservation Service (SCS) curve number (CN) method (USDA-SCS, 1972) and the Green–Ampt infiltration method (Green and Ampt, 1911). Runoff is routed through the channel network using the variable storage routing method (Williams, 1969) or the Muskingum river routing method (Overton, 1966). In this study, the SCS curve number (Equation 2) and the variable storage routing method were used for surface runoff and stream flow assessment. Surface runoff was calculated by:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)}$$

Equation: 3

Where, Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the daily rainfall depth (mm), *Ia* is the initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm) and *S* is the soil water retention parameter (mm). Hence, runoff occurs when *Rday*>Ia. The retention parameter varies spatially and is defined as:

$$S = 25.4.(\frac{1000}{CN} - 10)$$

Equation: 4

Where *CN* is the curve number controlled by the soil type, the soil hydrological condition, vegetation cover, land use and treatment, and the antecedent moisture condition (I=dry, II=average, III=wet) of the soil (NCRS, 2004).

Sediment component

SWAT derives sediment yield (*SY*) generated by rainfall-runoff processes in each HRU by means of the Modified Universal Soil Loss Equation (MUSLE; Williams and Berndt, 1977):

$$SY = 11.8(Q_{surf}.q_{peak}.area_{hru})^{0.56}.K_{USLE}.C_{USLE}.P_{USLE}.LS.CFRG$$

Equation: 5

Where *SY*=daily sediment yield (tons per the event day);Q_{surf}=surface runoff (mm.ha^{-1}); Q_{peak}=peak runoff rate (m^{3}s^{-1}); $area_{hru}$=HRU area (ha); K_{USLE} = USLE (Universal Soil Loss Equation) soil erodibility factor (t.ha.hr).(ha.MJ.mm)$^{-1}$; C_{USLE} = USLE daily cover management factor; P_{USLE} = USLE conservation practice factor; LS_{USLE} = USLE topographic factor (steepness and length); *CFRG* = coarse fragment factor.

In this study, $\mathrm{P_{USLE}}$ is of particular interest, as it reflects the impacts of conservation practices on erosion – concretely, $\mathrm{P_{USLE}}$ describes the ratio of long term average sediment yield occurring from a treated area compared with similar condition area without the specific treatment. Moreover, as seen in Equation 4, the topographic factor LS impacts the erosion behavior of a hill slope connected with certain HRU topographic characteristics.

Input data

SWAT requires daily climate input, knowledge of the watershed topography, soil, land use and management. For the present modeling study the following data was set up:

- Climate data: Daily rainfall data from a rain gauge located at Sbaihia hill lake, collected from DGACTA/IRD (1994-2000). Weather data such as relative humidity, air temperature, solar radiation and wind speed were provided by the National Centers for Environmental Prediction (NCEP) for the period 1979-2014. The used climate station (364n103e) is located at 36.3747°Latitude North and 10.3125°Longitude East, in a 25 km distance from the lake outletat an elevation of 58 m.a.s.l.
- Topographic Data: the watershed configuration was extracted from 'Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model' version 2011 (30-m resolution) . The DEM was used as topographical input to define the watershed boundary, river network, sub-basins, and to derive slope-related parameters.
- Land cover and soil: at the scale of 1/50000, as described in the above section were digitized and used as model input.Land cover was assessed using google earth images validated through field visits.

Runoff and Sediment Data

Hydrometric records, obtained from hill lake gauging station (DGACTA/IRD, 1994-2000), were used for calibration and validation of the watershed's runoff. For the period 1994-2000 average annual runoff was 11.6 mm coinciding with an average annual rainfall of about 426 mm. Maximum annual runoff was 22.0 mm corresponding to 630 mm rainfall recorded in 2004. A clear rainfall runoff correlation can be observed on daily basis (Figure 5). At the monthly scale, maximum runoff was observed in April with an average of 15 mm. Sbaihia hill lake sedimentation data were used as a reference to verify the sediment yield simulated. Two bathymetric measurement data were acquired: one was carried out in October 1996, with a sediment volume of about 10,550 m^3, and the other one in November 2006, with a sediment volume of 43,500 m^3. This is equivalent to an average of 13.6 tons ha^{-1} per year of sediment yield from the catchment.

Model set-up

During ArcSWAT watershed delineation procedure seventeen sub-basins were created. The sub-basins were further divided into hydrological response units (HRUs) using a threshold of 10% for land use, 10% for soil type and 10% for slope, which resulted in 210 individual HRUs. The HRU threshold is employed to further discretize each sub-basin considering landscape heterogeneity found from its land use, soil, and slope (Her et *al*., 2015).

Calibration and validation using SWAT-CUP

SWAT-CUP (Calibration and Uncertainty Procedures) is a standalone program which contains five different automated calibration procedures including functionalities for validation and sensitivity analysis as well as visualization of the results (Abbaspour et *al*., 2007). In this work, SUFI-2 calibration algorithm (Abbaspour, 2007) was used as it has been extensively applied for watershed hydrology calibration (Yang et *al*., 2008). The model has been calibrated and validated using the daily runoff records obtained from the watershed's outlet (hill lake) through automatic five minutes interval records (1994-2000), for daily, monthly and annual steps. SWAT-CUP calibration was performed for the 1994 to 1997 time period, with a three years warm-up period (1991-1993). Validation was executed using the 1998 to 2000 time series. Twelve calibration parameters were selected based on the authors' knowledge of the watershed, SWAT parameter sensitivity analysis, and on literature examples as reported by Malagò et *al*. (2015) and Abbaspour (2007). Ten parameters were used for SWAT-CUP automated runoff calibration (Table 2) and two parameters (K_{USLE} and P_{USLE}) were manually adjusted matching the observed sediment yield. Due to non-equal interval sampling sediment data were used for manual model adjustment only, and was therefore not subject to the automated SWAT-CUP calibration procedure.

Nash-Sutcliffe Efficiency (NSE; Nash and Sutcliffe, 1970), the coefficient of determination (R^2), and the root mean square error (RMSE) (Singh et *al*., 2004) were used to evaluate the performance of the simulation:

$$NSE = 1 - \frac{\frac{1}{N}\Sigma\left(Q_{sim}(t) - Q_{obs}(t)\right)^2}{\Sigma\left(Q_{obs}(t) - \overline{Q}_{obs}(t)\right)^2}$$

Equation: 6

$$R^2 = \left(\frac{\sum_{i=1}^{n}(Q_{obs}(t) - \overline{Q}_{obs}(t))(Q_{sim} - \overline{Q}_{sim}(t))}{\sqrt{\sum_{i=1}^{n}(Q_{obs}(t) - \overline{Q}_{obs}(t))^2 \sum_{i=1}^{n}(Q_{sim}(t) - \overline{Q}_{sim}(t))^2}}\right)^2$$

Equation: 7

$$RMSE = \sqrt{\sum_{i=1}^{n}(Q_{sim}(t) - Q_{obs}(t))^2 / N}$$ Equation: 8

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

Parameterization of the effect of the SWC structures

In this study, modification of the surface runoff characteristics of HRU's affected by SWC treatment have been simulated through Curve Number (CN) adjustment. Spatially distributed SWAT-CUP calibration procedure was undertaken to assess CN II values associated with average soil moisture conditions based on the five-days antecedent rainfall amount (Williams et *al*., 2012) targeting different slope steepness classes of the bench terrace treated HRU's. By default derived CN's for the untreated areas (such as forests, shrub land and bare soil) were kept in narrow ranges of variation (mostly between +/-10% relative adjustment). For the terraced HRU's the Slope Length (SL) and the support practice factor (P_{USLE}) were obtained from field investigations, observations performed through Google Earth imagery and literature suggestions (Arnold et *al*, 1998; Zante & Collinet, 2001; Attia et *al*., 2004; Hermassi et *al*., 2014). According HRU's SL were initially set based on the local terrace spacing obtained from the field and Google earth images, and later slightly adjusted during calibration of variable slope steepness classes. However, the slopes were kept constant as the native hill inclination might not significantly change due to bench terrace application. The USLE conservation practice factor (P_{USLE}) was initially set based on general SWAT literature (Arnold et al, 1998 ; Waidler et *al*, 2011), local evaluations in the frame of Tunisian SWC study (Hermassi et *al*. 2014), and adjusted during calibration according to variable slope classes. Concretely, P_{USLE} of the treated HRUs was manually adjusted to approximate the sediment accumulation in the hill lake observed between 1996 and 2006. Having two sediment records, a temporally distributed erosion calibration was not possible, and therefore the sediment measurements were used for matching the magnitude of simulated sediment yield amounts only. In this study the soil erodibility values (Ki) were manually adjusted in the model according to the ranges assessed by Attia et *al*. (2004) to upgrade modeling performance. Hence, three sources of knowledge, 1) locally assessed soil erodibilies, 2) overall sediment yield to the hill lake (bathy metric measurement), and 3) erosion control impacts (P-factor) based on literature suggestions and local studies (Hermassi et *al*., 2014) have been merged to estimate on-site erosion pattern.

RESULTS

Daily runoff calibration achieved a NSE of 0.64, while validation led to a NSE of 0.68 (Figure 6a). On a monthly scale, the obtained NSE is 0.89 and 0.60 for calibration and validation respectively (Figure 6b). The calibrated model tends to slightly overestimate the discharge during calibration period, while the discharge is underestimated during validation. On annual scale, the NSE is around 0.80 for calibration and around 0.60 for validation (Figure 6c). Opposite behavior was observed compared with the monthly time step with an underestimation during calibration and an overestimation during validation period. Figure 6 indicates the good simulation of both low and extreme values on a daily and monthly temporal scale. On the other hand, few data available for the annual scale influences model performance evaluation, which leads to a more or less vague assessment.

The core-result of this research, the parameterization of terrace impact on surface runoff and sediment yield according to SCS CN and MUSLE methods is illustrated in Table 3. The SWC treated agricultural areas yielded CN values ranging between 59 and 71 – linked with to the different slope steepness classes. The calibrated SL and PUSLE values vary between 25 m and 70 m and between 0.5 and 0.9, respectively (Table 3).

A hypothetical scenario without SWC structures was also run excluding the bench terraces by setting back the CN and SL values of the treated areas to SWAT default values, and setting P_{USLE} to 1.0 adopted for untreated areas. The miss-match of the observed runoff with the model-generated runoff was attributed to the terracing effects. The percentage of annual surface runoff and sediment yield, calculated for both scenarios, are illustrated in Figure 7.At sub-watershed level, the SWC-treated scenario reduced surface runoff between 4% and 78%, with an average of 19%, and sediment yield between 4% and 86%, with an average of 22%.

Sbaihia hill lake is bounded by a steep and degraded silt loam soils in the northwestern part of the reservoir and most likely large amounts of sediments are generated from this highly erosive area, which is consistent with the present modeling results. The overall amount of sediment yield simulated was also controlled through the erodibility factor (Ki) of the soils. This procedure has given satisfactory results since the simulated sediment yield is about 14.0 t ha^{-1}, similar to the observed sediment yield (13.6 t ha^{-1}).

DISCUSSION

Large agricultural areas of the Sbaihia watershed have been homogeneously treated by bench terraces in the past. Therefore, and because of its limited size and high-quality runoff data recorded, it represents proper case study for calibration and parameterization approaches aimed at simulating the effects of the SWC structures on runoff and erosion. In Sbaihia watershed the impact of bench terraces is only present on spring wheat HRU's, where upon only limited number of the generated HRU's are affected by the performed calibration. Nevertheless, certain spatial distribution of terraced HRU's, addressing all different slope steepness classes, have been achieved through the performed watershed delineation. Concretely, 210 HRU's have been generated for the 3.2 km^2 large watershed.

Calibration was based on runoff data– in form of daily discharge to Sbaihia hill lake – whereas sediment yield in the hill lake was used for manual model adjustment approximating several years' cumulative soil erosion rather than automated calibration using SWAT-CUP software. This implies that the impact of bench terraces on runoff represents certain degree dynamic watershed response on a daily basis, whereas the simulation of sediment yield is rather vague – interlinked with the common practices and consequential uncertainty of sediment yield monitoring performed in rural and dry areas. However, several SWAT studies from the Mediterranean, such as Licciardello et *al*. (2016), indicate the strong performance of SWAT for modeling sediment yield on an annual basis once the monthly channel flow calibration is successful.

In Tunisia, different studies have been carried out considering the effects of variable local SWC measures. One example is the study conducted by Abouabdillah et *al*., (2014), where retention effects of the contour structures were successfully related to a "pothole" effect applicable within SWAT software. However, in this study more common approach based on CN value's modification was performed as implemented in many hydrological models (Hawkins et *al*., 2009). In this research, CN starting values, as affected by bench terraces, were set in accordance to the literature between 55 and 61 (Arnold et al., 1998) and have been further adjusted to the variable HRU (Hydrologic Response Unit) characteristics present. Calibration was performed in an iterative manner: during calibration specific CN ranges of the terraced areas were set narrow (+/- 10%) to avoid uncontrolled variation between the differently sloped terraced HRU's. At the same time the CN values of the untreated areas (forests and rangeland) were kept as derived by default by ArcSWAT 2012 software considering a common +/-10% parameter range in SWAT-CUP. In cases where SWAT-CUP suggested the overall increase or decrease of entire runoff the terraced HRU's CN's were modified iteratively, whereas the relative differences within the treated areas (related with different slope steepness classes) were controlled, and also the non-treated areas CNs were kept within the given 'default' ranges mentioned above. This allowed the fine tuning of the local terrace impacts within controlled ranges, accounting for different slope classes.

However, SWC structures underlie certain temporal evolution -such as the decreasing SWC efficiency over time through siltation or the appearance of sudden structure breaks (Baccari, 2008). Moreover, sediment accumulation may also lead to minor changes of the hill slope topography. Such effects certainly impact a watershed's response and the related model calibration.

Anyways, overall aim of this study is the generation of reliably defined and easily usable initial dataset describing bench terrace impacts on water and sediment yield. This demands for concise parameter dataset usable for outscaling. Further watershed level studies will be carried out to validate and consolidate the results obtained by this research.

CONCLUSION

The investigation of spatially distributed impacts of bench terraces on surface runoff and erosion yielded into the adjustment of the SWAT model parameters Curve Number (CN) and conservation practice factor (PUSLE) interrelated with slope length and steepness. The set up model was capable to simulate the watershed's runoff regime achieving a monthly based NSE of 0.89 and 0.60 for calibration and validation respectively. Moreover, eleven year time period (1996-2006) simulation led to sound erosion results suggesting on the usability of SWAT to capture the spatial erosion pattern for both treated and untreated conditions. Comparison of the calibrated model with a hypothetical zero-treatment scenario (removing bench terraces) indicated the impacts of SWC on reducing sediment yield (approximately 22%) and runoff (approximately 19%).

The parameterization of bench terraces achieved through this study will support ongoing modeling campaigns in northern Tunisia at a larger scale. Even though the local conditions might vary for several aspects (scale, climate, topography, soil, land use, land cover, management and the applied SWC structure) the obtained values related with widely applied SCS CN runoff and MUSLE sediment yield computation approaches can be used as a reference or starting parameter set for complex landscapes.

ACKNOWLEDGEMENTS

This work was undertaken as part of the CGIAR Research Program on Dryland Systems led by the International Center for Agricultural Research in the Dry Areas (ICARDA). Funding support for this work was provided by the CGIAR Research Program on Dryland Systems and by the National Research Institute for Rural Engineering, Water and Forestry (INRGREF).

The opinions expressed here belong to the authors, and do not necessarily reflect those of Dryland Systems, ICARDA, or CGIAR.

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Table1 : Soil units as defined for the study area

Unit	C.P.C.S. (1967)	WRB (2014)	Source	Brief description	Hydrologic Soil Groups
A	Lithosols	Lithic Calcaric Leptosols; Rock Outcrops	B	Shallow eroded soils, with high rock fragment content and balanced texture, observed on the compact limestone outcrops of the northernmost sector of the watershed.	C
B	Lithosols, Affleurements rocheux	Lithic Calcaric Leptosols; Rock Outcrops	C	Very shallow and severely eroded soils alternating with rock outcrops, fine textured (clayey), observed on the grey marl formation outcropping East and North-East to the reservoir.	D
C1	Rendzine	Calcaric Leptosols; Lithic Calcaric Leptosols	a, b	Poorly developed shallow soils, rich in calcium carbonate, fine textured (clayey to clayey loam), outcropping along the eastern boundary of the watershed according to the Agriculture map.	D
C2	Rendzine humifère	Rendzic (Somerirendzic) Calcaric Leptosols; Calcaric Leptosols	b, c	Similar to the above soils, characterized by relatively dense vegetation cover (forest, shrubland) and by higher organic matter content, more intense biological activity and more developed structure and porosity.	D
D	Sol brun calcaire	Calcaric Cambisols; Leptic (Cambic) Calcisols	a, b	Moderately deep and developed soils, fine textured (clayey to clayey loam to silty clay), rich in calcium carbonate, well structured and porous, with intense biological activity, mostly observed on marl-dominated formations in the central part of the watershed	C
E1	Complexe de sols		a, b	Unit including a complex of soils belonging to units C1 and D, with undetermined spatial pattern, along with poorly developed soils formed on alluvial and colluvial material, as inclusions, showing variable depth and loamy texture (Regosols, Leptosols).	D
E2	Complexe de sols (humifère)		a, c	Unit similar to E1, but characterized by dense vegetation cover (forest, shrubland) and by higher organic matter content, more intense biological activity and more developed structure and porosity.	D

Sources: a) Agriculture map; b) Attia et *al.*, (2004); c) authors observations

Table 2: Parameters used for calibration

Parameter	Description	Range	
		Min	Max
r_CN2.mgt	Curve number for moisture condition II(*1)	-0.1	0.1 / 0.2
v_GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	1.40	1.75
v_ALPHA_BF	Base flow alpha factor (days)	0.7	0.9
v_GW_DELAY.gw	Groundwater delay (days)	471	473
v_GW_REVAP.gw	Groundwater "revap" coefficient	0.15	0.2
v_ESCO.hru	Soil evaporation compensation factor	0.080	0.085
v_REVAPMN.gw	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	0.78	2.37
v_RCHRG_DP.gw	Deep aquifer percolation fraction	0.002	0.008
r_SOL_K.sol	Saturated hydraulic conductivity.	-0.91	-0.89
r_SL.hru	Average slope length (m)(*2)	-0.28	0.004

r__ means the existing parameter value is multiplied by (1+*a*given value); v__means the parameter is replaced by a given value. *1: CN2 was separately calibrated for different HRU's (separated for treated and non-treated areas and five slope steepness classes) – the according ranges were mostly between -0.1 and 0.1, except for shrubland. *2: SL.hru was only adjusted for treated areas allowing minor variation of the bench terrace spacing.

Table 3: CN, P factor and Slope Length (SL) values after calibration

Slope	CN2	P factor	Slope length (m)
0-2%	59	0.5	70
2-8%	59	0.5	70
8-12%	64	0.6	55
12-16%	64	0.7	35
>16%	71	0.8	25

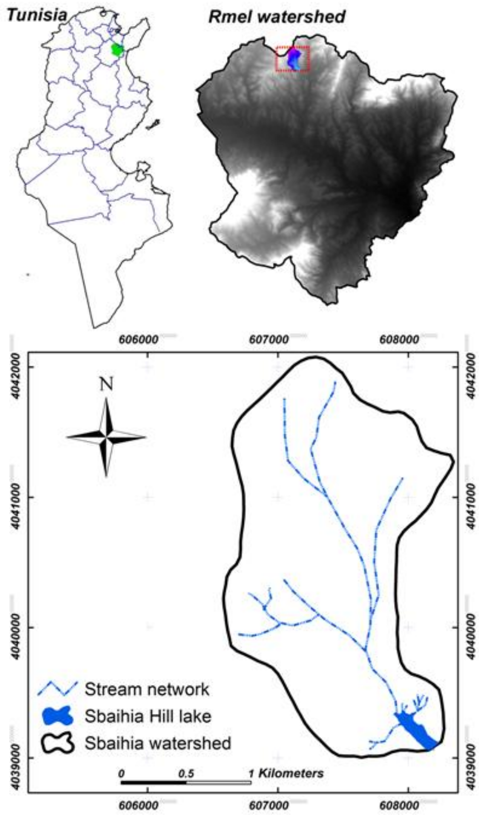

Figure 1. Location of the study area (Albergel et al., 2004).

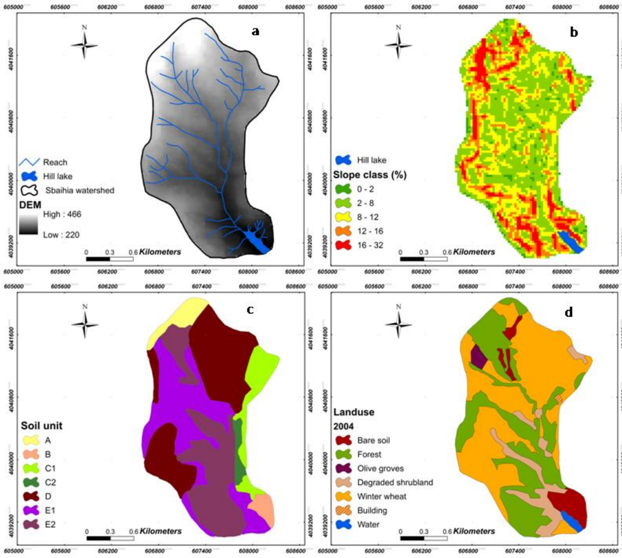

Figure 2. DEM (a), Slope (b), Soil unit (c) and landuse (d) maps of the Sbaihia (Figure 2c).

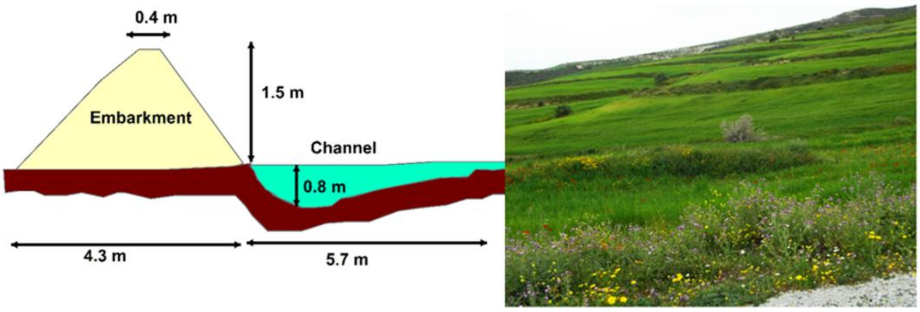

Figure 3. The existing bench terraces in the study area and their transversal section of bench terraces (Figure 3).

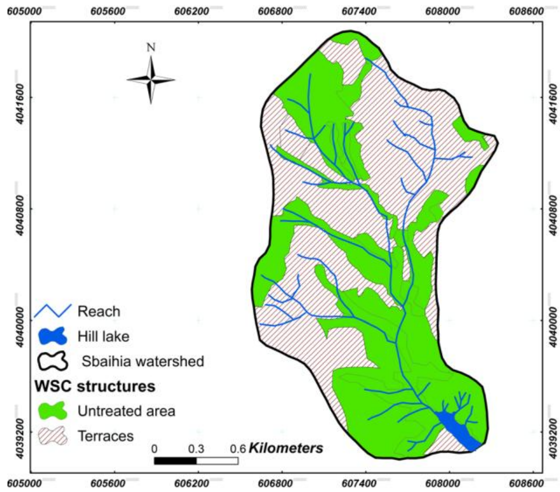

Figure 4. Terraces in Sbaihia watershed by terraces (figure 4)

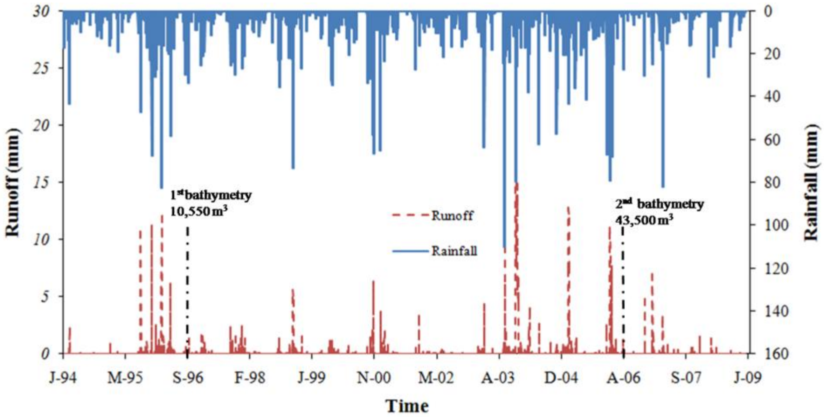

Figure 5. Temporal distribution of the observed data (rainfall, runoff and sediment yield) in the Sbaihia watershed. on daily basis (figure 5).

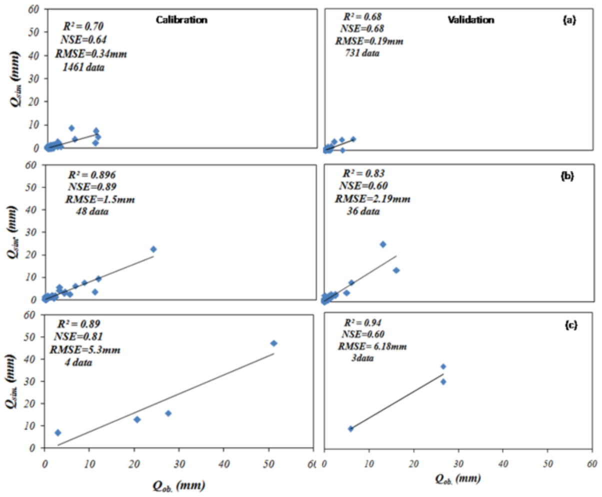

Figure 6. Observed and simulated daily (a), monthly (b) and yearly (c) runoff in the Sbaihia watershed. (Figure 6c).

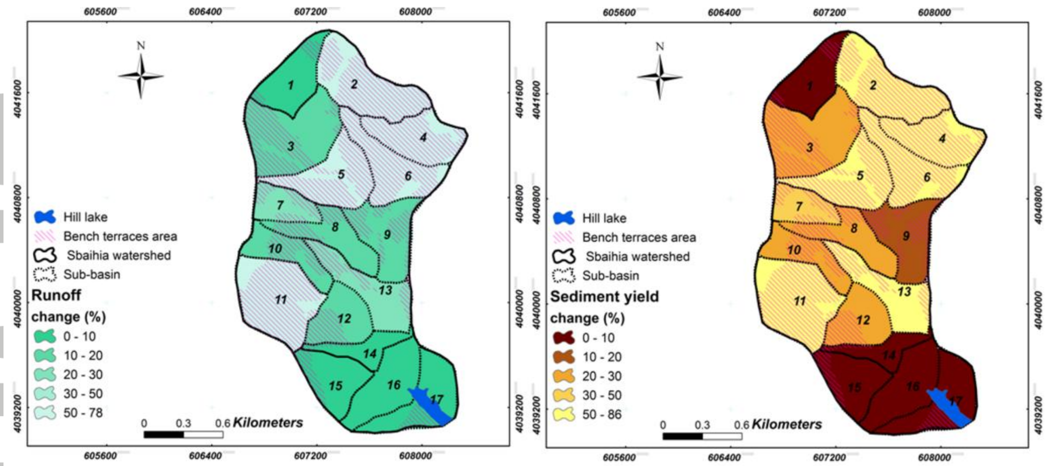

Figure 7. Impact of terraces on the yearly sediment yield and runoff in the period of 1996-2006 are illustrated in Figure 7