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Assessment of SWC intervention impacts at the watershed scale: Case study of Rmel watershed in central Tunisia

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Abstract.

The objective of this study is to evaluate the large scale impacts of the bench terrace SWC technique– widely applied in central and northern Tunisia –using SWAT (Soil and Water Assessment Tool). The model was set up for the 675 km^2 large Rmel watershed located in northeastern of Tunisia. Daily stream flow data from the outlet of the watershed was used for model calibration (observation years 2000-2006) and validation (observation years 2007-2011) respectively.

The model allowed to satisfactorily assess the runoff characteristics of Rmel watershed locally affected by bench terrace treatment of agricultural areas achieving a model efficiency (Nash-Sutcliffe Efficiency (NSE)) of 61% and 89% for calibration and validation. After successful set up and calibration the model was used to generate a zero treatment scenario) for comparison. Thus, to evaluate the spatially variable effect of bench terraces on surface runoff to provide a tool for targeted land and water management.

Keywords: SWAT, SWAT-CUP, SWC, Rmel, Tunisia

30. Introductıon

Improvement of the world's food security is an issue that depends on the land and water resources and how they are used (FAO 2011). However, with growing population and increasing vulnerability of these resources especially in arid and semi-arid countries, the global demand for water, in terms of collection of water resources, is expected to increase by approximately 55% in 2050 (WWAP 2015).Nowadays, agricultural areas already cover 11% of the world's land surface for crop production(FAO 2015).

Tunisia is considered as scarcely endowed with fresh water resources in the Mediterranean basin (Lebdi 2005) having significant interannual variability (Ministry of Agriculture 2014) mainly due to the small but erratic rainfalls achieving around 207 mm per year in the long term average (FAO 2016).To cope with this context of water shortage, Tunisia adopted a rigorous water policy which led to the development of valuable hydraulic infrastructures(Omrani and Ouessar 2011) to store and re-distribute the harvested water. Nowadays, Tunisia has 33 large dams, 253 small dams and 837 hill lakes (Ministry of Agriculture 2014). However, due to siltation the capacity of these dams is declining by 17 10^6 m^3per year (Ministry of Agriculture 2014). Soil and Water Conservation (SWC) interventions in the landscape, such as benches terraces (Cherif et al. 1995, Nasri et al 2004; Nasri, 2007) have been designed to reduce sediment yields through reducing erosive surface runoff generated by the torrential rainfalls (Zahar 1997) and thus to protect water impoundments from massive siltation. Moreover, SWC interventions aim to improve agricultural productivity by enriching soil moisture through local infiltration of the collected surface runoff.

Recently, several approaches have been used to assess the impact of SWC interventions in Tunisia (Nasri 2007; Boufaroua 2011, Ouessar et al. 2004; Ouessar et al. 2008; Lacombe et al. 2007). Among the most efficient methods used by hydrologist is hydrological modelling (Hermassi 2010) which was also applied in the present research.

Simulation of terraces has been performed in a variety of models (Shao et al. 2013), the SWAT model (Arnold et al. 1998;Gassman et al. 2007; Arnold et al. 2012) has been used successfully to assess the impact of terraces on runoff (Yang et al. 2009 Ouassar et al. 2008), using an empirical approach involving adjustment of key input variables such as the runoff curve number (CN) (Shoe et al. 2013).

In the Tunisian semi-arid region, the SWAT model was used to respond to several issues related to evaluate a runoff and sediment yield (Bouraoui et al. 2005; Mosbahi et al.

2012; Ben Salah and Abida 2016), and to assess the impact of water quality. Other authors applied the model to examine the impact of landuse, agriculture practice and climate change (Abouabdillah et al. 2010 ; Aouissi et al 2014 Sellami et al., 2016). It is be noted that in Tunisia, few studies were targeted the impact of SWC structures on watershed hydrology (Ouessar et al. 2004; Ouessar et al. 2008; Abouabdillah et al. 2014).

The objective of this study is the assessment of the impact of bench terrace Water Harvesting (WH) intervention in large scale treated Tunisian watershed(Rmel) in semi-arid region using the SWAT model (Arnold et al. 1998; Arnold et al. 2012). For model calibration and validation SWAT-CUP (Calibration and Uncertainty Procedures; Abbaspour 2015) standalone program for parameterization analysis was applied. The set up and calibrated watershed model aims to support future water and land management studies for optimized implementation of SWC interventions in central and north Tunisian landscape.

31. Materials and Methods

Study area

The Rmel watershed is located in the north-eastern of Tunisia, between 36° 32.0.9’ and 36° 14.20’ Latitude North and between 10° 13.47’ and 10° 13.4’ Longitude East. The basin has a highly irregular terrain ranging from 20 to 1235 m.a.sl m. (Figure 1). The watershed covers an area of 675 km^2 and drains into the Rmel dam.

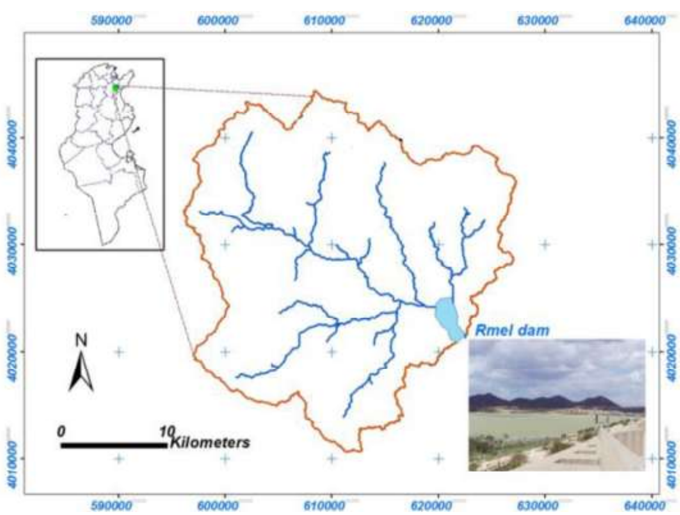

Figure 1. Location of Rmel watershed

The study area's channel runoff has been monitored since 1998 using high quality hydrological equipment.

The climate is classified as semi-arid according to the UNEP aridity index (UNEP 1992). Thus, the watershed is subjected to multiple influence: Mediterranean, by the effect of the sea and continental under the influence of mountain massive prevailing in the region. Average annual temperature and rainfall are 19.4°C and 470mm, respectively.

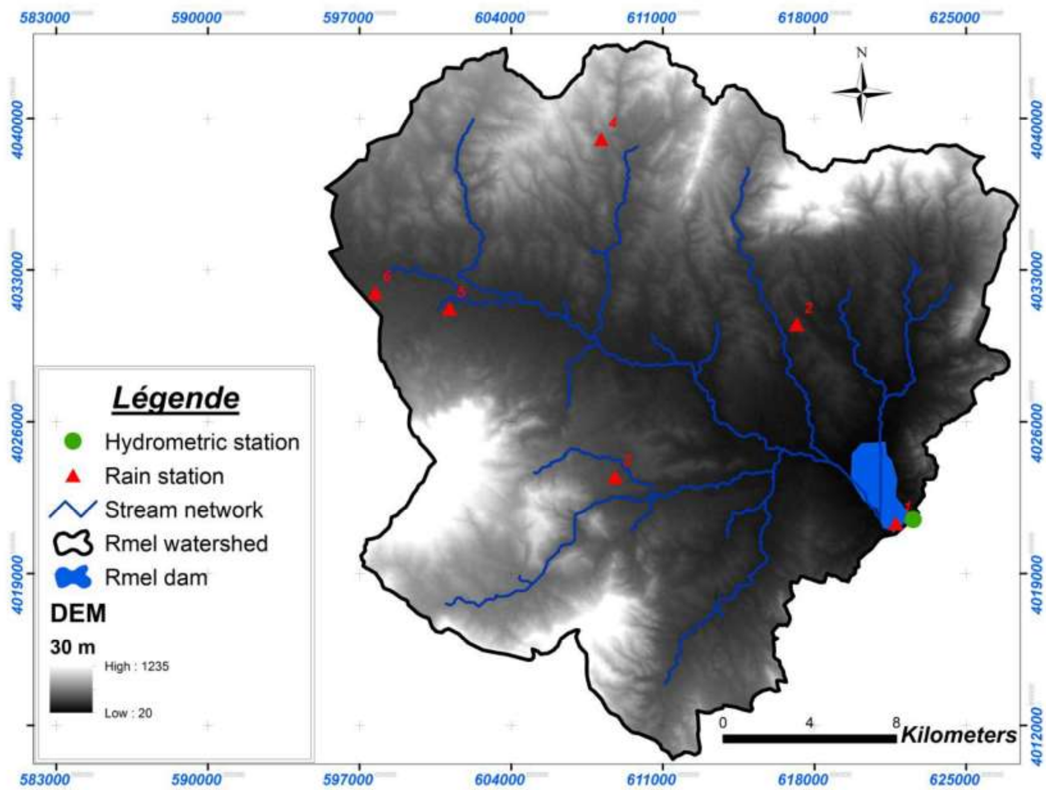

Figure.2. DEM and the localization of rain gauge and hydrometric stations

During the 1980s, agricultural areas of Rmel watershed have been intensively treated with Soil and Water Conservation (SWC) interventions, predominately through the establishment of bench terraces. Nowadays, more than 30% of entire watershed is treated. The benches terraces are an earth embankments built along contour lines, perpendicular to the slope, to intercept and store runoff water. The spacing between two successive benches varies according to the slope, between 30 to 70 m (Nasri 2007).

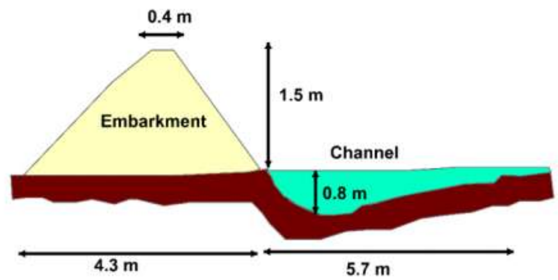

Figure 3 : the design of a bench terraces in study area

SWAT model

SWAT (Soil and Water Assessment Tool) is a physically based distributed hydrologic model operating on a daily time step and is designed to predict impacts of land management practices on water, sediment and agricultural yields (Arnold et al. 1998 Arnold et al. 2012).

For SWAT model set up the study catchment is divided into multiple sub-watersheds based on a DEM, which are then further subdivided into Hydrologic Response Units (HRUs) based on topography, landuse and soil types. Simulation of watershed hydrology is separated into the land phase, which controls the amount of water, sediment, nutrient, and pesticide loads to the main channel in each subbasin, and the in-stream or routing phase, which describes the movement of water, sediments, etc., through the channel network of the watershed to the outlet (Neitsch et al. 2011).The hydrologic cycle for each HRU is simulated based on the water balance:

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

Equation: 1

Where SWt 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), ET_i is the evapotranspiration (mm), and Q_{subi} is the groundwater flow (mm).

Surface runoff is estimated 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).

Flows are simulated from the HRUs to the sub-catchment level, and get routed through the stream system using either variable storage routing method (Williams 1969) or Muskingum routing method. (Overton 1966).

In this study, the SCS curve number and the variable storage routing method, were used for surface runoff and stream flow computations.

Surface runoff was calculated by the Soil Conservation Service (SCS) Curve Number (CN) method:

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

Equation: 2

Where, Qsurf is the accumulated runoff or rainfall excess (mm), Rday 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 due to changes in soils, land use, management and slope and temporally due to changes in soil water content – adjusted based on the antecedent rainfall. The retention parameter is defined as:

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

Equation: 3

Where CN is the curve number of the day which is an empirical parameter used in hydrology for predicting direct runoff or infiltration from excess rainfall. CN is 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).

SWAT input data and set up

SWAT model requires climatological, topographical, soil and land-use data. The data sources used in this study are as follows:

- Precipitation: Daily rainfall data from five rain gauge stations (Rmel dam, Oued Ezzit, Zriba, Zaghouan, Mograne and Sbaihia)were collected from the Direction of water resources of the Ministry of Agriculture.
- Climate data such as air temperature, relative humidity, solar radiation and wind speed were provided by the National Centers for Environmental Prediction (NCEP) for the period 2000-2011. The used climate station (364n103e) is located at 36.3747°Latitude North and 10.3125°Longitude East.
- Aster (Advanced Spaceborne Thermal Emission and Reflection Radiometer) GDEM (Global Digital Elevation Model) grid with a resolution of 30 m was used as topographical input to define the watershed boundary, river network, sub-basins, and to derive slope-related parameters.
- Soil map, at the scale 1/50000 m, obtained from the agricultural map of the Ministry of Agriculture for the year 2000. Soil classes were defined according to the CPCS (1967) classification system.
- Land-use map,at the scale 1/50000, was taken from the the agriculture map(Ministry of Agriculture 2000).The dominant landusesarewheat, followed by forest and rangebrush,

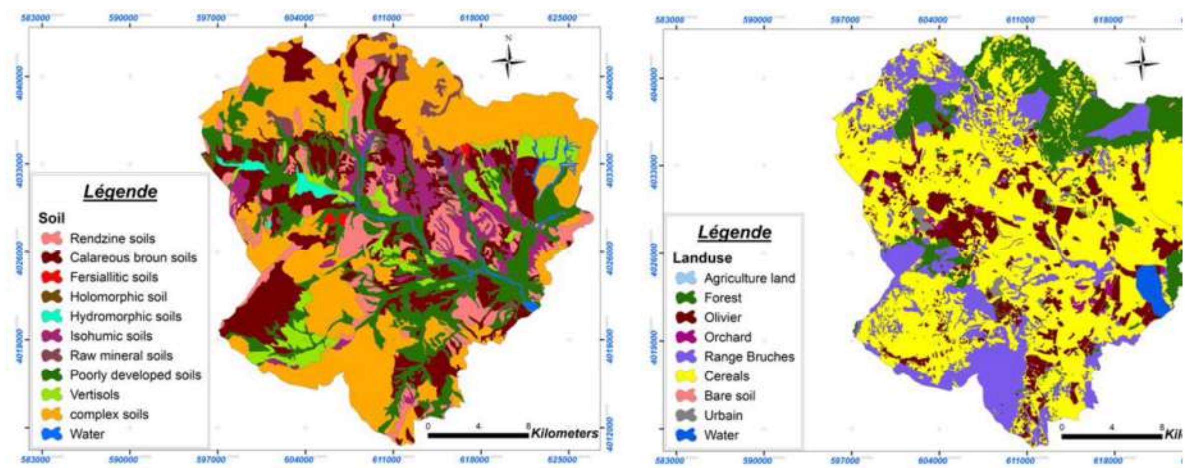

Figure 4 .Soil and landuse maps of the Rmel watershed

- Daily runoff data from 2000 to 2011 of the Rmel watershed measured at the Rmel dam gauging station were collected from direction of dam of the Ministry of Agriculture. The Location of the gauging station is shown in Figure. 1.

Model Calibration and Validation

Both calibration and validation of the model was performed based on daily runoff data recorded at the outlet of the watershed close to Rmel dam. The performance of the simulation was assessed based on the Nash-Sutcliffe Efficiency (NSE; Nash and Sutcliffe 1970).

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

Equation: 4

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

For model calibration SWAT-CUP software (Abbaspour et al. 2007; Abbaspour 2015) was used. In this research, various SWAT parameters related to runoff were estimated using the SUFI-2 algorithm (Abbaspour et al. 2007).

32. Results and Discussion

Rmel watershed was delineated using SWAT and the above mentioned SWAT input data considering 10% land use, 10% soil and 10% slope thresholds for creating the according HRUs analogue to the procedure performed by Her et al. (2012). After model set-up calibration was executed using SWAT-CUP software following the SUFI-2 procedure. The observed runoff at the outlet was calibrated for 5 years (2002-2006) using monthly and yearly runoff values and validated for five years of observation (2007-2011) with the consideration of two years as warming period as recommended by Abbsapour et al. (2015). Ten calibration parameters were selected based on the authors' knowledge of the watershed, SWAT parameter sensitivity analysis, and literature examples as reported by Malagò et *al*. (2015) and Abbaspour (2015). The selected parameters are shown in Table 1.

Table 1: Parameters used for calibration

Parameter	Description	Range

		Min	Max
r_CN2.mgt	Curve number for moisture condition II(*1)	-0.1	0.05
v_GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	4	14
v_ALPHA_BF	Baseflow alpha factor (days)	0.3	0.8
v_GW_DELAY.gw	Groundwater delay (days)	470	480
v_GW_REVAP.gw	Groundwater "revap" coefficient	0.15	0.18
v_ESCO.hru	Soil evaporation compensation factor	0. 80	1
v_REVAPMN.gw	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	0.1	2
v_RCHRG_DP.gw	Deep aquifer percolation fraction	0.006	0.2
v_AWC.sol	Soil available water capacity	0.5	0.9
r_SOL_K.sol	Saturated hydraulic conductivity.	-0.75	-0.35

r__ means the existing parameter value is multiplied by (1+*a*given value); v__means the parameter is replaced by a given value.

The model's performance was evaluated using graphical and statistical indicators (Nash-Sutcliffe efficiency (NSE)). The calibrated model simulates runoff reasonably well with a Nash-Sutcliffe efficiency of 0.80 for the monthly time step, and 0.74 for the yearly time step. In case of validation the Nash-Sutcliffe efficiency were 0.89 for the monthly time step, and 0.87 for the yearly time step. The results obtained after calibration and validation are depicted in following Figures 4 and 5.

Some peak runoff events are not well captured by the model which might be mainly related with the observed rainfall events and their spatial distribution (based on five observation stations).

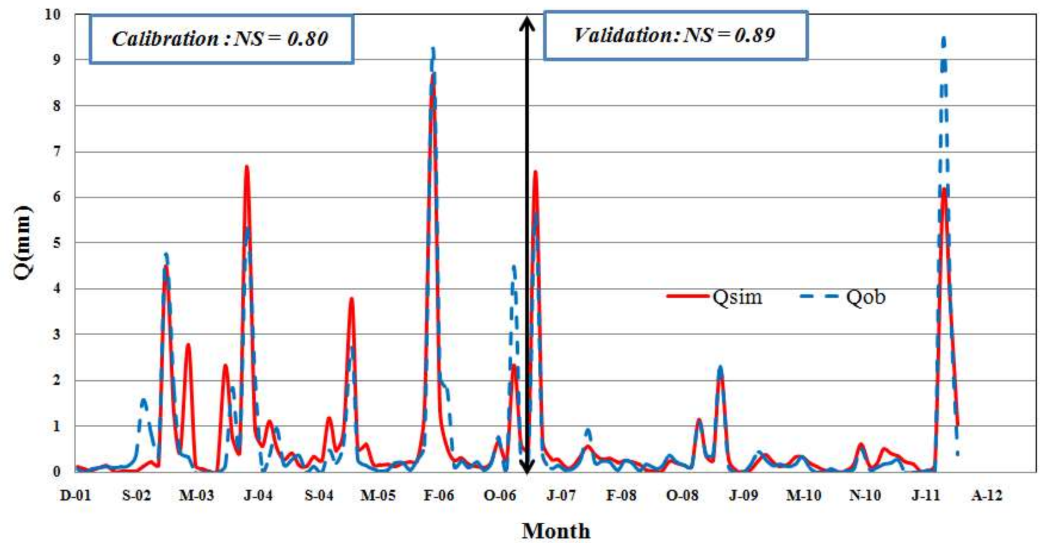

Figure 5 . Observed and simulated monthly runoff in the Rmel watershed during calibration and validation periods

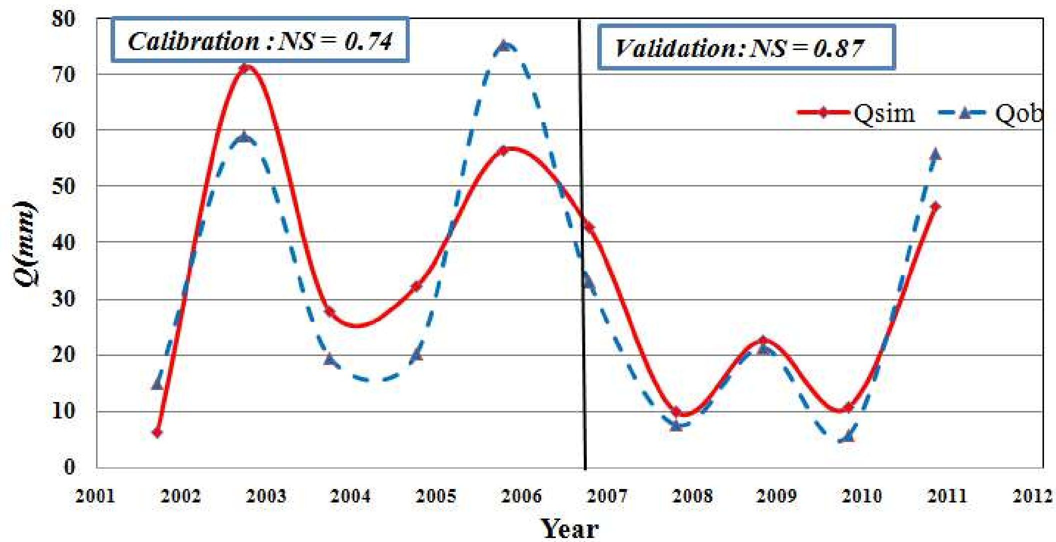

Figure 6 . Calibration and validation of yearly runoff in the Rmel watershed

Core-element of this research is the assessment of benches terraces impact on surface runoff implemented in the Rmel SWAT model. In this study, the surface hydrological effects of bench terraces were modeled through modifying the according Curve Number (CN) controlling the generation of surface runoff from the related HRUs representing treated areas. The starting values of those CNs were set - in accordance to the literature (Ben khelifa et al. 2016) - between 55 and 61 related/adjusted to the variable HRU (Hydrologic Response

Unit) characteristics. The specific CN ranges of the terraced areas were kept narrow (+/-10%) to avoid uncontrolled variation between the different terraced HRU's during calibration. The CN values of the untreated areas (forests and rangeland) were kept as derived by default by ArcSWAT 2012 software and a common +/-10% parameter range was set for SWAT-CUP calibration. After calibration of the in-situ Rmel watershed environment including local bench terrace treatment a 'zero-treatment' scenario was generated substituting the CNs of the treated areas with non-treatment values. Thus, the spatially distributed effect of bench terraces on runoff was evaluated as demonstrated by the 'percentage change map' (Figure 7).At the watershed level bench terraces reduced surface runoff by average of 44%.

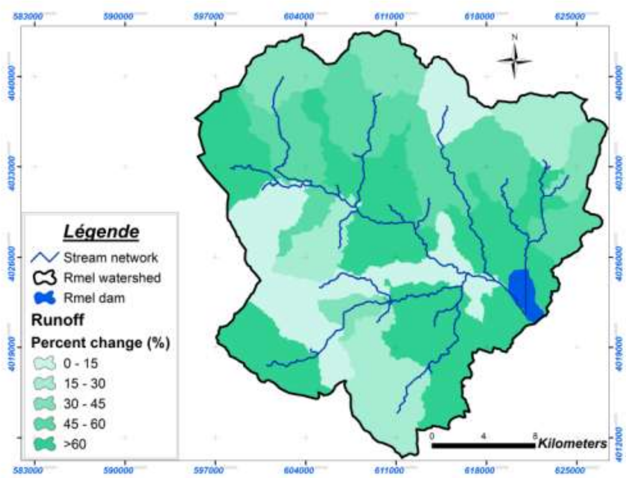

Figure 7 . Impact of bench terraces on the yearly runoff in the Rmel watershed

33. Conclusions

SWAT is a powerful tool for the assessment of multiple aspects of a watershed's land and water resources and their different process interactions. By means of the actual case study, carried out in northern Tunisian Rmel watershed, it has been demonstrated that SWAT also performs well in marginally studied semi-arid environment. Besides capturing general rainfall-runoff response, evaluated based on channel runoff records obtained from the outlet of the watershed, bench terrace Water Harvesting (WH) structures constructed on large areas of the agricultural lands have been considered and satisfyingly simulated. The case study uncovered significant spatial variability of bench terrace impacts on surface runoff and specified an overall reduction of 44% of surface runoff compared to a zero-treatment scenario. Some specific runoff events have been misinterpreted by the SWAT model which may be due to the small scale variability of erratic rainfalls assessed by five rain gauges distributed over the 675 km^2large watershed. Nevertheless, the research indicated a large potential for hydrological modeling for SWC impact assessment and various scenario generation. Detailed studies targeting the SWC impacts on agricultural production, soil erosion and reservoir siltation need to be carried out to provide a multi-disciplinary tool for optimized future water and land management.

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