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# Use of SWAT Model for the Assessment of Land Use Changes in an Arid Watershed of Southeast Tunisia

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**Résumé**
Dans les régions arides de la Tunisie, des efforts énormes sont menés pour la mobilisation des eaux de ruissellement et la conservation de sol et qui nécessitent actuellement l'évaluation des leurs impacts. L'objectif de cet article est d'adapter et de tester le modèle SWAT (*Soil Water Assessment Tool*) pour l'évaluation de impacts hydrologiques des travaux de conservation des eaux et des sols. Pour adapter le modèle à la réalité du secteur d'étude, des ajustements ont été entrepris à côté de l'utilisation de quelques options pour simuler les conditions du bassin versant d'étude. Des corrélations raisonnables ont été obtenues moyennant quatre indices statistiques en comparant les valeurs observés et simulées des débits de crues enregistrés. L'application du modèle pour l'estimation des impacts hydrologiques (ruissellement et recharge) a montré que SWAT présente des potentialités importantes dans l'étude des impacts malgré que la carence des données demeure un grande contrainte.

## Introduction

During the last two decades, the Tunisian government has engaged in a vast program for the conservation and mobilization of natural resources. In the Jeffara region, which encompasses the study site, huge works for soil and water conservation (water harvesting) have been implemented whose immediate effects are visible but their efficiency in both the short and the long term need to be assessed and evaluated in detail (De Graaff J. and Ouessar M., 2002). By simplifying and simulating natural processes, models have become efficient tools for analyzing the impacts of land use changes and the development of management practices. The objective of this paper is to adapt and evaluate the GIS-based SWAT model for the assessment of land use change impacts in an arid watershed of southeast Tunisia.

## Materials and Methods

### SWAT model

SWAT is a physically-based, watershed-scale model developed by Arnold *et al.* (1998) and has a GIS (ArcView) interface (DiLuzio *et al.*, 2002). It is a continuous time model that operates on a daily time step to estimate the effects of land and water management and pollutant releases in stream systems in large complex watersheds with varying soils, land use and management conditions over long period of time. SWAT has a database with default crop and soil parameters for the US conditions. These parameters need to be modified and tested for the study area conditions. In addition, the model code was adjusted to represent the typical conditions of watersheds in dry Mediterranean environments. A summary of the adjustments made will follow but details are found in Ouessar (2006) and Ouessar et al. (2006).

### Study Site and Parameter Selection

The model application has been carried out in the 336-km$^2$ watershed of Wadi Oum Zessar. The watershed is located in southeast Tunisia and has an arid Mediterranean bioclimate with an annual rainfall ranging between 150 and 230 mm. A variety of water harvesting structures

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is found: *jessour* in the mountains, *tabias* in the foothills and plains, and recharge structures (gabion check dams, recharge wells) in the wadi beds.

Daily rainfall measurements were collected from ten stations in and around the watershed. Daily values of maximum and minimum temperature were obtained from the weather stations of Médenine, Béni Khédache and El Fjè (IRA). Considering the availability of data, the PET was calculated by the Hargreaves method.

The subbasin delineation was obtained from a 30-m DEM was generated by the interpolation of digitized contour lines and altitude points obtained from topographic maps and information from a SPOT stereo pair. A soil map of the region (Taamallah, 2003) was adjusted to include the characteristics of the soils of the water-harvesting systems. The soil texture and organic matter were determined for representative profiles. The water holding characteristics were calculated with the texture triangle of Saxton *et al.* (1986).

To assess the effects of different land use changes resulting mainly from the implementation of water harvesting projects, two diachronic situations were chosen. The year 1991 was considered as the situation before the large scale implementation of water harvesting works 'before project' and the year 2004 as the situation 'after project'. The land use map elaborated for the *Jeffara* region by Hanafi *et al.* (2003) was modified with the help of a semi-supervised classification of the Spot XS image of 1991 of the area undertaken by Zerrim (2004). In addition, field checks were conducted. The following classes were distinguished: fruit trees (mainly olives) on *jessour*, fruit trees (mainly olives) on *tabias*, rangelands (mountains, plains, halophytes), and cereals. The runoff curve number (CN) was determined based on the land use and the soil hydrologic group.

To collect the runoff water behind the various water harvesting structures (jessour and old and new tabias), the SWAT code was modified to allow the use of surface runoff within the subbasin. This option is referred to as "irrigation from surface runoff". The new structures, which were developed to reduce floods and improve groundwater recharge, were represented in the model as follows: (i) the gabion check dams, installed on the main wadi beds (reach), were modeled as reservoirs but with relatively high K-values (leaky bottoms); (ii) The recharge wells, built for direct recharge of groundwater just upstream of the check dams, were modeled by increasing the K-value of the checks dams.

Runoff events recorded between 1975 and 1992 near the village of Koutine in the downstream area of the watershed were used for model evaluation. Eighteen events were used for calibration and sixteen for validation.

## Results and Discussion

The jessour and old tabias take a fraction (FLOWFR) of the surface runoff that is generated in the subbasin. The remainder, plus the amount that exceeds the dike height (DIVMAX) flows downstream. The calibration was performed by adjusting the values of DIVAMX and FLOWFR. The final values of DIVMAX were set at 0.20, 0.25, and 0.30 m for jessour, tabias, and new tabias, respectively, while the FLOWFR was set at 100% (jessour, tabias) and at 30% (new tabias). The evaluation of the hydrologic goodness-of-fit of the model for the observed and simulated runoff data, using four statistical criteria, gave reasonable results. The values of the regression coefficient, the model efficiency (Nash-Sutcliffe coefficient), the standard error, and the mean absolute error for the validation period were: 0.83, 0.83, 8.39, 0.21, respectively.

The results of the discharge evolution for the two different land use situation at the up-, mid-, and downstream compartments are presented in Figure 1. The water harvesting works undertaken in the area after 1991 reduced significantly (50-100%) the discharge, especially at the mid- and downstream compartments, and particularly during high rainfall events. In addition, the installation of the gabion check dams and recharge wells induced also a further

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reduction of the outflow. In fact, the water harvesting works concerned mainly the midstream area between the piedmont up to the village of Koutine. The main impact was induced by the installation of the new tabias that receive water by the partial diversion of the floodwater from the main reach.

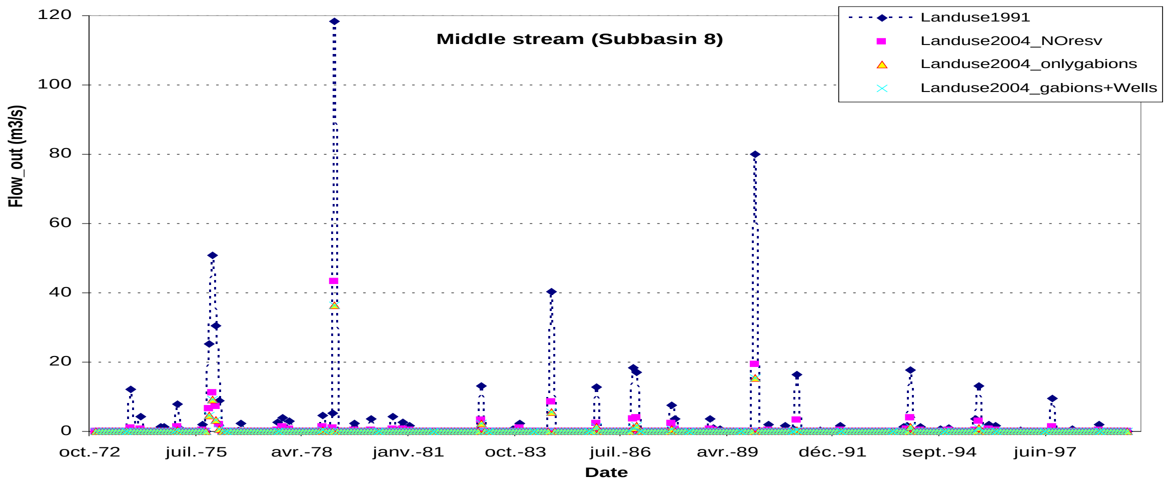


Figure 1. *Discharge at the midstream compartments of the watershed for the two different land use situations during the 27-year simulation period.*

The recharge was calculated for the subbasins overlapping with the preferential recharge area of the aquifers as shown in Figure 2.
The changes in land use induced positive effects (more recharge) during normal years but the effect was more significant during wet years. The recharge from transmission losses through the wadi beds occurred only during wet years, when important runoff flow takes place. However, no significant difference was found as a result of the installation of the gabion check dams and recharge wells. In fact, the percolation represented always more than 90% of the total recharge while the transmission losses and seepage from the wadi beds behind the gabion check dams rarely exceeded 4% in all land use cases, even though the problem of silting up was not taken into consideration. This is probably due to the fact that the area of the wadi network is negligible when compared to the crop and pasture lands where percolation to subsurface layers occurs.

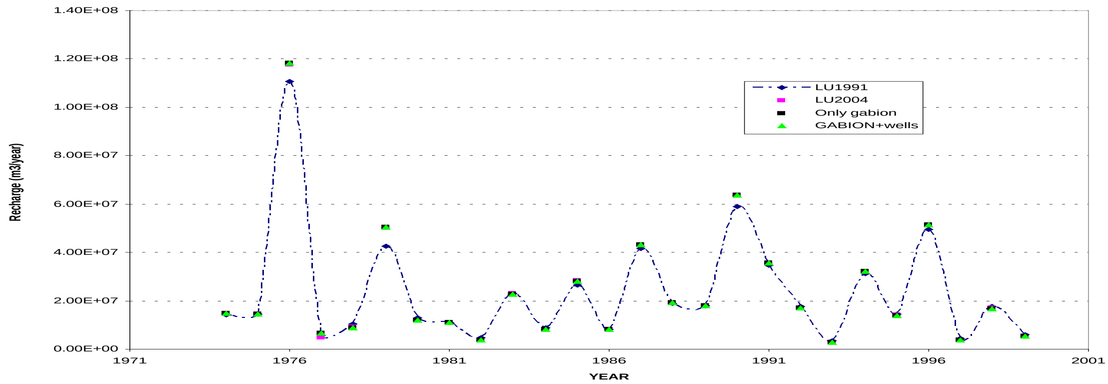


Figure 2. *Total recharge at the level of the watershed for the different land use situations during the27-year simulation period.*

## Conclusions

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The GIS-based model SWAT (version 2000) was adapted and evaluated in a dry environment of southeastern Tunisia represented by the study watershed of wadi Oum Zessar. All input data were prepared from available data and information. The selection of parameter values was mainly based on the knowledge of the site, in addition to information available in the literature. However, to adapt the model to the specific conditions of the study area, many adjustments were made.

Four statistical criteria were used to evaluate the hydrologic goodness-of-fit: the regression coefficient, the model efficiency or the Nash-Sutcliffe coefficient, the standard error, and the mean absolute error were used. Reasonable correlations were obtained for the outflow though better relations were found for the validation than the calibration period. Severe limitations were encountered during the calibration and validation of the model for the study site because of the limited number of observed runoff events and the uncertainty of the observed data. It is recommended to ease the access and/or exchange of data between the concerned departments (agriculture, research, education, environment, meteorology) at different levels (local, sub-national, national) especially for research and development purposes.

Although watershed modeling could be very useful, it is a labor and time consuming task. Still, the model remains very attractive for application, considering the gradual generalization and widening of the scope of the use of digital data layers and spatial decision support systems by the different target end users (agriculture, environment, planning, etc.) in the country (Min. Agr., 2002).

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