ASSESSING THE PERFORMANCE OF THE SOIL AND WATER ASSESSMENT TOOL HYDROLOGICAL MODEL FOR A SMALL MOUNTAIN FORESTED WATERSHED IN THE CENTRAL PART OF ROMANIA

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ABSTRACT

The Soil and Water Assessment Tool (SWAT) is a physically based watershed scale model, most widely used in many studies focused on predicting, over different periods of time, the impact of water, sediment and nutrients taking into account different land management in gauged or ungauged watersheds. The purpose of this study is to assess the SWAT model performance in a small mountain forested watershed, from the central part of Romania (Tărlungul Mare upstream Tesla). Using the SWAT-CUP (Calibration and Uncertainty Program) and the SUFI-2 algorithm (Sequential Uncertainty Fitting) was conducted a sensitive analysis of the parameters, and the calibration and validation of the SWAT model. The model obtained a good performance in simulating discharges compared to the measured ones. To assess the degree of uncertainty of the SWAT model results for the studied watershed were used the *p* and *r* factors. According to the literature, the values obtained for those factors indicate a low level of uncertainty in regards to the model's results and high performance in simulations. Therefore, based on the good performance of the SWAT model obtained for our study case, we can conclude that, depending of the accuracy of the input data, the model can be successfully applied in small river basins to assess the dynamics of hydrological processes and various land use and climate scenarios, this also represents the future research directions of this study. In addition, this work could bring an important support for stakeholders and decision makers in adopting coherent strategies for a sustainable management of small forested ungauged watersheds.

Keywords: *SWAT, mountain watershed, forest, stakeholders, hydrological modeling*

INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) estimates that the 21st century marks the beginning of a worldwide climate change, with it a warmer and wetter climate especially for the end of it [11]. The most recent set of scenarios put forward by this important organization foreseen an average air temperature increase of 5°C by the year 2100 and a differentiated rainfall regime according to the altitude [11]. Likewise, due to the climate variability and the socio economic and technological developments an increase of severe weather phenomena such as floods and droughts is foreseen [11]. Furthermore Vano et al. [14] states that water resources will be the most affected by the predicted climate changes thereby a sustainable management plan is necessary to ensure their availability. This can be achieved through the use of hydrological models. Therefore, at international level multiple studies have been conducted aiming to quantify the impact of climate change on the water resources. Thus, a series of hydrological models were developed for different watersheds areas and from distinct regions in order to evaluate the dynamics of hydrological processes over time. Most models report in the climate change context, a reduction of discharges and an intensification of extreme weather phenomena, emphasizing in the same time the importance of adopting the strategies to minimize these threats as much as possible and as well for the achieving a stability of water resources over time. For our country is foreseen that by the end of the 21 century the average temperature will increase by 2.8°C and the rainfall will be diminished by 3 to 21% [5]. Moreover, by the end of the 21 century, were also forecasts the reduction of the average annual runoff between 20 to 40% and also an increasing probability of severe weather phenomena such as floods and droughts [10]. The aim of this study is to evaluate the applicability of the SWAT model in a small forested watershed which is also the most important source of blue water for the Brașov metropolitan area, covering 90% of the water requirement.

MATERIAL AND METHODS

STUDY AREA

The Tărlungul Mare study watershed is part of the Tărlung river basin and it is located în the upper part of it, upstream of the confluence with the Tesla brook. The

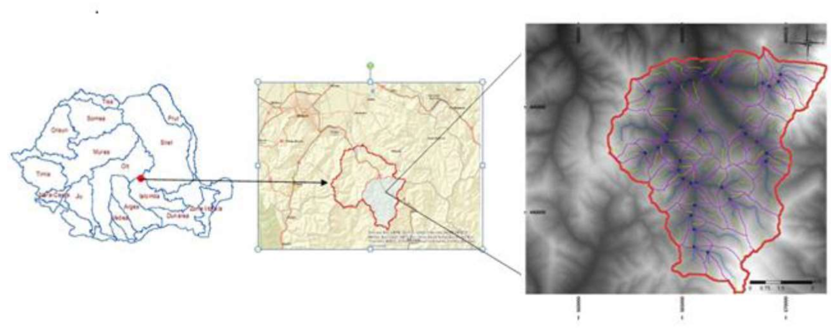

Figure 1 Study area location

Tărlung river basin is located in the central part of Romania, approximately to 20 km from the Brasov city (Figure 1). The computing section of the studied watershed

Tărlungul Mare is located at 45°52” eastern latitude and 25°84” northern longitude. From a climatic point of view, the analyzed area is in a moderate continental climate, characterized by quite accentuated thermal amplitudes.

The main morphometric description of the studied basin is present in Table 1. From an altitude the basin was divided by 11 classes, differentiated at 100 m intervals, their distribution being shown in Figure 2. In regards to the slope, 64% of the basin surfaces are lands with a slope between 15-45 degrees.

Table 1. Morphometric description of the watershed

Area	hectares	7169.53
	km^2	71.69
Altitude (m)	minimum	874
	medium	1248
	maximum	1842
The main stream length - 14.95 km		
The hydrographic network length - 216.49 km		

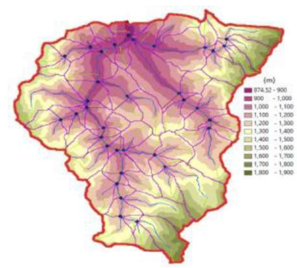

Figure 2. Watershed altitude distribution

SWAT MODEL DESCRIPTION

SWAT (Soil and Water Assessment Tool) [3] is one of the most widely used hydrological models for assessing the ways how climate change could influences hydrological processes that take place within different sizes watersheds [8]. It is a semi-distributed conceptual model that operates with a daily time step used to make predictions for different time intervals, regarding the impact of the land management methods on the hydrology, sediments and nutrients [13]. The model has its own database, valid only for United States territory, but it can be changed by each user (USERWGN) so that the study area to be most well represented [13]. The model database requires spatial and daily climatic data, the basin being divided into sub-basins further divided in turn into hydrological response units [3].

BUILDING SWAT MODEL DATABASE

As is mentioned previously, for researchers developed in regions outside of the United States, the model initially requires defining, in a specific format, the database that includes both the physical-geographic information of the studied area and daily and continuous data of certain climatic parameters. For the present study, the ArcSWAT 2012 version was used, and the steps will be described below.

DIGITAL ELEVATION MODEL (DEM)

It represents the first component in building the SWAT model. For the studied watershed, DEM was provided by *National Institute of Hydrology and Water Management* with 10 m spatial resolution. Based on this, the boundaries and the area of the watershed as well as the hydrographic network (streams and flow directions) were defined through the *Watershed Delineator* command. The watershed was afterwards split in 69 sub-watersheds and 1001 hydrological study units (HRUs) (Figure 3)

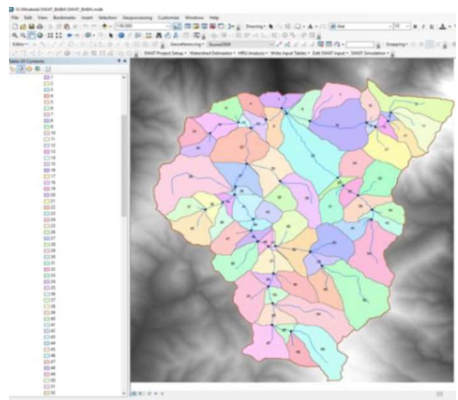

Figure 3. Sub-watersheds delineation

WEATHER DATABASE

The climate database was provided by the ROCADA V1.0 [4, 6] project and represents a homogeneous database designed for the 1961-2013 period. In order to elaborate this complex set of data like the ROCADA project, the authors used the daily climatic data recorded at 188 meteorological stations in Romania, whose spatial resolution is 0.1° [6]. The *National Institute of Hydrology and Water Management* provide us the data regarding the discharges recorded between 1974-2012 at the Babarunca hydrological station, located in the lower part of the studied watershed, data that were further used to run, calibrate and validate the model SWAT.

LAND USE DATABASE

The spatial distribution of the land use in the watershed (Table 2) was obtained after consulting the forest and forest-pastoral management plans [7, 15] developed for the studied area by the *National Institute for Research and Development in Forestry "Marin Drăcea"*. Furthermore were also analyzed satellite images of the area. Subsequently, correspondence between the land uses identified in the region and the ones defined in ArcSWAT was achieved in order to obtain the distribution of the land uses for the entire studied watershed (Figure 4). Almost 80% of the watershed area is forested. The next dominant land use is represented by pastures (about 19%).

Table 2. The land uses area within the watershed

SWAT Code	Definitions	Area	
		ha	%
FRSE	Forest Evergreen	2176.923	30.36
FRSD	Forest-Deciduous	3557.225	49.62
PAST	Pasture	1352.4919	18.86
Other		82.89	1.16
Total		**7169.53**	**100**

Figure 4. The land uses identified in the watershed

SOIL DATABASE

The database regarding the properties, characteristics and soil distribution within the Tărlungul Mare watershed is a detailed and personalized. This was also created using informations, maps and analytical reports from the forest and silvo-pastoral managements plans developed by the *National Institute for Research and Development in Forestry "Marin Drăcea"* for the studied territory [7], [15]. However, there were certain parameters such as SOL_BD (bulk density), SOL_K (hydraulic conductivity) and SOL_AWC (water availability), for which there was no available data. The determination of those parameters was performed using the *Soil-Plant-Atmosphere-Water-Field & Pond Hydrology* program. The main types of soil found in Tărlungul Mare basin (Figure 5) belong to two classes: Cambisols (Dystric Cambosol - 63.2% and Eutric Cambisol - 15.93%) and Spodisols (Entic Podzols - 15.85%) (Table 3).

Table 3 Soils types identified in the watershed

Soil type	SWAT CODE	Area	
		ha	%
REND	RO001	93.6101	1.31
EUTRT	RO002	966.0713	13.47
EUTRM	RO003	78.9001	1.1
EUTRL	RO004	5.62	0.08
EUTRG	RO005	22.58	0.31
EUTRS	RO006	69.3801	0.97
DYSTT	RO007	3070.5643	42.83
DYSTU	RO008	555.0908	7.74
DYSTP	RO009	95.6101	1.33
DYSTL	RO010	810.3111	11.3
HAPLL	RO012	1096.0815	15.29
HAPLH	RO013	40.2601	0.56
UDORL	RO014	165.6835	2.31
DYSTRFL	RO015	51.2601	0.71
DYSTRFLG	RO016	35.63	0.5
Total		***7169.53***	***100***

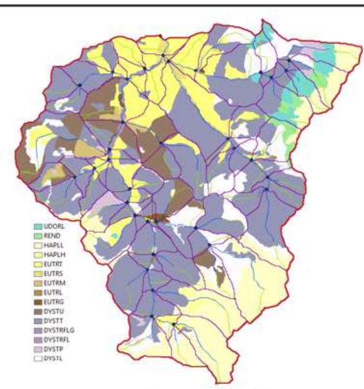

Figure 5. Soils types distributions

RESULTS AND DISCUSSIONS

RUNNING SWAT

The next step after filling the required database was running the SWAT in order to obtain the monthly discharges for the 1979-1988. The representation of measured and simulated discharges as well as rainfall is presented in Figure 6 and as it can be seen in certain months of the considered interval, the model has the tendency to underestimate the discharges recorded after high-flow events (May 1980 and 1984). A similar performance was also notice by Abbas et al. [1] and this can be attributed to the spatial variability of the rain in the watershed [9]. An overestimation of discharges rates from March 1982 and 1986 was also observed when the model generated much higher discharges compared with the measured, when the amount of rainfall recorded was lower and this might be due to snow melt during that period (the recorded average temperature was -3 ° C), a similar situation being mentioned by Abbas et al. [1].

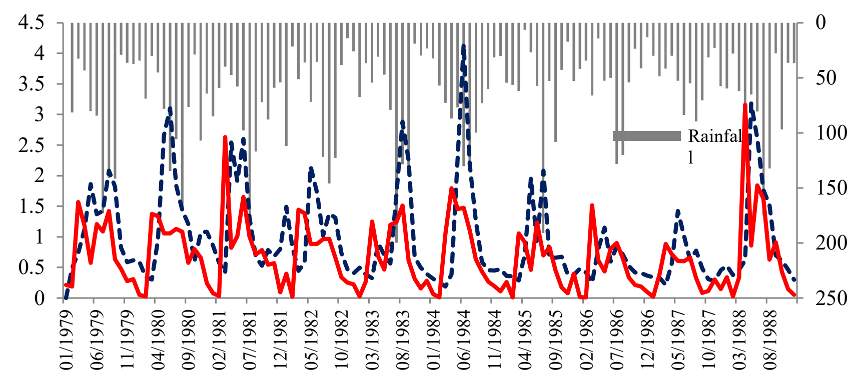

Figure 6. Rainfall, observed and simulated discharges in the Tărlungul Mare watershed

SWAT MODEL CALIBRATION AND VALIDATION

Before calibration and validation of the SWAT model is necessary to perform a parameter sensitivity analysis in order to identify the parameters with greatest influence on the surface runoff. This analysis was done using the SWAT-CUP program (Calibration and Uncertainty Programs [2]. In the analysis were included 12 parameters, out of which the most influence on the surface runoff was manifested by those which characterizing the groundwater and the lateral runoff, namely: REVAPMN, OV_N, GWQMN, LAT_TTIME, GW_REVAP, SOL_AWC. Calibration and validation stages are designed to evaluate model performance in discharges simulation and to analyze the similarities between the simulated and recorded values, quantified by statistical indices specific for adopted statistical function. In the present study, calibration and validation of the SWAT model were performed using the SWAT-CUP program, the SUFI-2 algorithm and the statistical function NSE (Nash-Sutcliffe Efficiency) [2]. This was conducted for the 1974-

1988 time period with a 5 year warm-up period necessary for model initializing. Six iterations of 500 simulations were performed to achieve a good performance between simulated and observed discharges. According to the statistical parameters of the adopted function (**R^2=0.79, NSE=0.67, RSR=0.**57 and **PBIAS=26.4**) and interpreted according to Moriasi et al. [12], the model fits to a good performance in simulating the liquid discharges compared to the measured ones. Moreover, the uncertainty level of the SWAT model assess according the *p*=0.72 and *r*=0.91 factors and interpreted according to Abbaspour [2] indicate a low degree of uncertainty in regards to the model's results.

The validation was carried out for the 2007-2012 period (with 2 years warm-up period) and confirmed the calibration results [2]. A single iteration of 500 simulations was performed. The results obtained (**R^2=0.66, NSE=0.65, RSR=0.59** and **PBIAS=2.1**) and interpreted according to Moriasi et al. [12] show a good performance of the SWAT model. Observed and simulated discharges and rainfall are shown in the Figure 7. Even though the model overestimate certain discharges (March and October 2009, March 2011 and 2012), there are also situation where these are underestimated (July 2010, May and June 2012) and this may be due to some high-flow events. This deficiency of the model was also reported by Abbas et al. [1].

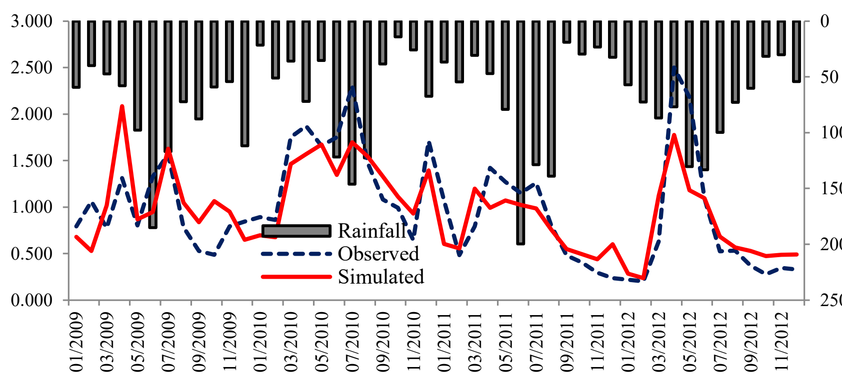

Figure 7. Rainfall, observed and simulated discharges during the validation

Using the 95 Percent Prediction Uncertainty (95PPU) it can be seen, according to the value of the *p* factor, that the 95PPU band data rate is 72% in calibration and 75% in validation (Figure 9). According Abbaspour [2] a value of *p* factor exceeding 70% signifies a low degree of uncertainty and the model acceptance. Also, for the both factors (*p* and *r)* we obtain higher values in validation, which means that the efficiency and model performance in simulated discharges are confirmed.

CONCLUSIONS

The aim of the present study was to assessing the performance of the SWAT hydrological model in the small mountain forested watershed located in the central part of Romania. The analyzed watershed is also the most important source of blue water, covering 90% of the water requirement of the Brașov metropolitan area. After building a detailed and personalized database for the studied area we run the model for 15 years period. Even though the model showed some tendency to underestimate the discharges recorded after some high-flow events, the overall performance obtained within the calibration and validation stage was a good one, derived from the accuracy of the input data. Moreover, the value of the p and r factors revealed a low degree of uncertainty of the SWAT model. Based on the obtained results we can conclude that, even the most researches are conducted in large watersheds, the model could also be successfully applied in the watersheds with small areas. Further directions of the research are applying the climate and land use regional scenarios which are designed to provide forecasts regarding the water dynamics in order to help the regional or local decision makers and stakeholder in development the management strategies for watersheds and for other sectors also related to the water resources.

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