Article

A regional sensitivity analysis of a multi-variable hydrological model: A case study of a Greek catchment

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Abstract: The importance of climate data in hydrological process simulation is widely recognized. The evaluation of the hydrological budget response to climate variability is required especially in water resource management. The present paper illustrates a case study of sensitivity analysis for the hydrological model SWAT (Soil and Water Assessment Tool) using climate data from the Havrias river basin in north Greece. The ERA-Interim reanalysis daily climate data, were used as input data to drive the SWAT model. The SWAT model was calibrated for the period from 1981 to 2000. The sensitivity of the hydrological parameters to the alteration of the climate data was analyzed by using eleven hypothetical scenarios. These scenarios regard different combinations of temperature, wind speed, precipitation and relative humidity. The results show that the changes of precipitation temperature and relative humidity have significant influence in evapotranspiration and percolation (and consequently recharge) in the study region. On the contrary, the wind speed negligibly affects on the hydrological components. Overall, the Havrias river basin hydrological budget is sensitive to shifts in climate data and the utilization of reliable and accurate climate models outputs is necessary in order water managers to be able to build scenarios providing sustainability against the potential future climate change impacts.

Keywords: SWAT software; Havrias River Basin; climate variability, water budget components

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1. Introduction

Numerous multi-variable hydrological models have been widely implemented to comprehend the hydrological processes and establish the water balance. The credibility and the effectiveness of these models are mostly dependent by their inputs, especially the climate data. The comphrehension of the hydrological budget components response to the climate variability has become more and more fundamental. Based on the Intergovernmental Panel on Climate Change [1], the climate change effects on water resources are unambiguously. In several scientific studies were used hydrological models in order to assess the hydrological cycle response under different climate scenarios [2-4]. Song et al. 2015 [5] presented a review of the sensitivity analysis in hydrological simulation underlining its importance and appropriate role.

The objective of this paper is the sensitivity analysis of the hydrological budget components of a watershed to variations in climate parameters. The Soil and Assessment Water Tool (SWAT) was used for the modelling of the watershed. The SWAT hydrological model is an suitable and useful tool for the watershed process simulation such as the water balance and quality, the crop growth, the climate change and the land management practices. The SWAT application was conducted in the

Havrias river basin which is situated in north Greece. The Havrias river basin was selected as the case study, because it is an agricultural and ungaged watershed and it can be considered as a represantative watershed of the Greek region. The ultimate scope of this paper is to comprehend which of the climate parameters mostly influence on model's performance.

2. Materials and Methods

2.1. Study Area

The Havrias river basin is one of the most significant watershed of Halkidiki in north Greece. The basin drains into the Kassandra Gulf. Its elevation varies between 0 m and 1090 m, covering an extent of 472 km^2, based on the GIS Analysis. The mean slope of the watershed is about 22%. The Mediterranean climate CSa, according to Köppen classification [6] is identified in the research area. The agricultural land represents approximately 33% of the total area. The major crops are the olive groves. Broad-leaved, coniferous and mixed forests occupy the northern part of the watershed. Geologically, the coastal part is consisted of alluvial deposits, lacustrine and lagoon sediments, red clay and basic conglomerates series. Metasedimentary rocks, gneiss, phyllite, recrystallized limestone, gabbro, pyroxenites and dounites are encountered in the rest of the basin. The main aquifer systems are developed within alluvial deposits (porous aquifer) and limestones (karstic aquifer). Water needs for domestic and irrigation use are mainly covered by the exploitation of the aforementioned aquifers through numerous boreholes and wells.

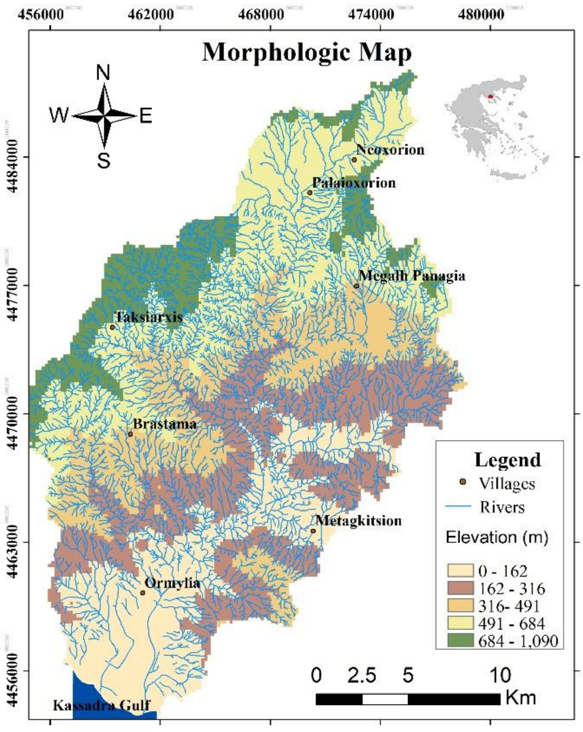

Figure 1. The morphological map of the Havrias river Basin.

2.2. SWAT Model

2.2.1 Description of SWAT Model

The Soil and Water Assessment Tool (SWAT) is a watershed scale hydrological model [7-8] which is developed by the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) (Arnold et al., 1998). It is a semi-distributed and physically based model, running on a daily time step. Its task is to assess the impact of the land and agricultural management practices on water, sediment and agricultural chemical yields. In SWAT, any watershed is separated into sub-watersheds based on the topography and the drainage network. Then, each sub-watershed is further divided into smaller units which are called hydrologic response units (HRUs). The HRU can be determined as an area within a sub-watershed with the same land use classification, soil properties, slope characteristics and management combinations. The hydrological process is described by the water balance equation:

$$SW_t = SW_o + \sum_{i=1}^{t}(R - Q_{surf} - ET - P - QR) \quad (1)$$

where

SW_t = the final soil water content (mm), SW_o = the initial soil soil water content (mm), R= the daily precipitation (mm), Q_{surf} = the daily runoff (mm), ET= the daily evapotranspiration (mm), P= the daily percolation (mm), QR = the groundwater flow per day

A detail description of the SWAT model is demonstrated by Arnold et al. (2012) [9].

2.2.2 Data

A variety of data such as morphological, climate, land use and soil is required for the SWAT implementation. A Digital Elevation Model (DEM) with a spatial resolution of 5 m was used in order to delineate the watershed. The topographical data of the study area were provided by the National Cadastre and Mapping Agency S.A. of Greece. The land use of the study area is derived from the Corine Land Cover 2012 (https://land.copernicus.eu/pan-european/corine-land-cover/clc-2012). The results of the laboratory soil tests, which took place in the Laboratory of Engineering Geology & Hydrogeology of Aristotle University in Thessaloniki, were taken into consideration in order to create the soil map of the study area.

Daily precipitation, maximum and minimum air temperature, solar radiation, wind speed and relative humidity data are demanded as SWAT input climate data. In this study, the ERA-Interim reanalysis data with a spatial resolution of 12.5 km, which are publicily available by the European Centre for Medium-Range Weather Forecasts (ECMWF) (http://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=sfc) were used to drive the SWAT model. In the framework of this paper, the ERA-Interim climate data cover the period from 1981 to 2000.

2.2.3 Model set up

The simulation of the Havrias river basin was conducted by using the ArcSWAT interface for SWAT2012. The Havrias river basin was divided into 23 subbasins after the watershed delineation. The HRU definition was carried out by using the land use, the soil and the slope data. The land cover and the soil data were reclassified based on the SWAT model's specifications. Five slope classes were defined for the HRU classification. A threshold of 0%-0%-0% was set up for the land use, the soil type and the slope, respectively. Overall, 309 HRUs were created.

The Penman-Monteith method was implemented so as to estimate the potential evapotranspiration (PET). The surface runoff was computed by using the Soil Conservation Service's curve number (CN2) method. The SWAT model was initially run for the period from 1981 to 2000.

The calibration was accomplished by using the trial – and - error procedure.

The sensitivity analysis of the hydrological budget components to the variation of the climate parameters was carried out by using eleven hypothetical scenarios. Table 1 illustrates these scenarios which include different combinations of temperature, precipitation, wind speed and relative humidity. The land use remained stable during the simulation of the hypothetical scenarios.

Table 1. The hypothetical climate scenarios.

Scenario	Temperature (°C)	Precipitation (%)	Wind speed (%)	Relative Humidity (%)
1	**+1**	0	0	0
2	**+2.5**	0	0	0
3	0	**-5**	0	0
4	0	**-10**	0	0
5	**+2.5**	0	**+50**	0
6	**+2.5**	**-5**	**+50**	0
7	**+2.5**	**-5**	**+50**	**-25**
8	**+2.5**	**+5**	**+50**	**+10**
9	0	**+5**	0	0
10	0	**+5**	0	**+5**
11	0	0	**+50**	0

3. Results

3.1. Hydrological bugdet componets simulation

Based on the SWAT simulation results regarding to the period from 1981 to 2000, the evapotranspiration was calculated equal to 309.6 mm, representing about the 60% of the mean annual precipitation (520.1 mm) of the Havrias river basin. The potential evapotranspiration was estimated equal to 949 mm. The percolation to shallow aquifer was estimated equal to 106.64 mm and the recharge to the deep aquifer equal to 5 mm. The surface runoff was computed at 59.51 mm. Figure 2 comprehensively depicts the hydrological procedures of the Havrias river basin.

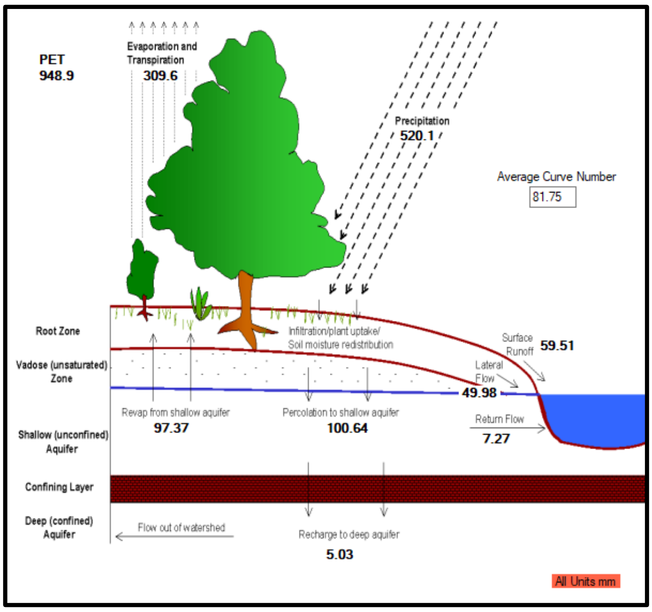

Figure 2. The hydrological procedures of the Havrias river basin for the period 1981-2000.

3.1.1. Hydrological budget components simulation under different hypothetical climate scenarios

Table 2 demonstrates the SWAT simulation results of the water budget under different scenarios. The following results can be drawn from the Swat simulation of the Havrias river basin under the hypothetical climate scenarios:

- The temperature increase by 2.5 °C (Scenario 2)resulted in increase by 8% and 1.4% in potential evapotranspiration and in evapotranspiration, respectively. On the contrary, the percolation to the shallow aquifer and the recharge to the deep aquifer was decreased by 9.3%.
- Reducing and increasing the precipitation, reduced and increased all the hydrological components, respectively. No changes observed in the potential evapotranspiration.
- Increasing only the wind speed (Scenario 11) resulted in slight decrease in evapotranspiration, percolation and consequently in recharge.
- The largest increases of evapotranspiration and decreases of runoff and percolation obtained when all the climate parameters (temperature, precipitation, wind speed, relative humidity) were changed.
- Scenario 7 showed an augment by 59% and 13% in potential evapotranspiration and evapotranspiration, respectively, whereas a decrease by 50% and 11% in percolation and hence in recharge to deep aquifer and in surface runoff, accordingly.

Table 2. The SWAT simulated hydrological budget components under the different hypothetical climate scenarios.

Scenario	Potential Evapotranspiration (mm)	Evapotranspiration (mm)	Percolation (mm)	Surface Runoff (mm)
1981-2000	949	309.6	106.6	59.5
1	979	311.3	98.6	60.2
2	1024.5	314.0	96.2	60.3
3	949.0	299.1	93.9	53.2
4	949.0	289.4	86.3	47.7
5	1219.3	332.1	84.4	56.5
6	1219.3	321.9	77.6	50.3
7	1515.6	359.4	52.9	41.9
8	1143.9	350.2	54.6	61.5
9	949.0	316.9	108.7	66.9
10	900.8	321.1	106.0	66.0
11	949	308.2	101.2	59.8

4. Discussion and Conclusions

A regional sensitivity analysis of the hydrological budget components of the Havrias river basin to the variations of the climate parameters was performed in this study. The sensitivity analysis showed that the Havrias river basin is vulnerable to the variability of the climate parameters. Based on the SWAT simulation results, the temperature, the precipitation and the relative humidity highly influence the hydrological budget components of the study area. In contrast, the wind speed has negligible role in hydrological processes. In accordance with the author's findings, Ficklin et al (2009) presented that the hydrological system of a highly agricultural watershed is sensitive to climate variability. According to their results, the changes in temperature highly influence on the hydrological components.

This paper is a preliminary research on the assessment of the sensitivity of the hydrological components to potential future climate change, laying the foundation for using the climate models outputs so as to quantify the climate change impacts on water resources. The couple of reliable climate and hydrological models is essential in order water managers to be able to build scenarios providing sustainability against the anticipated climate change.

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Author Contributions: Panagiota Venetsanou, collected and evaluated the data, and wrote the paper. Christina Anagnostopoulou conceived the idea and evaluated the climate data. Athanasios Loukas contributed to the application of the SWAT model. Konstantinos Voudouris coordinated and supervised the project.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviation is used in this manuscript:

SWAT: Soil and Water Assessment Tool

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