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SIMULATING HISTORICAL, ACTUAL AND FUTURE WATER BALANCE IN MOUNTAINOUS WATERSHED

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Abstract

Hydrological predictive models (HPM) represent a useful tool for surface water simulation analysis. In this study, the Soil and Water Assessment Tool (SWAT) was utilized to investigate the spatiotemporal variation of runoff, groundwater recharge and evapotranspiration within a mountainous basin in Campanian Plain in the south-western part of Italy. The SWAT was spatially calibrated and validated using monthly stream flow data (1954-1962) to simulate yearly historical (1950–1960), actual (2000-2010) and future (2030-2040) watershed system conditions. The simulation results revealed the impact of climate change on the runoff and recharge of aquifers. Considering future climate predictions, a slight increase in evapotranspiration with an additional decrease in recharge values has been forecasted. These results showed that groundwater recharge is strongly affected by surface water and climate variations.

1 Introduction

Nowadays climate variability is affecting the agricultural productivity worldwide and is also altering soil erosion and water quality. Thus, the use of long-term observation data in simulation models can provide important insight for the protection of surface-groundwater systems (Fu *et al.* 2010). The research and need of suitable solutions to contrast groundwater depletion led to the implementation of several water simulation models, such as the Soil and Water Assessment Tool (SWAT, Neitsch *et al.* 2000). SWAT operates on a daily, monthly, and yearly time step and simulates the land surface, vadose zone, in-stream, and soil domain processes (Arnold 1998). SWAT is considered an important tool for integrated river basin management, since its application can provide crucial information on the water balance variation depending on future climate and land use changes (Anand *et al.* 2018). The last years, SWAT model has been applied in numerous research for the investigation of spatial runoff and recharge changes due to climate variability (Krysanova and White 2015; Gassman *et al.* 2017; Busico *et al.* 2020; 2021). The aim of the present study is to investigate:

i) the spatiotemporal variation of runoff, groundwater recharge (RCHA), and potential evapotranspiration (PET),
ii) to quantify the groundwater depletion magnitude driven by climate variability within the Volturno and Calore basin in the Campania region.

For this purpose, future climate data were obtained from the Coordinated Regional Climate Downscaling Experiment (CORDEX) considering the Representative Concentration Pathway (RCP) 4.5 as well precipitation and temperature data from meteorological stations in the area. SWAT was spatially calibrated and validated using real monthly stream flow data (1954-1962) and then forced to simulate three main scenarios: historical (1950–1960), actual (2000-2010), and future (2030-2040).

2 Materials and Methods

2.1 Study area

The research area covers the Upper Volturno and Calore basins in Campania region (Tyrrhenian side of the Southern Apennines, Italy). The Volturno river is the largest river in Campania while the Calore river is its main tributary (Figure 1). The study area is about 4179 km^2, while the altitude varies from 20 to 1783 m. The mean annual temperature for the period of 2000-2010 was 16.4 °C and the mean annual rainfall was up to 1245 mm. Both areas are characterized by several agricultural activities (cereals, vegetables, orchards, and vineyards) while the higher mountains are mainly covered by forests and pastures. The geology setting of the Upper Volturno and Calore watersheds consists of dolomites, limestones, sandstones, clay-marl flysch, and pyroclastic fall deposits. Concerning the soil features, the Upper Volturno basin is characterized by clay and silty-clay soil texture while the Calore basin is characterized by clay-loam and loam soil texture.

Figure 1. Study area (Google map).

2.2 SWAT setup and calibration

SWAT requires some basic information for delineating the basin into sub-basins and hydrologic response units (HRUs). Thus, for the current study, the following input data were considered: i) Digital Elevation Model (DEM) with a resolution cell of 10 m, ii) Soil map (Digital Soil World Map; FAO 2007), and iii) Land Cover map (Carta utilizzo agricolo dei suoli; CUAS 2009) (Figure 2). SWAT was calibrated and validated using monthly stream flow data for the period 1954-1962, with 3 years of model warm-up. Historical data were collected from three meteorological stations (San Agata, Benevento, and Apice), actual data were collected from other three stations (Solopaca, Airola, and Vitulazio) and future climate data, for the period from 2030 to 2040, were automatically generated using the SWAT weather generator considering RCP 4.5 scenario. PET was calculated with the Hargreaves method.

The simulation has been calibrated and validated using monthly streamflow data coming from the Apice hydrometric station for the period 1954–1962. Calibration was performed using monthly data for the period 1954-1959 and validation was performed for the period 1960-1962. For the calibration procedure the standalone SWAT-CUP program and SUFI-2 uncertainty analysis algorithm (Sequential Uncertainty Fitting, ver. 2) (Abbaspour *et al.* 2007) were used. The Nash and Sutcliffe model efficiency (NSE), the percent bias (PBIAS), and coefficient of determination (R^2) were used as optimization functions to evaluate model performance, according to Moriasi *et al.* (2007). All the input data are mentioned in Table 1.

Table 1. List of input data.

Input data	Details
Land Cover	Agricultural land use map (Carta utilizzo agricolo dei suoli - CUAS, 2000, 2009)
Soil Characteristics	Land systems of Campania. (Sistemi di terre delle Campania), FAO classification, WOSIS dataset
DTM	Shuttle Radar Topography Mission (SRTM) 10mx10m
Climate data	World Climate Research Program's CORDEX and actual data from 3 meteorological stations
Hydrometric data	Yearly Hydrological

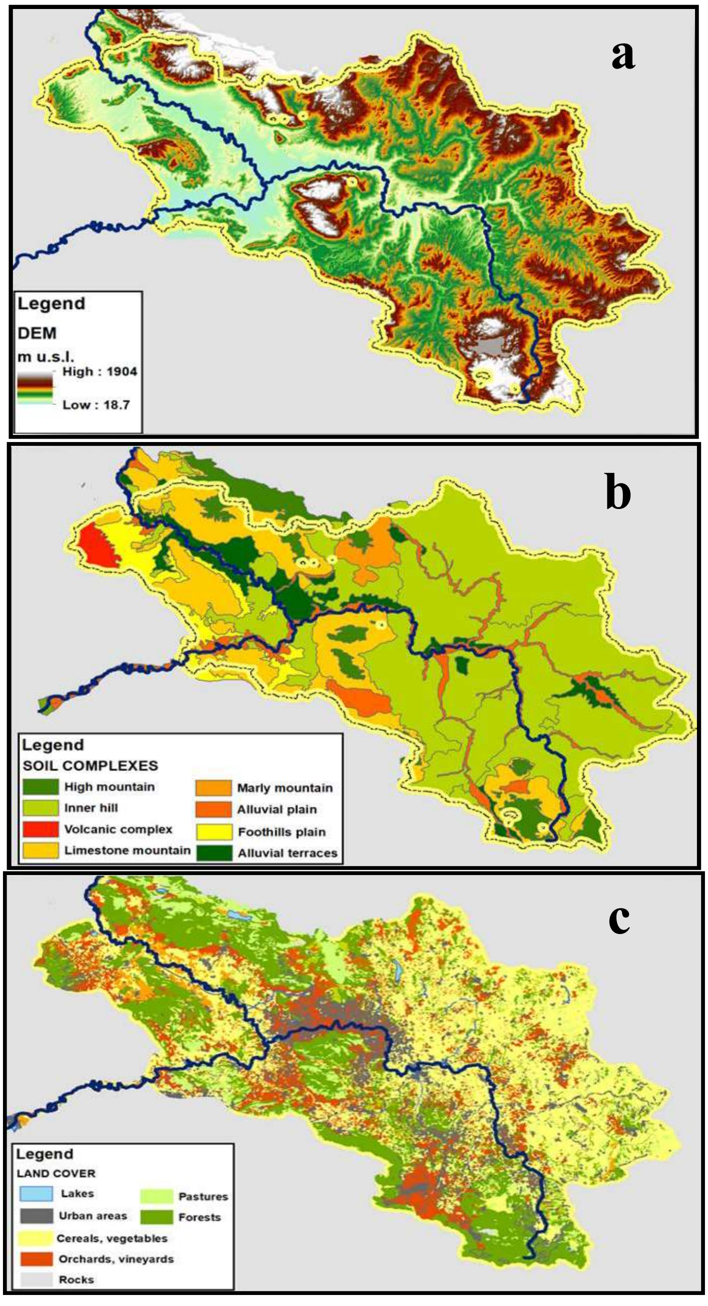

Figure 2. SWAT model setup for the Volturno-Calore basin containing the main watershed information, elevation (a), soil (b) and land use (c) dominance.

3 Results and Discussion

Five thousand calibration runs were performed until a satisfactory calibration was obtained. Eight parameters were selected for calibration, related to surface runoff (CN2), snowmelt (SMTMP, SFTMP), evapotranspiration (ESCO), groundwater recharge (RCHRG_DP), elevation bands (TLAPS, SNOEB), and soil (DEP_IMP) processes. For the calibration, the results showed a very high R^2 (0.8), followed by a good value of NSE (0.75), and a satisfactory value of PBIAS (15). For the validation period, R^2 and NSE values were found to be 0.78 and 0.75, respectively. The streamflow chart in Figure 4 shows a slight underestimation for both periods, within the acceptable range of PBIAS ±25%. Overall, the performance of the model can be considered satisfactory with a slight underestimation (Figure 3).

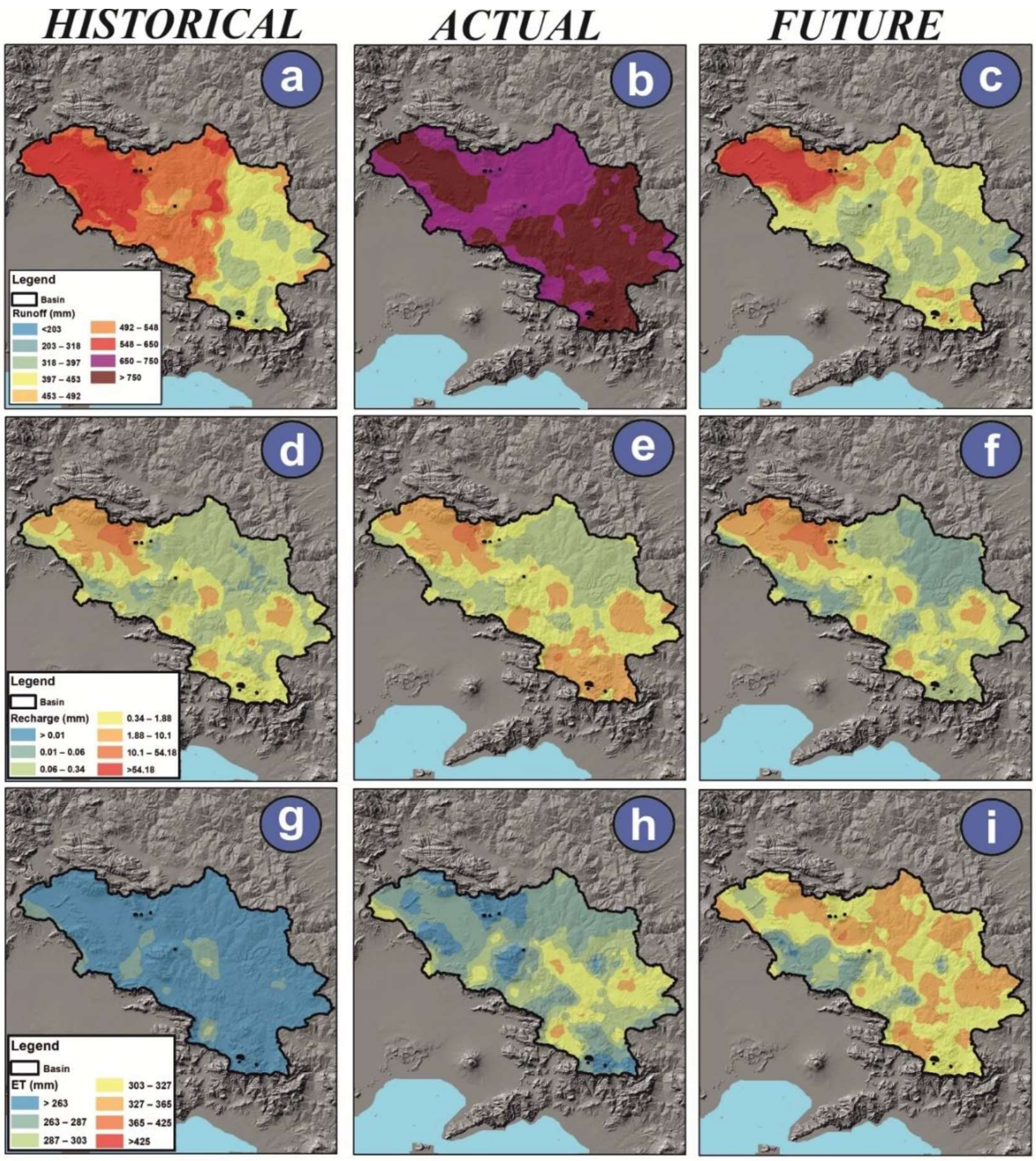

Figure 3. Spatial distribution and time evolution of runoff, groundwater recharge, and evapotranspiration.

The spatial distribution of RCHA and ET was obtained using the HRUs output, converting the data of each HRU in a point feature further spatialized using the kriging technique (Figure 4). Runoff shows an upward trend (Figure 4a, b) followed by a downward trend (Figure 4b, c)

during the three periods, due to the increase (1250 mm) and decrease (800 mm) of precipitation for the actual and future scenario, respectively. RCHA will also suffer a decrease in the future, but comparable to historical situation. In any case, the presence of areas with typical karst features, such as sinkholes or open shafts, could allow point recharge amplified by the very high runoff regime of the area. PET shows an increasing trend moving from historical, actual, and future scenarios according to the raise of temperatures (Figure 4g, h, i). Specifically, PET moves from a maximum of 55% during the historical period to a maximum of 64% in the future. The spatial distribution of the parameter suggests an increase of PET also in the mountainous area. The maximum RCHA is stable during the three periods but in terms of absolute values, the future scenario will be characterized by a lower amount of RCHA. Spatially, RCHA will lower in the Calore basin while it will be stable in the Upper Volturno (Figure 4d, e, f).
According to the above-mentioned, to avoid future water scarcity is mandatory to manage aquifer recharge techniques (such as small dam construction). Managed Aquifer Recharge (MAR) is a widely used method for subsequent recovery of the aquifers through injection wells etc. In addition, a combination of surface-groundwater modeling can improve the current results.

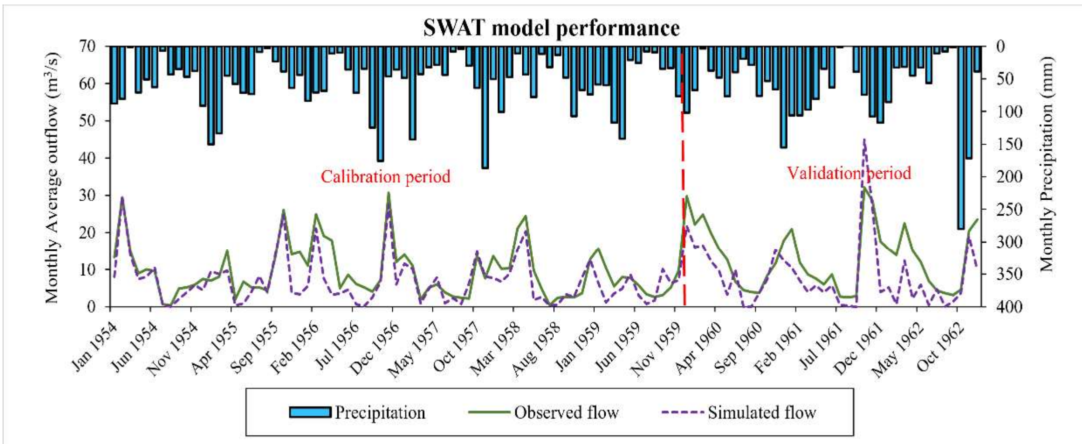

Figure 4. Calibration and validation result.

4 Conclusion

In this study, projections of runoff, recharge (RCHA), and potential evapotranspiration (PET) were investigated in the Upper Volturno and Calore basins. According to RCP 4.5 scenario, a reduction of RCHA is predicted in the study area for the period 2030–2040 with an increase of PET, accounting for up to 64% of the average annual water balance. The produced maps represent a useful tool to show the impact of climate variability in the area and to direct remediation actions. The maps also remarked some differences in the spatial distribution of runoff, RCHA, and PET among the two sub-basins.

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