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EDITORS:
K. VOUDOURIS, N. KAZAKIS, S. PIKOULA, M.M. NTONA

ΕΠΙΜΕΛΕΙΑ:
Κ. ΒΟΥΔΟΥΡΗΣ, Ν. ΚΑΖΑΚΗΣ, Σ. ΠΙΚΟΥΛΑ, Μ.Μ. ΝΤΩΝΑ

PREDICTION OF WATER BALANCE VARIABILITY IN MOUNTAINOUS WATERSHED

[1]BUSICO G., [1,2]NTONA M.M., [1]MASTROCCICO M., [3]COLOMBANI N., [2]BANNENBERG M., [4]CHALIKAKIS K., [2]VOUDOURIS K., [2]KAZAKIS N.*

[1]Campania University "Luigi Vanvitelli", Department of Environmental, Biological and Pharmaceutical Sciences and Technologies, Via Vivaldi 43, 81100 Caserta, Italy
[2]Aristotle University of Thessaloniki, Department of Geology, Lab. of Engineering Geology & Hydrogeology, 54124 Thessaloniki, Greece
[3]Polytechnic University of Marche, Department of Materials, Environmental Sciences and Urban Planning, 60131 Ancona, Italy
[4]UMR 1114 EMMAH (INRA-UAPV), 301 rue Baruch de Spinoza, 84916 Avignon, France

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*Corresponding author: kazakis@geo.auth.gr

1 Introduction

The Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) is a robust model widely applied for assessing hydrological responses (water, sediment, and nutrient loss) to land use and climate changes in watersheds and is characterized by different land covers, soil types, and management conditions (Golmohammadi et al., 2017; Tasdighi et al., 2018; Bhatta et al., 2019; Busico et al., 2020; Busico et al., 2021). The main step of the model consists in the creation of hydrologic response units (HRUs), referring to all parts of a territory characterized by a unique combination of land-use, morphological, and soil properties (Neitsch et al., 2000).
The aim of this study is the investigation of future variations of infiltration and runoff in Tsamantara basin, Holly Mountain (Greece) from 2020 to 2040. For a sustainable water resource management plan, the assessment of all relevant hydrological processes such as streamflow, recharge and evapotranspiration are mandatory for the proper quantification of aquifer recharge, especially in mountainous areas characterized by vast heterogeneity in morphology and climatic conditions. To achieve this goal, and to avoid the drawback of data scarcity that characterized the site, only "Open dataset" was utilized. The following input data were considered for the investigation of infiltration and runoff spatial distribution: i) a Digital Surface Model (DSM) with a cell resolution of 1 m, ii) a Soil map (Digital Soil World Map; (DSMW FAO 2007; scale 1:5 million), iii) a land use classification retrieved by Corine Land Cover (CLC) classes for the year 2018 and then discretized using satellite images and relevant literature and iv) remote sensing evapotranspiration from MODIS dataset.

2 Materials and Methods

2.1 Study area

The study area is located within the territory of Simonopetra Holy Monastery at Athos Peninsula, South-East Halkidiki, Greece. The morphology of the study area is characterized by steep slopes, with an average inclination of 55%. The total study area is about 2.39 km^2, while the altitude varies from 0 to 892 m at Tsamantara peak. The mean monthly temperature for the period of 2018-2020 range from -7.9 ºC to 32.1 ºC and the mean annual rainfall is up to 183.4 mm. The geological setting of the area consists of granites and gabbro/diorites. Concerning the soil features, the Tsamantara basin is covered mainly by clay and sand soil texture. Evergreen trees and small areas of agricultural activities are observed at the coastal zone while the mountainous part of the Simonopetra Holy Monastery is covered by chestnuts, beech, oaks, broad leaves forest and pines.

2.2 SWAT setup and calibration procedure

Land cover parameters have been obtained by SWAT default's database. Specifically, the RNGE attributes have been used to represent the Mediterranean shrubland while a split land use made of oak (70%) and pine (30%) have been applied for the high-altitude forest according with drone images interpretation. Two meteorological stations are available in the study area: a) Simonopetra, and b) Vatopedi. However, the data was not enough to produce a complete SWAT elaboration. To solve the problem of meteorological data scarcity, the Climate Forecast System Reanalysis (CFSR) (Saha et al. 2010) has been applied. Additionally, to fill the data gap and reproduce future trend of the climate parameters the Climate Model SMHI-RCA4 of CORDEX project has been chosen. The future hydrological regime for the whole watershed has been evaluated through different steps: i) firstly all the physical characteristics of morphology, land cover and soil properties were evaluated and used as main inputs for the setup of the SWAT model and to define the HRUs spatial distribution in the whole basin, ii) secondly the CFSR meteorological data was used to run the model for the period 2010-2019 with 3 years of model warm-up, iii) then the model was calibrated and validated using monthly value of MODIS data of potential evapotranspiration (PET) for the period 2016-2019 iv) finally the RCP 4.5 climate dataset was used to force the model by 2040 to produce the runoff and infiltration map of the study area. For the calibration procedure, the standalone SWAT-CUP program and Sequential Uncertainty Fitting version 2 (SUFI-2) algorithm were applied from sub-basin output of PET. The PET was calculated with Hargreaves method accordingly to data availability (Aschonitis et al., 2017). The Nash-Sutcliffe efficiency (NSE), percent of bias (PBIAS) and coefficient of determination (R^2) optimization functions were chosen to check the model reliability according to the performance values suggested by Moriasi et al. (2007). A total of two thousand calibration runs, divided in four interactions of five hundred runs each, were performed until a satisfactory calibration was obtained. The parameters investigated during the calibration were: i) groundwater "revap" coefficient (GW_REVAP), ii) deep aquifer percolation fraction (RCHGDP), iii) soil evaporation and plant uptake compensation factor (ESCO, EPCO), and iv) deep aquifer percolation fraction (RCHGR_DP).

3 Results

Tsamantara basin was divided into 39 sub-basins and a total of 202 HRU. The model was able to properly simulate sub-basin PET in the selected years. For the calibration, the results showed a very high R^2 (0.92) followed by excellent values of NSE and PBIAS (0.89, -5.98). Similarly, the results of validation fall within the range of an excellent calibration with a R^2 of 0.95.

For the catchment, considering the average values for the period 2020-2040, the total ET has been estimated at around 58% of the entire groundwater balance while the recharge (RCH) to the shallow aquifer and the superficial runoff (RF) constituted the 15% and the 20% respectively (Figure 1). Due to the presence of important slope values in the area, a considerable amount of water is lost as lateral flow (8%). A significant variation will characterize the future period from 2020 to 2040 according to RCP 4.5 scenarios.

The average yearly RCH and infiltration (INF) will present variations in all the simulation period following the changes of precipitation (PCP) values. Until 2035, the RF will retain an average value of 20%, reaching higher values between 2026 and 2030. The higher RCH rate instead will be registered between 2030 and 2035. Moreover, the spatial distribution of fraction and recharge will vary within the analysed watershed. Analysing the fractional distribution (Figure 2A), the higher streamflow values will characterize the northern part of the area in correspondence with the steep slopes. According to the results, up to 25% of the total precipitation will become RF in relation to the mainstream location. However, the lower percentage of RF will be registered in the southern part of the watershed. The same trend is detectable also for the spatial and temporal evolution of RCH (Figure 2B). The overall average RCH for the entire analysed period displayed the higher values (up to 18%) in the northern part of the catchments as for the RF. Nevertheless, it is important to be mentioned that the INF values are related also to precipitation intensity, giving an important aspect of INF for future investigation in the area.

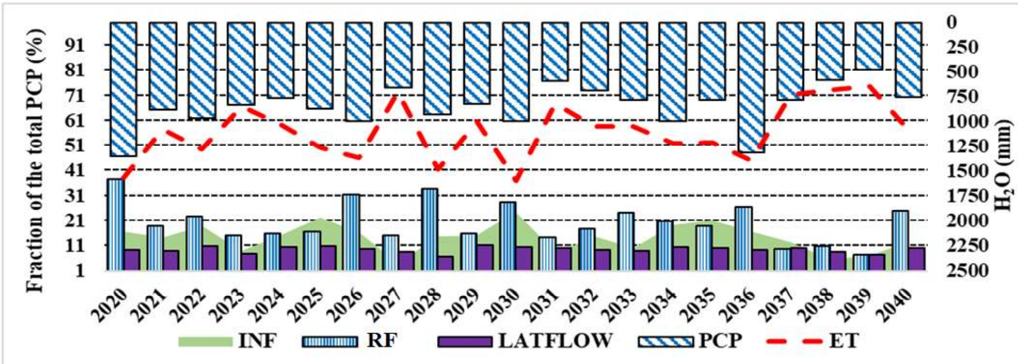

Figure 1. Water balance prevision for the years 2020-2040.

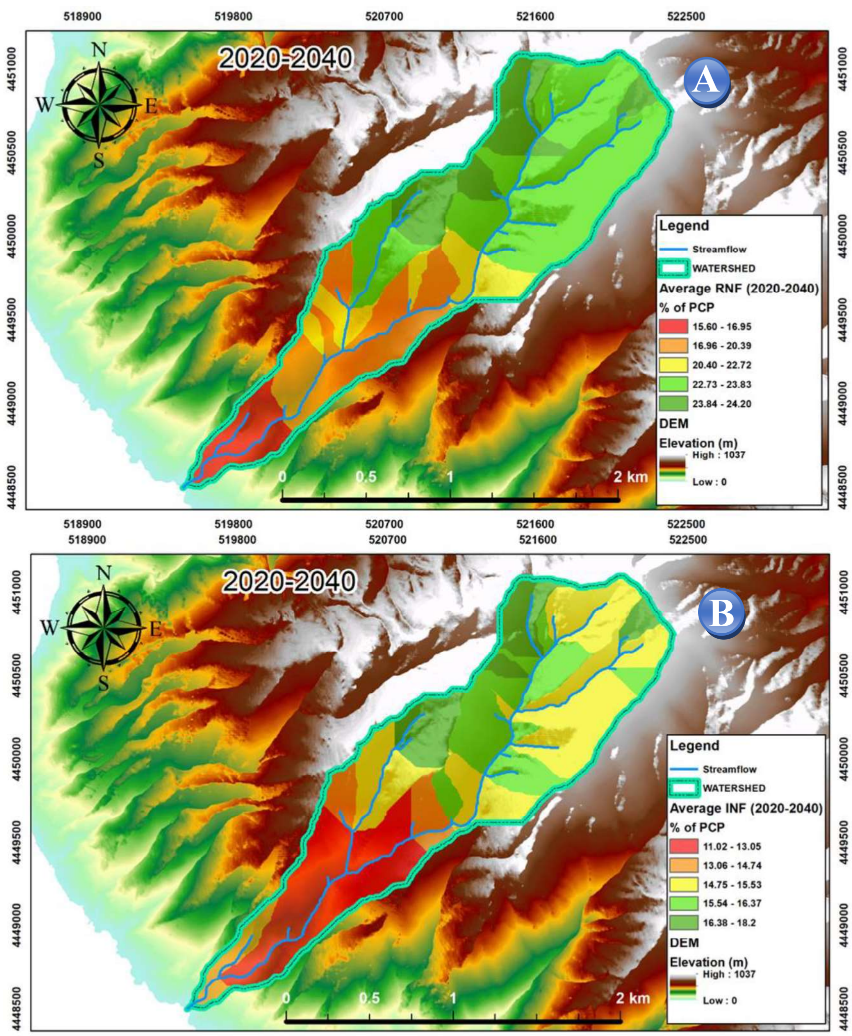

Figure 2. Runoff (a) and infiltration (b) spatial distribution.

4 Conclusion

In this study, projections of runoff (RF) and infiltration (INF) were investigated in Tsamantara basin. According to SWAT results, different percentages of variations will characterize the future period from 2020 to2040 based on RCP 4.5 scenarios. In general, the infiltration rate is estimated at 20% of the precipitation. However further investigations are necessary to better discretize the spatiotemporal variation of all hydrogeological parameters. This could be achieved by implementing an in-situ monitoring plan on the study area or using data of recharge, runoff, and soil water content from global hydrological models.

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