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Eco-Hydrological Modelling of a Highly Managed Mediterranean Basin Using the SWAT+ Model: A Preliminary Approach †

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Abstract: Highly managed Mediterranean river basins are facing considerable environmental management challenges. Water resource managers are increasingly concerned about the allocation of limited water resources, environmental quality concerns, and planning under present and future climatic change and uncertainty. We implemented a watershed-scale eco-hydrological model on the Cervaro river basin (southern Italy) using the Soil and Water Assessment Tool (SWAT+) model at daily timesteps from 1990 to 2019. A high-precision land use map derived from the Integrated Administration and Control System (IACS)/Land Parcel Identification System (LPIS) was used to grasp detailed information regarding landscape patterns. This research is a preliminary approach for implementing and running the model with these highly detailed datasets. Future efforts should be oriented to fine-tune the baseline scenario considering agricultural management practices and to evaluate model performances for calibration and validation by assessing the goodness-of-fit objective function values.

Keywords: agriculture; watershed modelling; nutrients; simulation; land use/cover; LPIS

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1. Introduction

Actual agricultural systems are based on intensive farming techniques that require deep plowing, and large usage of nitrogen (N), phosphorus (P), herbicides, pesticides, energy inputs, and land [1]. Leaching losses of sediments, nutrients, and chemicals from agricultural fields can lead to eutrophication of water and soil, deterioration of agroecological systems, and loss of ecosystem services. Agricultural production potential and the capacity to provide other ecosystem services in the future are both reduced as a result of pressures on agricultural systems and natural resources [2], endangering the main soil functions (such as filtering and serving as biological habitats) and their preservation [3]. Agricultural systems face several pressing challenges in resolving the apparent conflict between human needs and resource sustainability [4].

The management of the environment is a significant problem in highly managed Mediterranean river basins. Many solutions have been put out for addressing management issues and local environmental effects on agroecological systems. The use of eco-hydrological modelling for ex-ante quantification of nonpoint source pollution and soil erosion in agroecosystems is a useful approach for implementing sustainable agricultural systems [5]. Many studies have found that eco-hydrological models are effective in simulating the intricate interactions of water, nutrients (N and P), contaminants, and vegetation systems in both natural and agricultural ecosystems.

These models can help researchers and practitioners to better understand and manage these ecosystems, leading to improved crop yields and reduced environmental impact.

Additionally, eco-hydrological models can be used to predict the effects of climate change and other disturbances on agricultural ecosystems, allowing for more effective planning and adaptation. One of the most frequently utilized models is the Soil Water Assessment Tool (SWAT) [6]. Examples include streamflow and nutrient loadings [7], modelling of soil erosion [8], best management practices for reducing fertilizer application [9], and climate change studies [10].

This paper focuses on the application of the SWAT+ model in a Mediterranean river basin to evaluate the influence of anthropogenic management on water balance components, nutrients, and sediment loads. The model employs a high-precision land use map produced from the administrative geodata of the Italian Integrated Administration and Control System (IACS)/Land Parcel Identification System (LPIS) used for monitoring the Common Agricultural Policy (CAP) subsidies. High-resolution land use data provide precise information on landscape patterns and allow us to better represent the hydrological cycle. The model performances were assessed by comparing simulated and observed streamflow data and calculating a goodness-of-fit objective function. The preliminary findings show that the model reproduced the water balance in the watershed well. Future work will be oriented to analyze the effects of alternative management practices on water quality, sediment loads, and soil erosion.

2. Materials and Methods

2.1. Study Area

This study was carried out in the Cervaro river basin, which is located in the Apulia Region (southern Italy) between 41°07′–41°32′ N latitude and 15°06′–15°54′ W longitude (Figure 1). The Cervaro basin has an area of 841 km^2 and ranges in elevation from 0 to 1100 m on the southern side of the Daunia Mountains. The river system consists of the main river course and various major and secondary-order tributaries. The climatic regime is Mediterranean with a bimodal pattern of precipitation distribution with rainy winters and hot summers.

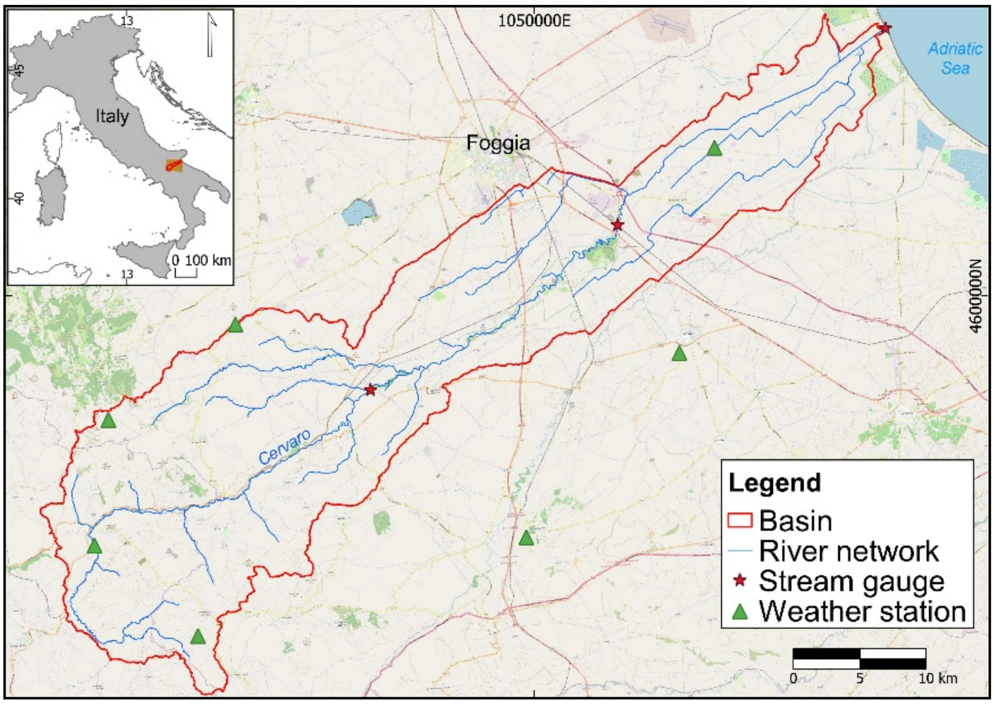

Figure 1. Location of the study area.

2.2. SWAT+ Model Setup

SWAT is a semi-distributed eco-hydrological model that segments a watershed and its sub-watersheds into homogenous geographical units known as Hydrologic Response Units (HRUs), each of which have a distinct combination of land use, soil, and slope [6]. The HRUs are used to determine the soil–water balance. HRUs represent the minimum computational unit within which the soil–water balance is determined. In this study, we used the new restructured SWAT+ model that is more efficient and flexible in terms of model construction and configuration.

2.3. Dataset and Model Setup

The SWAT+ model requires the following geospatial data for implementation (Table 1): land use/cover data, soil data, Digital Elevation Model (DEM), streamflow data, and climate data. In the first step, the DEM was used to delineate the basin and create sub-basin boundaries, while in the second step HRUs were created in conjunction with land use and soil data. In the third step, climate data for the period 1990–2019 were used to set up and run the model as the baseline scenario.

For land use data, we specifically developed a detailed land use map for the study area with 57 thematic classes from the IACS/Land Parcel Identification System (LPIS) conflation [11,12]. More than 70% of the area is devoted to agricultural uses. The SWAT+ model (rev. 60.5.4 – SWAT+ Editor 2.1) was implemented using a QGIS interface and run at daily timesteps from 1 January 1990 to 31 December 2019 considering a 4-year warm-up. The study area was discretized into 7345 HRUs. The Penman–Monteith method was used to calculate potential evapotranspiration.

Table 1. Data sources used to implement the SWAT+ model.

Data	Resolution—Scale	Description	Source
Land use	10 m	57 land use types	[12]
Soil data	10 m	16 soil units	[13]
DEM	10 m	elevation data	[13]
Streamflow	Daily (m^3/s); 1990–2012	runoff at gauge stations	[13]
Climate data	Daily; 1990–2019	temperature, rainfall	[13]

3. Results

The average annual values of the water balance for the whole simulation period are depicted in Figure 2, while monthly water balance components are reported in Table 2. Interannual variability showed that precipitations were concentrated in winter months, while in summer months the average precipitation remained quite stable due to the influence of the gauge stations in the Daunia mountains which have a maximum altitude of 1000 m.

Table 2. Water balance average monthly values [1].

Month	Precipitation	Runoff	Lateral Flow	Water Yield	ET	PET
January	74.1	9.5	9.3	9.5	8.9	9.3
February	59.3	7	25.4	7.0	23.7	25.4
March	67.4	7.2	62.9	7.3	58.3	62.9
April	63.9	2.8	104.6	2.8	95.3	104.6
May	51.7	1.6	151.2	1.6	118.2	151.2
June	43.8	1.5	172.9	1.5	92.7	172.9
July	35.9	1.1	185.2	1.2	58.8	185.2
August	34.3	0.9	158.5	1.0	38.8	158.5
September	58.0	1.7	102.7	1.8	49.0	102.7
October	66.5	2.4	56.0	2.4	36.2	56.0
November	75.5	2.7	17.8	2.8	15.6	17.8
December	71.8	4.5	5.2	4.6	5.1	5.2

[1] All values in mm.

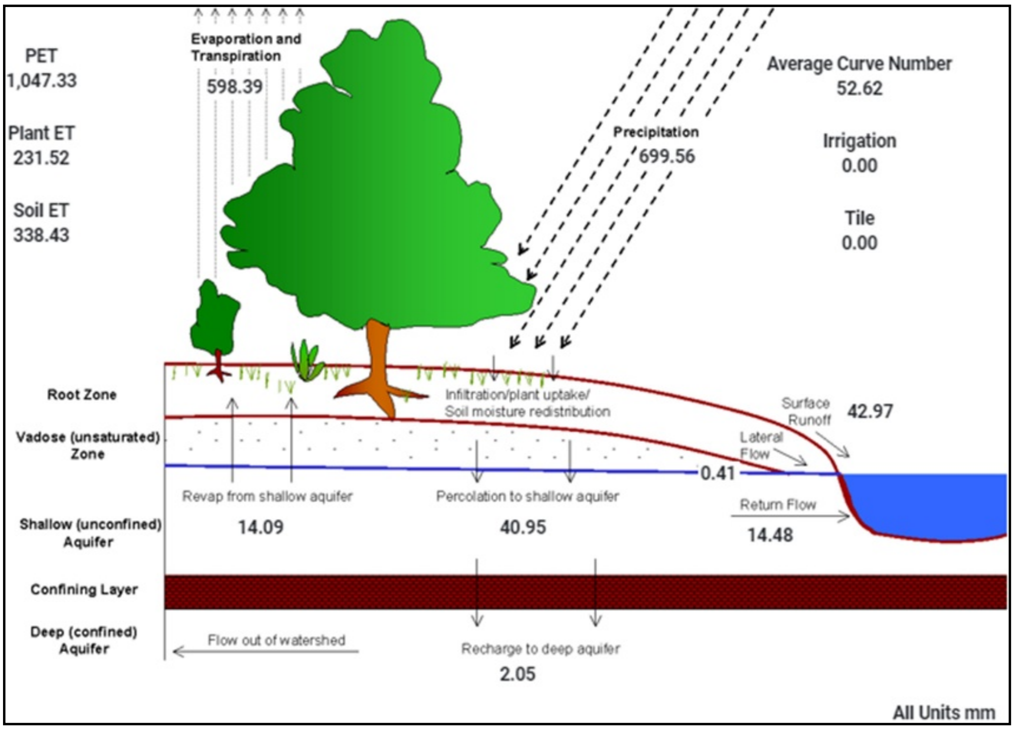

Figure 2. Schematic representation of average annual values of water balance. All units in mm.

The results showed that evapotranspiration was the predominant water balance component, with 598.39 mm year^{-1}, accounting for approximately 85.5% of the annual precipitation (699.5 mm), followed by surface runoff (42.97 mm year^{-1}, representing about 6.1% of the annual precipitation) and water yield (water discharged in the channels, 43.4 mm year^{-1}). The potential evapotranspiration component was equal to 1047.33 mm year^{-1}, while the average precipitation was equal to 699.5 mm year^{-1}. The average annual outflow for the whole simulation period was 0.44 m^3 s^{-1}, in line with the values registered for conterminous river basins in the Apulia region [14], confirming the overall reliability of the model.

4. Conclusions

This study presented a preliminary quantitative assessment of the eco-hydrological processes using the SWAT+ model in a highly managed Mediterranean watershed. The results of the preliminary model set-up of a baseline scenario in the Cervaro river basin (southern Italy) can be summarized as follows:

- The river basin has a vast and heterogeneous agricultural plan with 57 land use types that can strongly influence the water balance with management practices such as planting, irrigation, and fertilization;
- Overall, the SWAT+ model performed well and was able to adequately and reasonably represent the main elements of the hydrological budget; future work should be oriented toward calibrating and validating the model to adjust model parameters toward more realistic model results;
- The use of detailed land use/cover maps as was used in this study can improve the representation of hydrological models in complex agricultural systems, enabling the implementation of best management practices in the future.

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

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