Journal of Agricultural Sciences (Belgrade)
Vol. 68, No. 4, 2023
Pages 429-447

https://doi.org/10.2298/JAS2304429Z
UDC: 551.577.2:519.87
Original scientific paper

EFFECTS OF DIFFERENT SPATIAL AND PRECIPITATION INPUT DATA ON SWAT-DERIVED CATCHMENT FEATURES

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Abstract: Computer-based mathematical models are used in water management research to represent ecological problems, simulate different processes, deal with such problems and support their solution. Such studies require an interdisciplinary approach that is both user-friendly and comprehensive to integrate all of the processes that occur in nature. The use of available hydrological models requires a model setup with a reasonable level of data quality and quantity to represent catchment features to emphasize the distinctive local character of ecosystems. One of the models that comply with such requirements is the Soil and Water Assessment Tool (SWAT). This paper aims to address the possible impact of different spatial and precipitation input data on the catchment features by using SWAT for the case study of the floodplain located within the Danube River Basin in Serbia. The objective was to evaluate the impact of digital elevation models, land use, and soil types with different resolutions (1) SRTM and ASTER (30 m), TanDEM-X (12.5 m), (2) CORINE and GlobCover land use databases, and (3) FAO/UNESCO world soil map and digitized soil map of Vojvodina Province on catchment delineation. The research was conducted alongside the analysis of precipitation, using data from the CFSR, CarpatClim, and the national yearbooks. Regarding the spatial data, the results indicate that the high-resolution data need to be adjusted for this area, while the ASTER layer is suitable at an acceptable level for further modeling in SWAT. Interpolated precipitation data are better to use due to their higher resolution (10km) and the heterogeneous distribution of rain gauge stations.

Key words: spatial data, precipitation data, SWAT, hydrological modeling.

Introduction

Water stands out as the most dominant among the limiting factors for crop production. Urbanization, the rapidly growing human population, climate change, and land use change have transformed the environment and altered the quality of

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the main environmental elements (water, air, soil). Any changes in the environment are at the same time pressures that must be analyzed and processed to establish the optimal condition for the survival of ecosystems. Nowadays, there are scientifically confirmed statements that indicate that one of the factors on which the quality of the (local) water and the quality of the environment depend is the landscape of the surroundings (Galan et al., 2023). Changes in land use through deforestation, conversion of agricultural land, and modern urbanization, are changing the hydrological cycle and its components, such as volume and flow rate, infiltration, evapotranspiration, etc. Assessing the effects of anthropogenic activities, principally at the local level, is primarily important for decision-makers to whom environmental quality information is relevant when creating new management policies (Huang et al., 2020).

Hao et al. (2022) point to the lack of an integrated approach to the assessment that leads to inconsistent strategies and inefficient use of water resources, but they also point out the availability of adaptive, mostly mathematical and computer tools and models that could help in solving such problems. Nowadays, computer-based mathematical models are primarily used in scientific research to represent and simulate real-world system problems. The development of mathematical simulation models has contributed to a more efficient prediction of complex bio-geo-hydro-chemical mechanisms that occur in nature (Latinopoulos et al., 2020), which mainly require an understanding of the process, the mathematical basis, and the permissible conditions of uncertainty. The models have been developed over the years so that they can be used to monitor the quality and quantity of water resources under the pressure of current and predicted climatic and hydrological conditions around the world. One of the commonly used models is an open-source code SWAT (Soil and Water Assessment Tool), which is used to address various eco-hydrological problems worldwide (Tan et al., 2020). The model considers the effects of multiple factors, such as time distribution, changes in water resources, land quality, land use, topography, vegetation, and the impact of human activities in the study area. By using SWAT, it is possible to integrate different modules that evaluate the effects of numerous hydrological and chemical processes in the environment, as well as the complex relationships between climate, soil, water, environmental stressors, scattered sources of pollution, and climate changes.

The application of the SWAT model refers to a wide range of hydrological, environmental, and agricultural problems and can contribute to their better understanding (Gassman et al., 2014). It increases the understanding of natural processes, predicts the state of the system in different time steps, and allows users to perform simulations with different input data by constructing different management strategies for a selected catchment area. Catchment delineation can be performed automatically by loading the required input data for the SWAT model. The data can be roughly divided into two groups: the first group consists of spatial data, and the second group includes meteorological data. The main objectives of the catchment process modeling in SWAT are (1) to assess hydrological and polluting impacts as a result of current water use and land management, (2) to quantify current and projected impacts and climate change scenarios, (3) to assess soil erosion, 4) to predict future conditions, and (5) to address the main drivers of changes in land use and water cycle dynamics. Therefore, it is advisable to accurately simulate all the hydrologic processes in the catchment before performing parameter sensitivity analysis, calibration, and validation.

Global datasets are approved for modeling large-scale catchments (regional, international, transboundary), but for small-scale or ungauged catchments, the precision and resolution of these types of datasets could be unfavorable for further examination. The studies on evaluating the impact of different input databases on SWAT simulations, especially in data-poor catchments, have been recently gaining attention (Mararakanye et al., 2020; Akhtar et al., 2021; Kmoch et al., 2022). In recent research by Weber et al. (2020), it was found that global data could be a valuable source to substitute single missing meteorological variables or topographic information, but this fact can lead to a gap in important information about the local character of the river basin. Uncertainties in the SWAT modeling output can be caused by two different sources of error: (1) inappropriate input parameters or representation (input error), or (2) error in the model structure and algorithms (structural error). Uncertainties in the simulation output data can be reflected in (1) the delimitation of the basin that could be influenced by different resolutions of digital elevation models (Ortíz-Rodríguez et al., 2022), (2) land cover and soil datasets which can contribute to the creation of a different number of hydrological units for the same watershed (Busico et al., 2020), and (3) model execution that is sensitive to meteorological input datasets (Koo et al., 2020). Therefore, it is necessary to provide real-time datasets to obtain a model with high calibration and validation coefficients.

The purpose of this research is to analyze the potential effects of different input data that affect the catchment delineation of the selected case study – the Special Nature Reserve "Koviljsko-petrovaradinski rit" (KPR), Serbia. As Serbia is a developing country, almost no field data required for this type of environmental analysis could be collected. Finally, the results of this analysis (1) highlighted the critical importance of dataset resolution selection for SWAT applications and (2) improved the accuracy and understanding of the impact of different input data resolutions on the derived watershed information for similar case studies.

Material and Methods

The geographic information system (GIS) is one of the most promising information technologies today, given the wide range of application areas.

Hydrological models simulate hydrological processes using spatial parameters derived from geospatial data within a GIS framework, and geospatial data are used to represent the spatial variation of catchment properties that cause hydrologic processes. The SWAT model is a semi-distributed and physically based watershed-scale hydrological model. It was developed by Arnold et al. (1998) and a detailed description of the model operation and its components can be found in the suggested reference. The SWAT model requires various input parameters related to water quantity and quality, as well as input data related to climate parameters, topography, soil, and land use. After loading all the required input data, the model is ready to run (Figure 1), and the first two steps of the SWAT framework were performed in this paper.

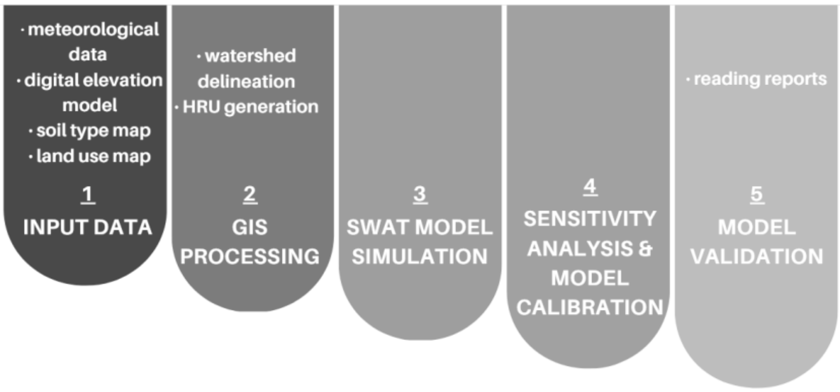


Figure 1. The SWAT model framework.

The main steps in creating the observed catchment are (1) the delimitation of the basin and the division of the basin into sub-basins interconnected by flow networks, and (2) the division of sub-basins into individual, smallest spatial units of Hydrological Response Units (HRUs), which the model automatically executes after loading the input data. The first step requires the input of a digital elevation model (DEM), from which the topographic properties of the catchment are calculated. In a subsequent step, the analysis of each formed HRU is performed based on loaded land use layers and a soil map. The last step in defining the observed catchment area, before the model run, is adding the locations of the weather stations and loading meteorological data. In the Results and Discussion section, the comparative results of the developed hydrographic networks created by different resolution DEMs and identified soil types based on different input data from soil type and land use databases are presented. Furthermore, the statistical analysis of mean annual precipitation values from different databases for the selected case study is shown.

Case study: The Special Nature Reserve “Koviljsko-petrovaradinski rit”

The selected case study is located in the southern part of Vojvodina Province (Serbia) (Figure 2) and has been declared a special nature reserve “Koviljsko-petrovaradinski rit” (KPR), which is a home to numerous endangered animal and plant species. The KPR reserve covers 5,895 ha along the Danube River and represents a very important floodplain in the Danube catchment area. The floodplain complex is a combination of forest, meadow, swamp, pond, and wetland ecosystems recognized on an international level. A fertile plain surrounds the reserve on one side, while the foothills of the National Park “Fruška Gora” are located on the other. It covers the territory of four municipalities where approximately 56,000 inhabitants are directly or indirectly connected to it (KPR Management Plan, 2012). For modeling purposes, the KPR area is expanded with a 10 km buffer zone (KPRbuff) and occupies 87,640 ha. The reason for this is that the protected area is heavily dependent on the water regime of the Danube River. It is not isolated from external pressures, and inadequate water and forest management can cause degradation of the quality of the environment and human well-being in the protected area.

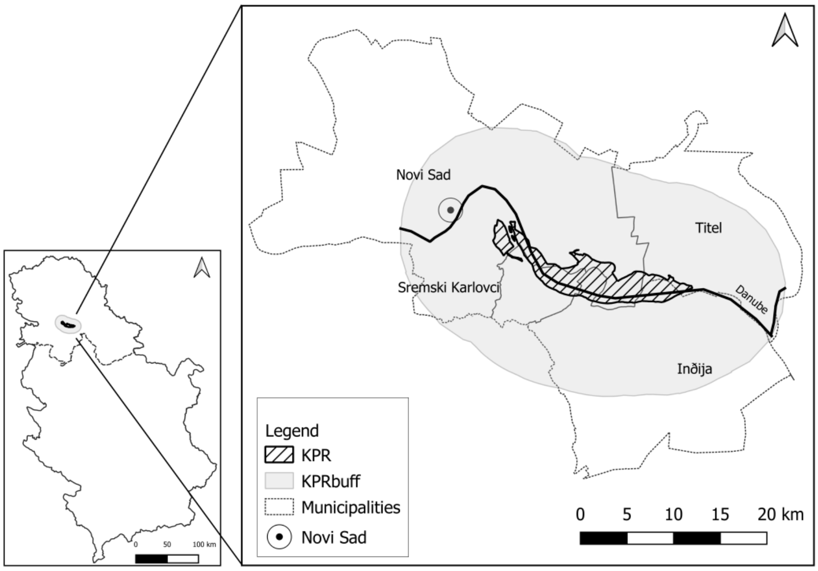


Figure 2. The location of the case study in Serbia.

To continue the research on the impact of land use change and anthropogenic activities on the quality of the environment in KPR, it was necessary to examine the impact of the quality of available data on the definition of catchment features in the pre-validation stage of modeling. The KPRbuff catchment delineation was built as a SWAT model for the case study using an extension of the QGIS software (version 3.18.1). The automatic catchment delineation was used to calculate and define features such as boundaries, river and drainage networks, and sub-basins, as well as to derive terrain slope parameters as well. All of the spatial input data were created in the UTM zone 34 projection system, which covers the Balkan region (WGS84/UTM zone 34N; EPSG: 32634). The computation of the catchment delineation parameters was conducted on an i5-4590 CPU Core Intel 3,30GHz, 16GB running on a 64-bit operating system. Overall, the real computational time for processing all the input data amounted to approximately 4 hours.

Model set-up

The input data for the KPRbuff model included data related to morphology, land use, soil properties, and climate data. As in other studies from Serbia where SWAT was applied (for example, Šabović et al., 2019; Gregorić et al., 2020; Potić et al., 2022), the lack of continuous, accurate, and quality-checked data were also a challenge when creating a hydrological model of SWAT for KPRbuff.

Table 1. Available online open-source databases for the case study.

SPATIAL DATA			
Data	Database	Resolution	Source
DEM	SRTM	1 arc-second 30 m	https://earthexplorer.usgs.gov/
	TanDEM-X	0.4 arc-second 12.5 m	https://tandemx-science.dlr.de/
	ASTER	1 arc-second 30 m	https://search.earthdata.nasa.gov/search
Land use map	CORINE	1:100,000	https://land.copernicus.eu/pan-european/corine-land-cover/
	The GlobCover 2009	300 m	http://due.esrin.esa.int/page_globcover.php
Soil type map	FAO/UNESCO soil map of the world	1: 5 000 000	http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/
	Digitized soil map of Vojvodina Province	1: 50,000	Internal GIS database
METEOROLOGICAL DATA			
Precipitation; Temperature;	CFSR	38 km	https://swat.tamu.edu/data/cfsr
Relative humidity;	CarpatClim	10 km	http://www.carpatclim-eu.org/pages/download/default.aspx
Solar radiation; Wind speed	Meteorological Yearbooks	/	http://www.hidmet.gov.rs/latin/meteorologija/klimatologija_godisnjaci.php

Some datasets were available at the local level (internal GIS database for soil type map or meteorological data from yearbooks), while others were downloaded from the global open-source datasets (Table 1).

Spatial data related to the catchment delineation

The DEMs loaded for the case study in this paper were chosen in the UTM projection system. The Shuttle Radar Topography Mission (SRTM) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer, Version 3 (ASTER) DEM at a resolution of approximately 30 m and TanDEM-X at a spatial resolution of approximately 12.5 m served as data input. Accurate information on the topographic model of the Earth's terrain could be particularly critically important in hydrological models when the DEM represents the input layer (Roostaee and Deng, 2023). Raster data are represented as a matrix of cells where each cell contains information and is independent of the other cells. The SWAT model delineates the investigated basin and creates the catchment based on topographic attributes (slope, field slope length, channel lengths, channel width, etc.), estimating this information from the loaded DEM. As a result of using different spatial resolution DEMs in lowland catchment, significant geomorphologic changes, such as an improved representation of the surface and watershed characteristics (mainly to capture water bodies), are expected (Rocha et al., 2020). To illustrate the impact of the different resolution DEM layers on the catchment delineation, the percentage of matching of the created hydrographic network by the SWAT model with the real hydrographic network, extended by a buffer zone of 100 m, was calculated.

Land use

Land use maps are a valuable source of information for understanding the different features of the environment: the geographical distribution and state of natural and protected areas, the geographical distribution and abundance of wild fauna and flora, an abundance of natural resources (water bodies, arable land, forests, wetlands, etc.) as well as urban landscape characteristics. In addition to the numerous available databases providing land use data around the world, the most commonly used for the SWAT model is a product of the European land mapping project CORINE (CLC) with five main categories (artificial surfaces, agricultural areas, forests, and semi-natural areas, wetlands and water bodies) and 44 types of land use. To date, there are five created CLC databases for referenced years: 1990, 2000, 2006, 2012, and 2018. To compare the CLC datasets from 2006 and 2012, the GlobCover 2009 database were used in this research. The GlobCover 2009 land cover product is a 300-m land cover map and the information is in raster format. It is generated from an automated classification of MERIS Full Resolution time series and covers 22 globally characterized land classes based on the UN Land Cover Classification System from an independent reference dataset. The land use information is classified into three main categories: closed-to-open shrubland, rainfed land, and closed-to-open forest. In this research, the proportion of the area of polygons representing different land use classes was calculated for 2006, 2009, and 2012.

Soil type

The most common compatible soil databases that can be loaded in the SWAT model are the open-source State Soil Geographic Database (STATSGO) and the Soil Survey Geographic Database (SSURGO). These databases are digital soil databases that include all the necessary data on soil parameters in vector format. Both are the most widely used soil databases for hydrological simulation models but cover only a limited part of the world. In addition, it is possible (or even necessary) to load other databases on soil types in the model, i.e., databases that are created or reprocessed by the user (Hao and Wu, 2023). For this research, the digitized soil map of Vojvodina and the FAO/UNESCO layer were used. The soil map of Vojvodina contains 231 soil types based on the general principles of the World Reference Base Classification System (Mrvić et al., 2016). At the European level, the FAO/UNESCO map contains 64 soil types that differ in their physical and chemical properties. For the study area, no comprehensive data on soil properties for the soil map of Vojvodina were available, so impact analysis on the catchment delineation could not be performed and discussed. Soil plays a key role in the hydrological cycle, so the use of high-resolution and high-quality soil-type data can be reflected in more efficient model performance and more accurate model results (Bhandari et al., 2018). Such information can be obtained from field observations and research, but the effort required to collect and statistically process newly created databases often requires time. Nevertheless, it is important to examine whether the available global databases meet the conditions of the research area, which was achieved by comparing the percentages of polygon areas of different soil types using two soil maps.

Precipitation data

The climatic conditions of the studied catchment area provide the parameters needed to manage the water balance by running the model. It is also possible to determine the relative impact of the individual components of the hydrological cycle. The meteorological inputs are required to be in text format and include daily precipitation, maximum and minimum daily temperature, solar radiation, wind speed, and relative humidity. It is important to point out that the required data are often missing (due to their length or lack of spatial coverage), so a time generator module in the SWAT could be used when necessary (Alodah and Seidou, 2019). The SWAT model also allows preparing and processing of meteorological data manually by the users. To do so, some of the statistical results need to be entered, such as average values, standard deviations, skewness values of temperatures, wind speed, solar radiation, and sequences of wet or dry days derived from the precipitation data.

The most commonly used meteorological database for SWAT modeling is the Climate Forecast System Reanalysis (CFSR), whose precipitation data were used for this research. The CFSR database contain data interpolated at a spatial resolution of 38 km and it is available in SWAT file format and does not require additional time for processing. The second online available open-source database is from CarpatClim with 10 km grid resolution interpolated data. The disadvantage of this database is that it is limited to a certain region, in this case, the Carpathian Mountains. The third database included in the analysis is precipitation data from the Serbian Meteorological Yearbooks. The aim was to detect statistical differences in datasets based on true measurements and the interpolation of different gridded data. This was done by statistically analyzing the annual precipitation amount for the period 1979–2009.

Results and Discussion

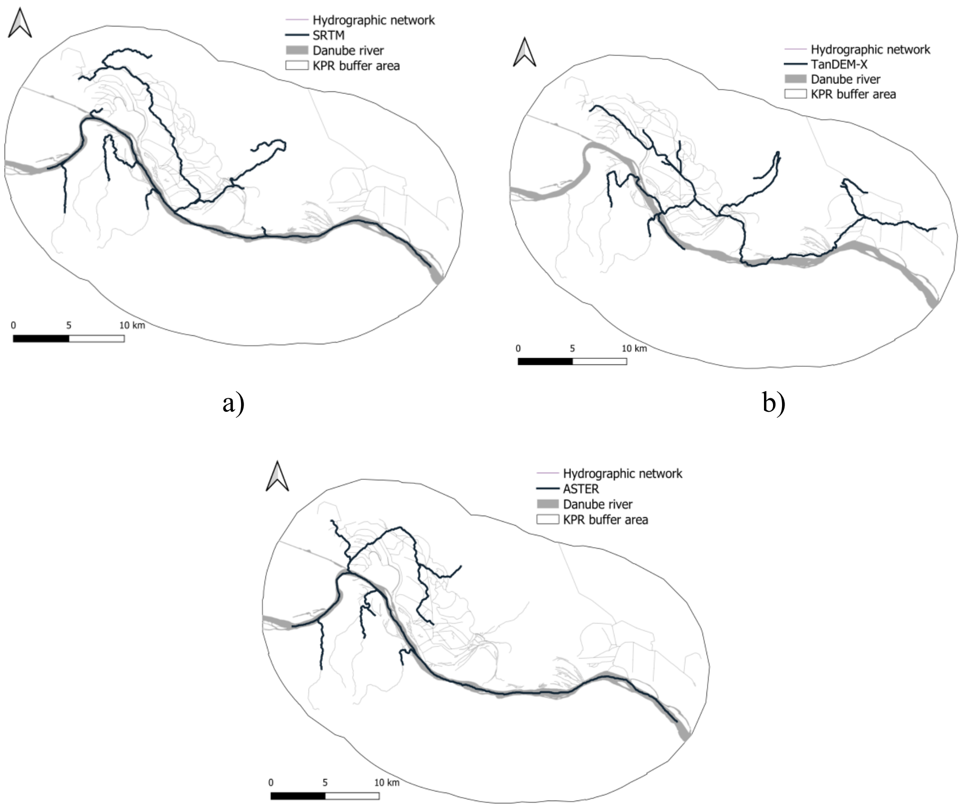
Impact of the use of different DEMs

The hydrographic network affects the simulated hydrologic response of a catchment, which implies that accurate water streams are important for accurate model performance. Due to the availability of different databases of DEMs, the extraction of the hydrographic networks and the definition of the topography were performed automatically. The impact of DEM layer resolution on minimum elevation, maximum elevation, number of cells, cell size, cell area, number of sub-basins, and computational time was analyzed using three DEM layers: SRTM, Tandem-X, and ASTER (Table 2). The SWAT model divided the watershed of the selected KPRbuff into 19 sub-basins, and the input data led to the production of 214 HRUs by using the SRTM DEM. Watershed delineation when loading ASTER and TanDEM-X resulted in 16 and 19 sub-basins with 92 and 368 HRUs, respectively.

Table 2. Impacts of DEM resolution on watershed properties.

	SRTM (a)	TanDEM-X (b)	ASTER (c)
Minimum elevation [m]	12	12	9
Maximum elevation [m]	512	568	535
Number of cells	24,456	128,135	20,470
Cell size [m]	22.09 x 30.59	8.83 x 12.23	22.09 x 30.59
Cell area [ha]	0.0488	0.0093	0.0583
Number of sub-basins	19	22	19
Computational time [min]	10	180	5

The highest point of the National Park "Fruška Gora" is 539 m above sea level, hence using the aforementioned DEMs with recognized heights of 512 m, 568 m, and 535 m could result in misconceptions in the subsequent modeling processes. The number and size of cells that were automatically generated by loading one of the observed DEM layers indicate the degree of resolution of the model itself. Accordingly, TanDEM-X had the highest number of cells, which consequently increased the time to process such data. After loading TanDEM-X as an input layer, significant errors in terrain heights were noted, which affected the creation of the Danube River stream inappropriately (Figure 3b).



c)

Figure 3. Different digital elevation models for KPRbuff derived by (a) SRTM, (b) TanDEM-X, and (c) Aster DEM.

Due to the lack of data in terms of no values (blank data) for the pixels of the water surfaces, TanDEM-X recognized surface water height as a special, unreal height (-32,767 m). This caused difficulties in catchment delineation where the produced hydrographic network in the SWAT model only matched the real network up to 3%. Because the produced hydrographic network did not match the real network sufficiently, further analysis should not be performed using the above DEM layer. Additionally, the highest resolution TanDEM-X for this case needs to be further corrected before it can be used. The delineation of the catchment when loading two other DEM layers lasted much shorter and more than 70% of the hydrographic network that was created matched real data of the watercourse of the Danube River and drainage networks (Figure 3a, c).

Respectively, 72% of the hydrographic network matched the real network when SRTM was used as DEM, and 77% when ASTER was used. The lack of proper delineation of the drainage network, when using ASTER DEM and SRTM DEM, was also noted in Rana and Suryanarayana (2019), which is certainly a shortcoming of these DEM layers. The high percentage of correspondence between the created hydrographic network and the same number of created sub-basins implies that these two layers are convenient for further use. However, ASTER DEM should be preferred due to the shorter computation time required for catchment delineation.

Impact of the use of different land use datasets

A layer of land use is another dataset required for watershed delineation. The study results revealed that there were no noticeable changes in the percentages of recognized classes of CLC in the KPR land use between the years 2006 and 2012. There were no significant changes in urban areas, forest areas and water bodies as a result of the designation of the case study as a protected area. When the CLC land use maps were produced, urban areas made up 12% of the total KPRbuff, water surfaces accounted for 15%, and grasslands occupied 33%. By loading the GlobCover 2009 map, 37% of the total study area was found to be covered with mosaic crops, 36% with rainfed crops, and 10% of the total KPRbuff area was identified to be covered by mosaic vegetation. It has been shown how different land use classifications can be identified for the same area, and the study by Cüceloğlu et al. (2021) has shown that different land use datasets can be used successfully for SWAT modeling without having a major effect on the model outcome. For example, when using GlobCover 2009, one class of water bodies was identified, but when using the CLC layer, it can be assumed that several classes were identified as water surfaces. These results were influenced by the methodological classification, where GlobCover contained 22 land use classes and CLC contained 44 land use classes.

In addition to the vegetation cover, the CLC land use map also identified urban areas and water bodies. It can be concluded that the use of this layer contributed to a better understanding of the dynamics of anthropogenic activities in that area. Since GlobCover 2009 was released in 2010 and there are no later versions, this type of data should not be used in hydrological models. Furthermore, up-to-date information on land cover is of major importance due to the accelerated ongoing processes that affect land cover and land use dynamics. Kmoch et al. (2022) illustrated that local high-resolution datasets can improve SWAT performance over the CLC data, but it has been noted by Szarek-Iwaniuk (2021) that a larger number of classes do not necessarily mean a larger amount of information.

Impact of using different soil type datasets

The last set of required data in the process of catchment delineation was the soil type map. Before loading the soil type database, an analysis of the soil types contained in the different databases was performed. The identification of the present soil types in the KPRbuff case study was determined by calculating the percentage of soil type polygons. By loading a digitized soil map of Vojvodina Province, it was found that ten soil types were recognized, and five soil types were identified by using the FAO/UNESCO soil map of the world (Table 3). Chernozems and Fluvisols, the dominant soil types in Vojvodina, were identified by loading both soil databases, and Vertisols, also a common soil type in Vojvodina, were identified only by loading in the digitized soil map. The fact is that the soil map of Vojvodina Province was created at a scale of 1: 50 000, which led to the production of a larger number of soil types with a lower percentage of coverage.

Table 3. The soil types on KPRbuff determined by calculating the percentage of soil polygons.

Digitized soil map of Vojvodina Province		FAO/UNESCO soil map of the world
Chernozems	54.3%	31%
Fluvisols	23%	56%
Cambisols	6.3%	13%
Vertisols	5.1%	
Plansols (0.1%), Solonchaks (0.1%), Solonetz (0.5%)		
Regosols (0.7%), Gleysols (2.9%), Leptosols (7.1%)		

The framework of SWAT modeling required additional soil characteristics that none of the databases used in this study contained. This step can be performed by the supplemental efforts of users to aggregate all the necessary soil type information. The KPR catchment delineation was completed by loading the available SWAT soil-type databases, STATSGO and SSURGO, to investigate the influence of different DEM layers on the identification of soil types (Table 4). The presented soil type percentage may indicate that different terrain models may affect the production of the different percentages of soil types, even of different soil type categories. This can be induced by using available databases loaded from the SWAT (STATSGO and SSURGO) with adjusted soil properties that recognize soil types with similar properties. Cambisols are especially common in alluvials. KPR is located in a part of Serbia known as the Pannonian alluvial plain.

Table 4. Different soil types identified in the SWAT report on KPRbuff.

SRTM DEM		ASTER DEM	
Fluvisols	75%	Fluvisols	74%
Chernozems	24%	Chernozems	25%
Gleysols	1%	Cambisols	1%

The provided soil results demonstrate the potential for using various databases, i.e., information differing in precision about the type of land that can cause some of the problems. For example, it is possible that if the soil types differ significantly in their characteristics, the model can show inaccurate results of stream flow, sediment, and nutrient predictions, thus losing the purpose of modeling. Busico et al. (2020) highlighted that different spatial discretization schemes of soil types could contribute to the complexity of the model, influencing the production of a different number of HRU units. Similarly, users must generate and extract a large number of physical and chemical characteristics to use their self-created databases. This requires the time to collect all the data for the model, making the creation of the SWAT input database a tedious task.

Impact of the use of different meteorological datasets

The next section compares open-source databases with the precipitation time series (1979–2009) currently available for the Rimski Šančevi rainfall gauge station. The precipitation data from the Rimski Šančevi rainfall gauge station (45°07′01"N, 19°41′16"E), the highest priority station in Serbia, were used. On the territory of Vojvodina Province, where the case study is located, the amount of precipitation is unevenly distributed throughout the year – extremely rainy June and almost no precipitation in March and November.

Table 5. Statistical characteristics of mean annual precipitation for the Rimski Šančevi rainfall gauge (1979–2009).

	CarpatClim	Serbian meteorological yearbooks	CFSR
Average	632 mm	640 mm	724 mm
Median	612 mm	596 mm	729 mm
Min	290 mm	289 mm	364 mm
Max	954 mm	999 mm	940 mm

The average annual precipitation amount ranges from 550 to 600 mm (Malinović-Milićević et al., 2018) and the results in Table 5 show that the average precipitation from the CFSR database was 724 mm, which also affected the value of the median. A comparison of meteorological data from three databases showed similar dynamics of annual average precipitation for data formed locally and regionally, while data from the most commonly used global CFSR database showed small to significant (up to 30% of the overall average) deviations (Figure 4). The biggest difference in average annual precipitation was between the Serbian Yearbook data (519 mm) and the open-source CFSR (940 mm) in 1985. The aforementioned differences between the data can cause imprecise and incorrect results and lead scientists to wrong conclusions since precipitation is the most important flux in hydrological processes. There are numerous examples of high SWAT model performance using the CFSR database (Tomy and Sumam, 2016; Jaberzadeh et al., 2022), but there are also negative experiences confirmed, for example, by Zhu et al. (2016) and Duan et al. (2019).

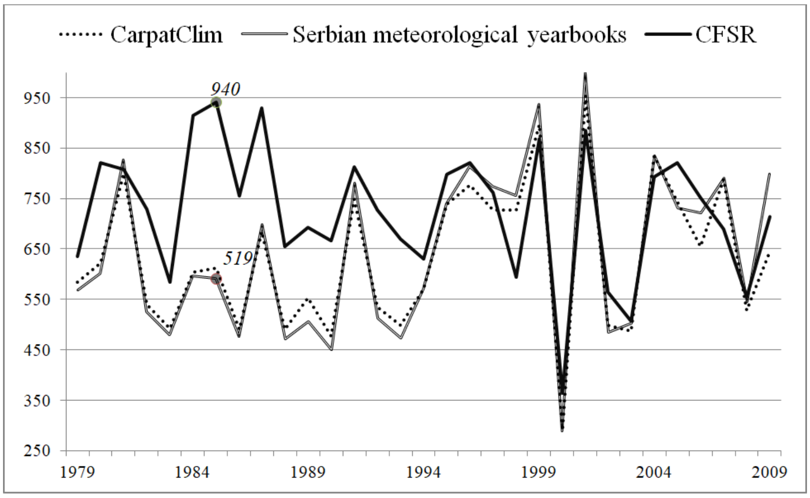


Figure 4. Average annual precipitation collected from different databases for 30 years.

Since the SWAT model takes into account both dry and wet days, the precipitation data need to be appropriate to represent the climate conditions to enable accurate predictions and impacts of climate change. Furthermore, based on the input precipitation data, the reliability of the simulation and the accuracy of the results depend on the input precipitation data, as concluded by Tobin and Bennett (2009). Although the resolutions (38 km, 10 km, and observed grid resolution) of the input data in the available databases vary widely, the authors suggest the use of the higher resolution data in hydrological modeling of smaller areas that require additional data validation. In this case, the average precipitation values using CarpatClim highest-resolution interpolated data were similar to the values recorded at the gauge stations. However, this database cannot be used for further, subsequent analysis because the database has not been updated since 2010. Other databases containing the same type of climatic data include, i.e., WorldClim and Copernicus sources.

Conclusion

In river catchments, where various hydrological and climatic factors must be examined simultaneously, computer simulations are commonly used. This study assists researchers to select reasonable and feasible data for environmental models and comprehend how sensitive SWAT is to spatial resolution. For the Balkan region, which is covered in UTM zone 34N, additional data processing time and a coordinate transformation from a curved surface to a plane are required because the longitude and latitude system does not work in a rectangular coordinate system, but the SWAT model does. Although the choice of the hydrological model remains a preference of the researchers and the resolution of the model depends on the availability of data, the results of this study can provide guidelines for identifying an appropriate approach for future SWAT applications in similar floodplain regions. The availability of regional, national, and international climate and other datasets has allowed modelers to scale up hydrologic models from the global to the local scales. Undoubtedly, the local character of natural ecosystems must be taken into account, so that, if possible, the highest possible resolution of data should be used, since (1) data at local measurement stations can be missing or are not verified and are therefore uncertain; (2) the number and distribution of stations are not homogeneous; (3) data interpolations are accomplished by neglecting measurement uncertainties.

The aim of this research was to evaluate the effects of input data at different resolutions in the initial steps of SWAT modeling. The ASTER layer with a resolution of 30 m should be preferred (with appropriate adjustment if needed), as it showed a better percentage of matching in the building of the hydrographic network and the same soil types were recognized with the digitized soil map of Vojvodina. Additionally, the computation time for catchment delineation was shorter when loading the ASTER layer. Regarding precipitation data, interpolated data were better to use due to their higher resolution (10 km) and heterogeneous distributions of rain gauge stations in Vojvodina.

Unfortunately, high-resolution data are often not available for many regions around the world, especially in developing countries. Combining remote sensing techniques that can be used to obtain both climate and land cover data results in a potent tool for the spatial analysis of hydrological changes. Thus, it is plausible to acquire the essential data required to make real and equitable decisions about the conservation and management of water resources by using high-resolution watershed models.

Acknowledgements

This work was supported by the Ministry of Education, Science and Technological Development of Serbia (Grant No. 451-03-47/2023-01/ 200117).

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Received: June 8, 2023
Accepted: October 16, 2023

UTICAJ ULAZNIH PROSTORNIH PODATAKA I PODATAKA O PADAVINAMA RAZLIČITE REZOLUCIJE NA FORMIRANJE SLIVNOG PODRUČJA PRIMENOM MODELA *SWAT*

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R e z i m e

Kompjuterski zasnovani matematički modeli nalaze široku primenu u oblasti upravljanja vodama za predstavljanje, simulaciju i rešavanje ekoloških problema. Takva istraživanja zahtevaju interdisciplinarni, korisnički orijentisan, sveobuhvatni pristup koji integriše sve procese koji su prisutni u prirodi. Upotreba dostupnih hidroloških modela očekuje razumni nivo kvaliteta i kvantiteta ulaznih podataka kako bi se na pravi način predstavile karakteristike slivnog područja i kako bi se zadržale karakteristike lokalnog ekosistema. Jedan od modela koji ispunjava takve zahteve je model *SWAT* (engl. *Soil and Water Assessment Tool*). Cilj ovog rada je ispitivanje uticaja različite rezolucije ulaznih prostornih podataka i padavina na kreiranje slivnog područja primenom modela *SWAT* na primeru plavnog područja koje se nalazi u slivu reke Dunav u Srbiji. U radu je izvršeno istraživanje procene uticaja (1) digitalnih modela terena različite rezolucije, odnosno baza podataka *SRTM* i *ASTER* (30 m) i *TanDEM-X* (12.5 m), (2) baza podataka *CORINE* i *GlobCover* o načinu korišćenja zemljišta, (3) mape svetskog zemljišta *FAO/UNESCO* i digitalizovane pedološke mape Vojvodine na kreiranje slivnog područja. Istraživanje je sprovedeno uporedo sa analizom klimatskog parametra, padavina, koristeći podatke iz različitih izvora *CFSR*, *CarpatClim* i nacionalnih godišnjaka. Kada su u pitanju prostorni podaci, rezultati ukazuju da je podatke sa visokom rezolucijom (*TanDEM-X*) za ovo područje neophodno dodatno analizirati i prilagoditi, a sloj *ASTER* na prihvatljivom nivou odgovara za dalje zahteve modeliranja u modelu *SWAT*. Bolje je koristiti interpolisane podatke o padavinama, koji su izvedeni iz nacionalnih godišnjaka s obzirom na veću rezoluciju i heterogenu rasprostranjenost stanica.

Ključne reči: prostorni podaci, padavine, *SWAT*, hidrološko modeliranje.

Primljeno: 8. juna 2023.
Odobreno: 16. oktobra 2023.

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