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ESTIMATION OF SOIL EROSION DYNAMICS USING REMOTE SENSING AND SWAT IN KOPAONIK NATIONAL PARK, SERBIA

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Abstract: Soil erosion is a global environmental and economic problem that is significantly related to land-use changes. Over the last decades, several mountain areas in Serbia were exposed to strong human pressure caused by winter tourism development. The largest ski center in Serbia is situated on Kopaonik Mountain within the boundaries of Kopaonik National Park, where the conflict between economic and conservation goals is rapidly growing. In this study, we calculated the sedimentation and surface runoff in three sub-basins in the area of Kopaonik ski resort for two years (1984 and 2018) using the Soil and Water Assessment Tool (SWAT) and analyzed the changes that occurred during the observed period. The results show an increase in surface runoff and sediment yield in sub-basins 1 and 3 and a decrease in sub-basin 2. The analysis of land cover change shows an expansion of evergreen forests, appearance of barren soil and urban areas, reduction of mixed forests and pastures, and the appearance of deciduous forests. These findings indicate that in the area studied, the dominant processes are the development of tourism and natural revegetation of abandoned agricultural land. Application of remote sensing techniques and SWAT contributes to identifying and monitoring land degradation problems and improving conservation and management practices.

Keywords: sedimentation; surface runoff; Landsat; mountain area; LCLU change

Introduction

Soil erosion is one of the main contemporary environmental problems and major causes of land degradation. Recognized as a serious problem in the 1930s, it is still expanding worldwide: rates of soil erosion have been exceeding the rates of new soil development during the last several decades (Bullock, 2004). This accelerated growth of the problem in many countries is related mainly to land-use changes, such as removing natural vegetation and transforming forests into agricultural areas, thus affecting food productivity and ecosystem functioning.

In Serbia, about 86% of the territory is potentially at soil erosion risk (Lazarević, 2009). However, the rate of soil erosion in Serbia has decreased in the last decades (Kostadinov et al., 2014; Zlatic & Vukelic, 2002). Decrease of soil erosion is not a result of conservation efforts and measures, but rather a consequence of demographic and economic processes (population migrations from rural to urban environments, demographic aging, depopulation, a decrease of agricultural activities, and abandonment of agricultural land), which are more developed in hilly and mountainous areas in the country than in lower zones. About 50 years ago, intensive erosion processes were active in these areas because the population was engaged in crop and livestock farming (Lazarević, 2009). Nowadays, because of population aging and migrations, meadows and pastures are being abandoned, and forested areas are expanding.

Despite this tendency, landscapes of some mountain areas in Serbia are exposed to severe land degradation, caused by winter tourism development. Clearance of forests, increasing erosion, construction of ski slopes and ski infrastructure, unplanned and illegal construction of buildings for tourists' accommodation, air and water pollution, irresponsible waste disposal, and noise pollution are the main threats to natural ecosystems in the mountain areas (Ćurčić, 2017; Ćurčić, Milinčić, Stranjančević, & Milinčić, 2019). Forest clear-cutting and machine grading of ski slopes below the tree line lead to erosion of shallow soil surfaces and further to the creation of a source of sediments that can be transported into streams and rivers (Ristić, Kašanin-Grubin, Radić, Nikić, & Vasiljević, 2012; Ristić, Vasiljević, Radić, & Radivojević, 2009). Comparison of some European ski resorts with those in Serbia shows that they have a different vertical distribution of tourist settlements and ski infrastructure in the mountains, i.e., it is usual that tourist settlements and accommodations are situated at the foot of the resort, while the ski slopes are built above the tree line, e. g., 80% of the ski slopes in Davos, Switzerland are situated at an elevation of more than 2,000 m a.s.l. (Ski regions in Davos Klosters, 2021). Since high-mountain areas over 2,000 m a.s.l. in Serbia cover only 0.3% of the country's territory (Ćalić, Milošević, Milivojević, & Gaudenyi, 2017), the main ski resorts in Serbia are situated below the tree line, thus causing landscape, soil, and vegetation degradation. The tree line of mountains on the Balkan Peninsula is considered to lie between 1,900 and 2,300 m a.s.l. (Belij, Nešić, & Milovanović, 2008).

The greatest ski resort in Serbia is located within the area of Kopaonik National Park, which is situated on Kopaonik Mountain. Even though the erosion problem is one of Serbia's main environmental problems, there are only a few studies that treat soil erosion and loss in Kopaonik region (Carić, 1968; Kostadinov, Dragović, Zlatić, & Todosijević, 2008; Pavićević, Antonović, & Nikodijević, 1969). In the present study, we aimed to expand the insufficient amount of knowledge about soil erosion caused by water in the study area using the Soil and Water Assessment Tool (SWAT). The objectives of the study were to calculate the sedimentation and surface runoff for two years (1984 and 2018) and analyze the impact of winter tourism development on the environment. These two years were selected because winter tourism expansion in Kopaonik area started in the early 1980s and because we started work on this study in 2019.

Materials and methods

Study area

For this research, we chose to study the area of Kopaonik Mountain which is mostly exposed to anthropogenic impact. Kopaonik Mountain is situated in central and south Serbia and is part of the Vardar Zone, which is located between the Dinaric Mountains in the west and the Serbo-Macedonian massif in the east (Ćalić et al., 2017). The mountain is characterized by northwest-southeast orientation and is situated between the rivers Jošanica, Ibar, Sitnica, and Lab. The mountain's length is about 80 km, and the width is between 40 and 60 km, while the total area is 2,758 km^2 (Djordjevic, Secerov, Filipovic, Lukic, & Jeftic, 2016; Gavrilović, 1979). The highest peak is Pančićev Vrh (2,017 m a.s.l.). According to the data from the Republic Hydrometeorological Service of Serbia (1981–2010), the highest average monthly temperature is in August (12.8 °C), while the lowest is in February (–5.1 °C). From lower to higher altitudes, mainly oak, beech, fir, and spruce forests interchange vertically. About 825 plant species with 91 endemics and 82 subendemics are registered in Kopaonik Mountain's highlands, thus making it a center of the arctic-alpine flora on the Balkan Peninsula (Lakušić, 1993; Stevanović et al., 2009).

Due to intensive geological activities in the past, Kopaonik Mountain evolved into a region of the heterogeneous geological structure, formed of magmatic, sedimentary, and metamorphic rocks that have been modified from the Palaeozoic to the Holocene. The Kopaonik Block represents a part of the Vardar Zone, one of the most complex mosaics of blocks (Cvetković, Poli, Resimić-Šarić, Prelević, & Lazarov, 2002; Schmid et al., 2008), and it is characterized by diverse structure, tectonic movements, volcanic and seismic activities, deposits of different raw materials, and presence of mineral and thermal waters.

The following rocks are registered at the territory of Kopaonik National Park: Palaeozoic—serpentinites, harzburgites, chlorite-sericite schist, metamorphosed sandstones, calc-schists, marbles, chlorite-epidote-actinolite-schists, and metabasites; Mesozoic—diabase-chert formations, flysch formations, calcitic breccia, conglomerates, and limestones; Tertiary—conglomerates, clays, sandstones and marls on the one hand, and volcanic rocks like dacites and andesites with transitions between them and tufas, granodiorites, porphyrites and keratophyres on the other, and Quaternary—alluvial sediments (University of Belgrade - Faculty of Mining and Geology, 2010; Urošević, Pavlović, Klisić, Karamata et al., 1973; Urošević, Pavlović, Klisić, Malešević et al., 1973). From the ancient times, this area was recognized as a mining region, with three main mining zones (Vasović, 1988): Ravni Kopaonik–Belo Brdo–Lukovo zone (lead, zinc, magnesite, iron, copper, tungsten, wollastonite, asbestos); the zone west of Kuršumlija Spa (copper); and the zone on the southwest slopes above Trepča (lead, zinc, magnesium).

The soil on the territory of Kopaonik National Park is represented by many types. The vertical distribution of soil types on Mt. Kopaonik, for the most part, coincides with the vertical zonation of vegetation: in the lower foothill belt up to elevations of 750/800 m a.s.l., where thermophilic oak forests are present, the soils include regosol on serpentine, humic-silicate soils on serpentine, and brunified humic-silicate soils on serpentine. At elevations of 750/800–1,100 m a.s.l., where mesophilic oak and beech forests are dominant, brown soils on serpentine are represented, together with acidic brown soils on silicate substrates, humic varieties of acidic brown soils, leached brown soils on serpentine, and brown soils on limestone. From 1,100 to 1,500 m a.s.l., where beech, beech-fir, and spruce-fir forests are present, the following soil types are represented: humic varieties of acidic brown soils; leached brown soils on serpentinite, and brown soils on limestone. At elevations of 1,500 to 1,800 m a.s.l., where mixed beech-fir-spruce and beech-fir forests grow, the soil types include brown podzolic soils, acidic humic-silicate soils, and organomineral and brunified chernozem on limestones. At elevations higher than 1,800 m a.s.l. on the upper boundary of forests and in the alpine belt, where phytocoenoses of spruce, blueberry, and flattened juniper are developed, and mountain pastures are present, brown podzolic soils are encountered, together with kalcomelanosol and humic-silicate soils (Jović, 1968).

From the beginning of the 20th century, Kopaonik has become a famous destination for naturalists and mountaineers, and the first skiing course was organized there in the 1930s (Ćurčić, 2017). With a long history of winter sports, this area is the largest ski resort in Serbia today, with 62 km of ski slopes and roads and a ski lift system with a capacity of 34,000 skiers per hour (Skijališta Srbije, 2020). During the period 1984 to 2018, the number of tourists per year increased from 38,656 to 132,080, i.e., 241.68%, and the number of nights spent increased from 202,359 to 550,962, i.e., 164.68% (Statistical Office of the Socialist Republic of Serbia, 1985; Statistical Office of the Republic of Serbia [SORS], 2019). Even though the number of tourists is growing, the population of the tourist settlement Kopaonik is decreasing—from 127 residents recorded in 1981 to only 19 in 2011 (SORS, 2014).

The area of interest is located in Kopaonik National Park (KNP), situated in Ravni Kopaonik area, the most elevated part of Kopaonik Mountain (Figures 1a and 1b). The highest Kopaonik Mountain area is characterized by outstanding geo- and biodiversity and is established as a national park in 1981. KNP covers an area of 11,969.04 ha (119.69 km^2) and includes the basins of the rivers Samokovska, Gobeljska, Brzećka, and Barska. The area of KNP is under different levels of protection: 12.38% is under the first level, 29.94% is under the second level, and 57.68% is under the third level of protection (Zakon o nacionalnim parkovima, 2018).

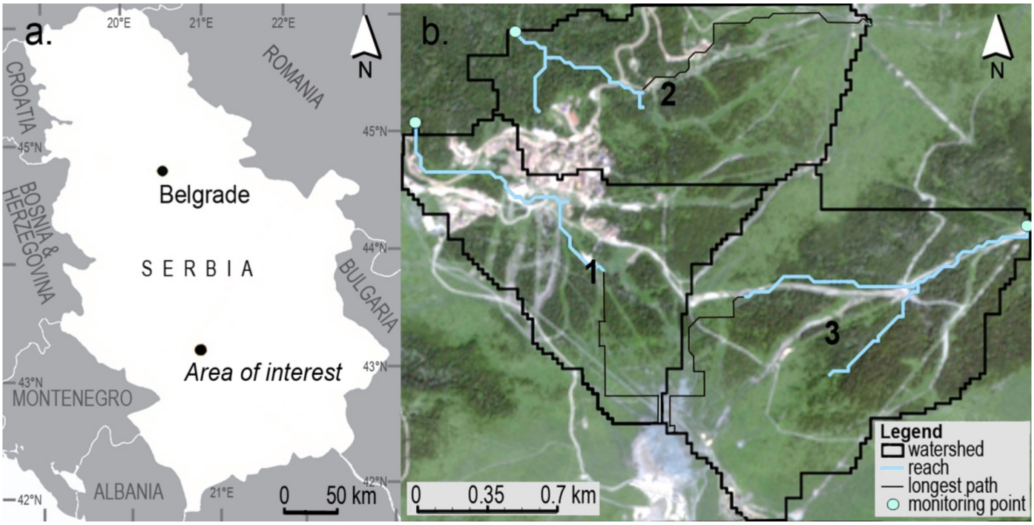

Figure 1. Basic information on the study area: Geographic location of the area of interest in Serbia (a) and the area of interest in 2018 (b). Data used for study area are obtained from *Landsat 5 Thematic Mapper C1 Level-1*, by United States Geological Survey, Earth Resources Observation and Science Center, 2019a (https://doi.org/10.5066/F7N015TQ) and *Landsat 8 OLI/TIRS C1 Level-1*, by United States Geological Survey, Earth Resources Observation and Science Center, 2019b (https://doi.org/10.5066/F71835S6). In the public domain.

The area of interest covers the zone of the ski resort with Kopaonik tourist settlement and a part of the old open pit mine (Figure 1b) within UTM34N bounds of 483866.352, 4790733.885, 487066.352, and 4793358.885 (westernmost longitude of 20° 48' 04.0111" E, northernmost latitude of 43° 17' 34.5978" N, easternmost longitude of 20° 50' 26.2442" E and southernmost latitude of 43° 16' 09.2819" N). All the used data are projected in UTM Zone 34 N projection, WGS84 data, and meters as units. The area of interest is divided into three sub-basins and covers 4.757 km^2.

Methodology

1. SWAT Model

One of the semi-distributed hydrological and powerful watershed models broadly used by researchers is the SWAT (Li, Liu, Wang, & Liang, 2015). It is used to model various hydrology-related environmental phenomena, such as hydrological conditions, transport of pollutants and sediments, erosion, etc. Also, SWAT is a highly suitable tool for covering a wide range of water resource problems and for the analyses of diverse scenarios. To assess water resources, erosion, and different pollution sources in remote catchments, SWAT is a very valuable tool. It is a semi-diffuse, process-based integrated hydrological model developed by the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) and is based on 30-year data of hydrological research (Gassman, Reyes, Green, & Arnold, 2007). The model simulates the daily water cycle, crop development, and transport of sediment, nutrients, and pesticides in a basin (Arnold et al., 2012; Vigiak, Malagó, Bouraoui, Vanmaercke, & Poesen, 2015).

SWAT model operates through two steps: 1) a land phase, solved at the hydrological response unit (HRU) level; and 2) a water phase, solved at the reach (sub-basin) level (Neitsch, Arnold, Kiniry, & Williams, 2011). In the land phase, the HRU daily water balance and sediment yields are calculated. The HRU daily water balance considers precipitation, irrigation, evapotranspiration, surface runoff, lateral flow, and percolation to shallow and deep aquifers (Neitsch et al., 2011).

The model is used to analyze maximum daily loads (Borah et al., 2006), large water areas (Jha, Arnold, Gassman, Giorgi, & Gu, 2006), and environmental protection within the framework of the USDA Conservation Effects Assessment Program (Mausbach & Dedrick, 2004). SWAT is also used in hydrological modelling to present the influence of climate changes on the environment and that of soil erosion on the water balance (Setyorini, Khare, & Pingale, 2017; Singh & Goyal, 2017; Yang & Zhang, 2016). SWAT has been employed to model the impact of urbanization on the hydrology of the area, to analyze an area, and run a hydrological simulation for a small hydropower plant (SHP) construction site (Goyal, Singh, & Meena, 2015; Potić, 2018; Rospriandana & Fujii, 2017). For the territory of Serbia, SWAT is used to simulate surface runoff, model the rainfall-runoff ratio, SHP site modelling, and other purposes (Divac, Milivojević, Grujović, Stojanović, & Simić, 2009; Milivojević, Simić, Orlić, Milivojević, & Stojanović, 2009; Potić, 2018; Simić, Prohaska, Milivojević, & Orlić, 2004). To achieve the goal and evaluate sedimentation change induced by the expansion of tourism in Kopaonik National Park and the ski resort during the period of 1984–2018, different geospatial data must be prepared for SWAT.

2. Input Data

Mandatory input parameters for SWAT analysis and simulation are the Digital Elevation Model (DEM), a land use-land cover (LULC) map, a soil map, and weather data. Those parameters are used to distribute HRUs across the area and perform hydrological, and erosion analyses for the created HRUs.

- DEM—In SWAT simulation, the role of DEM is very important. DEM with 4.4 m vertical accuracy (Tadono et al., 2016) and 22.45 m spatial resolution is selected as basic SWAT input data (Japan Aerospace Exploration Agency [JAXA], 2017). The JAXA ALOS Global Digital Surface Model AW3D30 (JAXA, 2017) was used to perform the initial SWAT steps (Figure 2a).

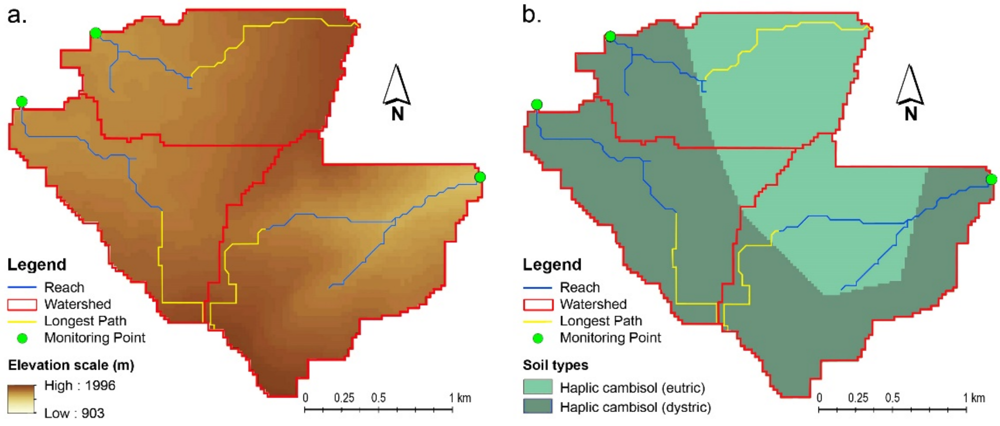

Figure 2. Elevation (a) and soil (b) map of the research area.

- Soil Map—A soil map for the research area was acquired from the Harmonized World Soil Database (Food and Agriculture Organization [FAO], Applied Systems Analysis [IIASA], ISRIC—World Soil Information, Institute of Soil Science, Chinese Academy of Sciences [ISSCAS], and the Joint Research Centre of the European Commission [JRC], 2012), and soil types were adjusted to SWAT database attributes (Figure 2b, Table 1).

Table 1
SWAT model input data

Land Cover	SWAT code	Slope (°)	Soil type	SWAT code
Water	WATR	≥ 0 < 5	Haplic cambisol (dystric)	Ao41-2ab-4271
Evergreen forest	FRSE	≥ 5 < 10	Haplic cambisol (eutric)	Ao85-2-3b-4278
Deciduous forest	FRSD	≥ 10 < 15	x	
Mixed forest	FRST	≥ 15 < 20		
Pastures	PAST	≥ 20		
Barren soil	BARR			
Residential-urban area	URMD			

- Land Cover—To produce a land cover map, Landsat 5 and 8 satellite imagery was downloaded from the USGS EarthExplorer application (United States Geological Survey, Earth Resources Observation and Science Center, 2019a, 2019b). The research period covers the corresponding earliest available Landsat 5 imagery from late 1984 summer-appropriate cloudless recording to early 2018 autumn-appropriate cloudless Landsat 8 recording. Landsat 5 was launched on March 1, 1984 and decommissioned on June 5, 2013 (United States Geological Survey, Earth Resources Observation and Science Center, 2018). Satellite imagery was acquired by Landsat 5 on September 9, 1984, and Landsat 8 on October 10, 2018. Red, green, blue, and near-infrared bands were used to analyze and classify the satellite data. In order to classify the satellite imagery into seven classes: water, evergreen forest, deciduous forest, mixed forest, pasture, barren soil, and residential-urban area, the Random Forest machine learning algorithm was employed. Random Forest supervised classification demands and made a comprehensive and accurate selection of training zones for each class (Duro, Franklin, & Dubé, 2012; Mas & Flores, 2008; Potić & Potić, 2017; Potić, Ćurčić, Potić, Radovanović, & Tretiakova, 2017). As a supervised learning task, regression is employed to model and predict variables where numerical true ground values for the research area are present. Regression trees (decision trees), which are used to classify satellite data, repeatedly split the dataset into separate branches and maximize the information gain so the algorithm can learn nonlinear relationships. Using classification trees, the Random Forest classifier classifies the data with high accuracy. Land cover classes are defined according to SWAT codes (Figure 3, Table 1).

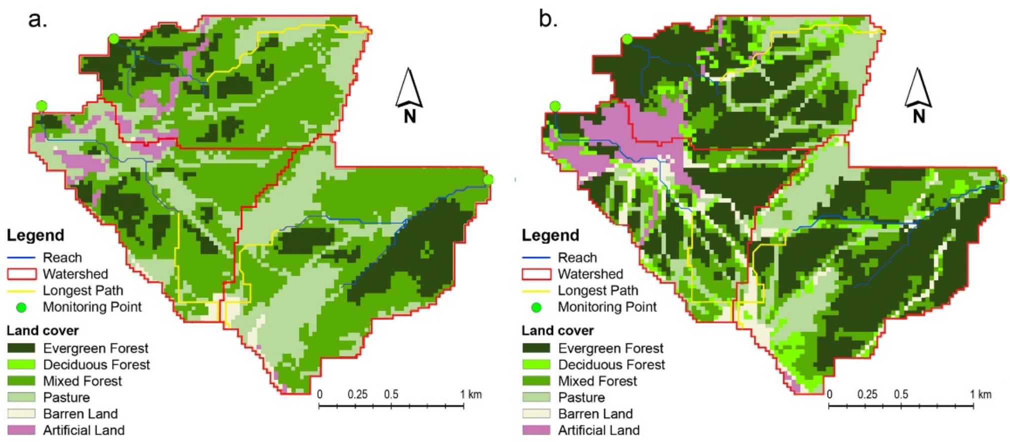

Figure 3. Land cover of the research area for: 1984 (a) and 2018 (b).

- Weather Data—Weather data necessary to simulate the process were obtained from the National Centre for Environmental Prediction (NCEP) and the Climate Forecast System Reanalysis (CFSR) Archive (University Corporation for Atmospheric Research [UCAR] & NCEP, 2018): temperature (°C), precipitation (mm), wind (m/s), relative humidity (percent), and solar energy (MJ/m^2). The data are SWAT-ready in .csv format and cover the period from January 1, 1979 to July 31, 2014. CFSR data are created from satellite products and the global weather station network on an hourly basis. Spatial resolution of the data is approximately 38 km and can be downloaded in SWAT ready format. Annual 1984 weather data are extracted and used for the analysis from the available dataset.

3. SWAT Workflow

The SWAT workflow consists of three mandatory steps. DEM is used in the first SWAT step, the watershed delineation. DEM is loaded, and flow direction and accumulation are calculated. The minimum area for a watercourse occurrence is set at 5 ha. The next step is creating the stream network and outlets. After three outlets are selected, sub-basin parameters are calculated, and watersheds are delineated.

In the second SWAT step, HRUs are created. DEM is utilized to create multiple slopes in five classes. Two other maps are necessary to accomplish this step: a Land Cover (LC) map and a Soil map. It is mandatory for all the input data that are in the same coordinate system, and is used for this research area.

The third step is the SWAT simulation, and it is performed for two annual periods, 1984 and 2018. For the first simulation period (1984), the input data are DEM, soil map, and the LC map obtained from the Landsat 5 satellite imagery acquired in 1984 and weather data from 1984. For the second simulation period, the same data are used, except that LC data based on Landsat 8 imagery acquired in 2018 is analyzed. The same DEM, soil, and weather data with different land cover will show the difference in sedimentation and surface runoff.

4. Sedimentation Calculation

In SWAT, the Modified Universal Soil Loss Equation—MUSLE (Williams, 1995) is used to calculate the HRU sediment yields. Originally developed for small catchments (< 40 km^2), MUSLE was successfully tested on catchments ranging between 0.01 and 234 km^2 (Williams & Hann, 1978). MUSLE estimation of HRU sediment yields for non-urban land use types is shown in Equation 1 (Williams, 1995):

$$SY = 11.8 \cdot (Q \cdot q_p \cdot A)^{0.56} (C \cdot P \cdot K \cdot LS \cdot F_{CRFG}) \quad (1)$$

where SY is HRU sediment yield (t/day); Q is daily runoff volume (mm); q_p is runoff peak discharge (m^3/s); A is HRU area (ha); and dimensionless factors accounting for: C—HRU crop cover, P—soil protection/anti-erosion practices, K—soil erodibility (0.013, t ha^{-1} MJ mm^{-1}), LS presents topography as defined in the original universal soil loss equation (USLE) (Ganasri & Ramesh, 2016; Wishmeier & Smith, 1978); and F_{CRFG} is a dimensionless factor that accounts for coarse fragment cover (stoniness).

Because it uses the energy of surface runoff rather than rainfall to estimate sediment yields, MUSLE is suitable for application on a daily time scale. MUSLE estimates sediment yields and not gross erosion, so it already accounts for sediment deposition within the HRU. The urban area HRU sediment yields are estimated based on precipitation or the "build-up/wash off" approach (Neitsch et al., 2011).

5. Surface Runoff Calculation

Surface runoff (Q_{surf}, mm H_2O) is calculated using the Soil Conservation Service Curve Number (SCS-CN) model (Rallison & Miller, 1981), which describes watershed runoff on the macroscopic scale (Equation 2). The model considers the relationship between total actual retention and total rainfall (Li et al., 2015):

$$Q_{surf} = (R_d - I_a)^2 / (R_d - I_a + S) \quad (2)$$

where R_d is actual daily rainfall (mm H_2O); I_a is the initial abstraction from rainfall (mm H_2O); S is the depth of effective available storage within the watershed and is calculated using Equation 3:

$$S = 25.4 \cdot (1000/CN - 10) \quad (3)$$

where CN is the curve number originally derived as a function of soil and land use types (Kumar, Singh, & Shrestha, 2016; Simić et al., 2004). Surface runoff is possible only if the condition $R_d > I_a$ is met.

The use of the SCS model in SWAT has made the SCS-CN method popular to calculate runoff (Gassman et al., 2007). The SWAT model calculates total basin runoff (Q_j) using two components: surface runoff (Q_{surf}) and underground runoff (Q_{gw}) for all HRUs at a given moment i (Equation 4) (Potić, 2018; Simić et al., 2004):

$$Q_j = \sum_{i=1}^{k} Q_{surf}^{i} + Q_{gw}^{i} \quad (4)$$

Results

In the present study, SWAT analysis is performed for three selected outputs (Figure 1b). A topographic report for all the sub-basins is presented in Table 2.

Table 2
Topographic report for three sub-basins

Sub-basin	Area (ha)	Min. elevation (m a.s.l.)	Max. elevation (m a.s.l.)	Number of HRUs 1984	Number of HRUs 2018
1	131.81	1,672	1,940	32	46
2	146.94	1,662	1,912	40	52
3	196.94	1,515	1,989	37	52

For the research area, three sub-basins occupying between 130 and 200 ha, with absolute elevations of between 1,515 and 1,989 m, were delineated. The number of HRUs is higher for 2018 due to the land cover changes that occurred. The HRU reports presented in Tables 3–12 present the cumulative data for all the HRUs of the adjacent sub-basin.

The largest land cover change for sub-basin 1 during 1984–2018 is registered in the mixed forest class, viz., from 49.65% of the total watershed area to 19.35%, which is a 30.30% decrease (Table 3). The greatest increase of the total watershed area (22.57%) is registered in the evergreen forest class, and significant expansion (10.96%) is recorded for the urban area class (residential-medium density).

Table 3
Land cover report for sub-basin 1

Land cover 1984	SWAT code	Area (ha)	Wat. area (%)	Land cover 2018	SWAT code	Area (ha)	Wat. area (%)
Evergreen forest	FRSE	16.68	12.65	Evergreen forest	FRSE	46.43	35.22
				Deciduous forest	FRSD	10.69	8.11
Mixed forest	FRST	65.44	49.65	Mixed forest	FRST	25.50	19.35
Pasture	PAST	38.38	29.12	Pasture	PAST	13.38	10.15
Barren soil	BARR	3.00	2.28	Barren soil	BARR	13.06	9.91
Residential-medium density	URMD	8.31	6.30	Residential-medium density	URMD	22.75	17.26

The coverage area of the pasture class in this watershed is decreased by 18.97%, while that of the barren soil class increased by 7.63%. New deciduous forest class appeared in 2018 covering 8.11% of the total watershed area. In total, the area of all the forest classes did not change notably, the obtained forest cover being ~62% of the area for both study years (62.30% in 1984 and 62.68% in 2018).

Two different soil types are present in sub-basin 1: eutric haplic cambisol and dystric haplic cambisol. According to soil report for this sub-basin, eutric haplic cambisol is dominant, covering more than 90% of the area (Table 4).

Table 4
Soil report for sub-basin 1

Soil	SWAT code	Area (ha)	Wat. area (%)
Haplic cambisol (eutric)	Ao85-2-3b-4278	118.94	90.24
Haplic cambisol (dystric)	Ao41-2ab-4271	12.87	9.76

Slope report shows that flat areas (0°–5°) in sub-basin 1 cover only 3.46% of the total watershed area. The highest percent of this sub-basin (31.62%) is very sloped—above 20°, and more than 80% of the watershed area is above 10° (Table 5).

Table 5
Slope report for sub-basin 1

Slope (°)	Area (ha)	Wat. area (%)
≥ 20	41.68	31.62
≥ 15 < 20	29.19	22.15
≥ 10 < 15	35.13	26.65
≥ 5 < 10	21.25	16.12
≥ 0 < 5	4.56	3.46

For sub-basin 2, the greatest change in land cover during 1984–2018 is registered in the area covered by mixed forests, i.e., a decrease of 36.62% (from 52.91% to 16.29%) of the watershed area. The largest increase is recorded in the evergreen forest class, which enlarged its size by 31.31%. A new forest class (deciduous forest) also appeared in this sub-basin in 2018, covering 7.49% of the sub-basin. In total, all the forest classes increased by 2.18%. The urban area (residential-medium density) class increased its cover by 2.51% of the total watershed area, while barren soil increased its area by 0.63%. The coverage of pastures decreased by 5.32% (Table 6).

Table 6
Land cover report for sub-basin 2

Land cover 1984	SWAT code	Area (ha)	Wat. area (%)	Land cover 2018	SWAT code	Area (ha)	Wat. area (%)
Evergreen forest	FRSE	25.93	17.65	Evergreen forest	FRSE	71.94	48.96
				Deciduous forest	FRSD	11.00	7.49
Mixed forest	FRST	77.75	52.91	Mixed forest	FRST	23.94	16.29
Pasture	PAST	36.00	24.50	Pasture	PAST	28.19	19.18
Barren soil	BARR	0.13	0.09	Barren soil	BARR	1.06	0.72
Residential-medium density	URMD	7.13	4.85	Residential-medium density	URMD	10.81	7.36

As stated in soil report for sub-basin 2, the same soil types are present as in sub-basin 1. The eutric haplic cambisol soil type covers more than 1/3 of the watershed area (35.26%), while dystric haplic cambisol is represented by 64.74% (Table 7).

Table 7
Soil report for sub-basin 2

Soil	SWAT code	Area (ha)	Wat. area (%)
Haplic cambisol (eutric)	Ao85-2-3b-4278	51.81	35.26
Haplic cambisol (dystric)	Ao41-2ab-4271	95.13	64.74

Slope report for sub-basin 2 shows that the highest percent of the watershed area is 20° or above. More than 78% of the area is highly sloped (more than 10°). Flat areas (up to 5°) cover 6.38% of sub-basin 2 (Table 8).

Table 8
Slope report for sub-basin 2

Slope (°)	Area (ha)	Wat. area (%)
≥ 20	49.49	33.68
≥ 15 < 20	36.63	24.93
≥ 10 < 15	29.19	19.87
≥ 5 < 10	22.25	15.14
≥ 0 < 5	9.38	6.38

The most significant land cover change in sub-basin 3 was recorded in the evergreen forest class, with the increase of 25.33% (Table 9). Notable expansion of coverage was also registered in the barren soil class, which increased by 4.54% of the total watershed area. The greatest decrease was recorded for the mixed forest class, which reduced its cover by 22.69%. Again, a new deciduous forest class appeared in 2018. In total, all the forest classes showed an increase of 8.61% of sub-basin area (from 64.67% to 73.28%) between 1984 and 2018. The urban area class changed slightly from 1984 to 2018, i.e., it increased by 0.07%. The coverage of pastures decreased by 13.20%.

Table 9
Land cover report for sub-basin 3

Land cover 1984	SWAT code	Area (ha)	Wat. area (%)	Land cover 2018	SWAT code	Area (ha)	Wat. area (%)
Evergreen forest	FRSE	36.81	18.69	Evergreen forest	FRSE	86.69	44.02
				Deciduous forest	FRSD	11.75	5.97
Mixed forest	FRST	90.56	45.98	Mixed forest	FRST	45.86	23.29
Pasture	PAST	64.69	32.85	Pasture	PAST	38.69	19.65
Barren soil	BARR	4.25	2.16	Barren soil	BARR	13.19	6.70
Residential-medium density	URMD	0.63	0.32	Residential-medium density	URMD	0.76	0.39

According to soil report for sub-basin 3, the same soil types are present as in sub-basin 1 and 2. Haplic cambisol (eutric) covers more than 56% of sub-basin 3 (Table 10).

Table 10
Soil report for sub-basin 3

Soil	SWAT code	Area (ha)	Wat. area (%)
Haplic cambisol (eutric)	Ao85-2-3b-4278	112.00	56.87
Haplic cambisol (dystric)	Ao41-2ab-4271	84.94	43.13

The terrain is highly sloped in this sub-basin, where more than 83% is with a slope greater than 20°. The flat area covers only 0.51% (1 ha), while the area with a slope greater than 10° covers more than 97% of sub-basin 3 (Table 11).

Table 11
Slope report for sub-basin 3

Slope (°)	Area (ha)	Wat. area (%)
≥ 20	164.31	83.43
≥ 15 < 20	17.69	8.98
≥ 10 < 15	9.56	4.85
≥ 5 < 10	4.38	2.22
≥ 0 < 5	1.00	0.51

SWAT simulation output data for 1984 and 2018 sediment yield and surface runoff are calculated and presented in the Table 12. Surface runoff showed an increase of 23.86 mm/yr in sub-basin 1 and 0.95 mm/yr in sub-basin 3 in 2018.

Table 12
SWAT simulation output data

	Sub-basin 1		Sub-basin 2		Sub-basin 3	
	1984	2018	1984	2018	1984	2018
Surface runoff (mm/yr)	269.67	293.53	224.17	222.02	239.78	240.73
Av. upland sediment yield (mg/ha)	28.23	38.57	12.7	11.22	70.6	73.09
Max. upland sediment yield (mg/ha)	574.48	469.69	120.24	220.86	561.68	643.49
In-stream sediment change (mg/ha)	–27.13	–37.43	–11.59	–10.1	–69.06	–71.57

In sub-basin 2, on the other hand, surface runoff showed a decrease of 2.15 mm/yr. The same tendency is recorded for the sediment yield. Sub-basin 1 showed an increase in average upland sediment yield of 10.34 mg/ha, while this increase for sub-basin 3 was smaller (2.49 mg/ha). On the other hand, sub-basin 2 showed decreased sediment yield (by 1.48 mg/ha).

Discussion

The results are based on daily loads calculated through two SWAT operating steps, land phase and water phase, where land phase is solved at HRU level while further calculation is focused on sub-basin (watershed) level to calculate water phase (Borah et al., 2006; Neitsch et al., 2011). The main goal of this research—the impact of the land cover change on erosion dynamics—is successfully achieved through SWAT calculation results comparison (Table 12). Besides the employment of SWAT for modelling the impact of urbanization on the hydrology of the area (as in Goyal et al., 2015; Potić, 2018; Rospriandana & Fujii, 2017), the research also covers the influence of climate changes on the environment and that of soil erosion on the water balance considering meteorological data (as in Setyorini et al., 2017; Singh & Goyal, 2017; Yang & Zhang, 2016) and satellite imagery for 34 years.

As mentioned, the usage of SWAT for the territory of Serbia is mainly focused to simulate surface runoff and model the rainfall-runoff ratio (Divac et al., 2009; Milivojević et al., 2009; Simić et al., 2004). This research widens the focus of SWAT usage into the area of urban expansion caused by an increase in tourist demands and how these changes make an impact on increasing erosion dynamics in the area.

The final SWAT simulation results present the change in erosion dynamics for the entire research area consisting of three separate watersheds (Table 12). There are noticeable differences in the surface runoff for all the three sub-basins, where the highest difference and an increase is for sub-basin 1. In the case of runoff, an increase was found for sub-basin 3, and a decrease for sub-basin 2. Regarding upland sediment yield, sub-basin 1 and sub-basin 3 showed an increase, while sub-basin 2 showed decreased sediment yield. The final SWAT simulation results are in accordance with the active natural processes present in the research area.

An increase of urban area is recorded in all the three sub-basins (in sub-basin 1—by 10.96%; in sub-basin 2—by 2.51%; in sub-basin 3—by 0.07%; in total—by 13.54%) (Tables 3, 6, and 9). This can be linked with the development of winter tourism in the area of the ski resort. On the other hand, forests also increased their coverage (in sub-basin 1—by 0.38%; in sub-basin 2—by 2.18%; in sub-basin 3—by 8.61%; in total—by 11.17%), the greatest increase being recorded in the evergreen forest class (in sub-basin 1—by 22.57%; in sub-basin 2—by 31.31%; in sub-basin 3—by 25.33%; in total—by 79.21%). In all the sub-basins, the mixed forest class decreased by 89.61% and the pasture class by 37.49%. Barren soil in all the sub-basins increased by 12.80%, which can be attributed to human activities in the area. The appearance of a deciduous forest class in all the three sub-basins (in total comprising 21.57%) can be linked with a decrease of the pasture class, i.e., land-use changes in the area, namely a decrease of agricultural activities (raising of livestock) and abandonment of pastures and meadows (Tables 3, 6, and 9).

The deviation of sub-basin 2 can be attributed to land cover change since forests' presence decreases surface runoff and sediment yield. The watershed area of sub-basin 2 experienced an increase of evergreen forests by 31.31%, i.e., from 17.65 % in 1984 to 48.96 % in 2018, and deciduous forests were found to have expanded by 7.49% in 2018 (Table 6). The increase of surface runoff in sub-basin 1 can be linked with intensified urbanization and logging since urban area and barren soil increased their coverage to a greater extent in it (by 10.96 and 7.63%, respectively; in total by 18.59%) than in the other two studied basins (the total values of the urban area and barren soil expansion were 3.14% in sub-basin 2 and 4.61% in sub-basin 3).

Data used for this research belong to medium-resolution spatial data. To achieve more precise calculations, it is further desirable to obtain high resolution satellite imagery to classify land cover, create more accurate DEM, collect more precise field meteorological data, and perform more precise soil analysis and mapping.

Conclusion

During the last several decades, KNP has been exposed to intensive human influences, so from a once primarily natural protected area, it evolved nowadays into the largest ski center in Serbia. Activities such as tourism, mining, and forestry have significantly altered its landscape and led to land degradation in some parts. KNP represents an outstanding natural area with unique and diverse geological and biological characteristics, so continuous studies of relations between man and nature and their consequences in the region are strongly needed. The present study is devoted to one aspect of these consequences—soil erosion. It aims to evaluate changes of surface runoff and sediment yield from 1984 to 2018 in the ski resort, the most vulnerable part of KNP.

Three sub-basins in the resort area are delineated. The main hydrological analyses (of surface runoff and sediment yield) were performed using SWAT for the observed period. The analyses involved different input data: DEM, a land cover map, a soil map, and weather data. To make the data comparable, the land cover map was created using satellite imagery from different periods. This methodology provides insight into the environmental response to human impact during the observed period. For each sub-basin analysis (and corresponding year), a different number of HRUs was created. Geospatial data were overlapped and analyzed for each HRU to calculate the results.

The results show an increase in surface runoff and sediment yields in sub-basins 1 and 3, while a decrease of both values was recorded in sub-basin 2. Analyzed together with the obtained data on land cover change, these findings indicate that agricultural stagnation and demographic processes have caused natural revegetation of abandoned meadows and pastures, which has mitigated the negative effects brought about by the development of winter tourism. Still, tourism is a growing activity in the area. The main threats to natural ecosystems are presented by deforestation, followed by intensified erosion, unplanned and illegal building projects, inadequate waste disposal, air, water, and noise pollution. The ski resort area is already saturated with tourists, buildings for their accommodation and ski facilities, so there is a real threat that tourism will, in the end, jeopardize its development. The application of remote sensing and SWAT techniques shows that these methods represent reliable tools for the analysis of environmental changes and processes during the past that can therefore be used to predict future tendencies and more complex studies of land change and degradation.

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References

Arnold, J. G., Kiniry, J. R., Srinivasan, R., Williams, J. R., Haney, E. B., & Neitsch, S. L. (2012). *Soil and Water Assessment Tool, Input/Output Documentation, Version 2012*. Texas, USA: Texas Water Resources Institute.

Belij, S., Nešić, D., & Milovanović, B. (2008). Savremeni geomorfološki procesi i oblici reljefa periglacijane sredine Stare Planine [Recent geomorphological processes and landforms of periglacial environment of the Stara Planina Mountain and their protection]. *Zaštita prirode, 59*(1–2), 19–50. Retrieved from https://www.zzps.rs/wp/casopisi_pdf/011/casopis.pdf

Borah, D. K., Yagow, G., Saleh, A., Barnes, P. L., Rosenthal, W., Krug, E. C., & Hauck, L. M. (2006). Sediment and nutrient modeling for TMDL development and implementation. *Transactions of the ASABE, 49*(4), 967–986. https://doi.org/10.13031/2013.21742

Bullock, P. (2004). Climate change impacts. In D. Hillel (Ed.), *Encyclopedia of Soils in the Environment* (pp. 254–262). New York, NY: Academic Press.

Carić, N. (1968) *Antropogeni faktori ubrzane erozije tla i konzervacija zemljišta na zapadnom Kopaoniku* [Anthropogenic factors of accelerated soil erosion and conservation in western Kopaonik]. (Doctoral dissertation). Faculty of Sciences, University of Novi Sad, Novi Sad, Serbia.

Cvetković, V., Poli, G., Resimić-Šarić, K., Prelević, D., & Lazarov, M. (2002). Tertiary post-collision granitoid of Mt. Kopaonik (Serbia) – petrogenetic constraints based on new geochemical data. *Geologica Carpathica, 53*, 1–7. Retrieved from http://www.geologicacarpathica.com/data/files/files/special%20issue/C/Cvetkovic_etal_02.pdf

Ćalić, J., Milošević, M. V., Milivojević, M., & Gaudenyi, T. (2017). Reljef Srbije [Relief of Serbia]. In M. Radovanović (Ed.), *Geografija Srbije* (Posebna izdanja, Knjiga 91) [Geography of Serbia (Special issues, Book 91)] (pp. 22–92). Belgrade, Serbia: Geographical Institute "Jovan Cvijić" SASA.

Ćurčić, N. B. (2017). *Prostorno-vremenska analiza antropogenih uticaja na prirodne ekosisteme u Nacionalnom parku „Kopaonik"* [Spatio-temporal analysis of anthropogenic impact on natural ecosystems in National Park "Kopaonik"]. (Doctoral Dissertation). University of Belgrade - Faculty of Geography, Belgrade, Serbia.

Ćurčić, N. B., Milinčić, U. V., Stranjančević, A., & Milinčić, M. A. (2019). Can winter tourism be truly sustainable in natural protected areas? *Journal of the Geographical Institute "Jovan Cvijić" SASA, 69*(3), 241–252. https://doi.org/10.2298/IJGI1903241C

Divac, D., Milivojević, N., Grujović, N., Stojanović, B., & Simić, Z. (2009). A Procedure for State Updating of SWAT-Based Distributed Hydrological Model for Operational Runoff Forecasting. *Journal of Serbian Society for Computational Mechanics, 3*(1), 298–326. Retrieved from http://www.sscm.kg.ac.rs/jsscm/downloads/Vol3No1/A_Procedure_for_State_Updating_of_SWAT-Based_Distributed_Hydrological-13.pdf

Djordjevic, D. S., Secerov, V., Filipovic, D., Lukic, B., & Jeftic, M. R. (2016). The impact of climate change on the planning of mountain tourism development in Serbia: case studies of Kopaonik and Zlatibor. *Fresenius Environmental Bulletin, 25*(11), 5027–5034. Retrieved from https://www.prt-parlar.de/download_feb_2016/

Duro, D. C., Franklin, S. E., & Dubé, M. G. (2012). A Comparison of Pixel-Based and Object-Based Image Analysis with Selected Machine Learning Algorithms for the Classification of Agricultural Landscapes Using SPOT-5 HRG Imagery. *Remote Sensing of Environment, 118*, 259–272. https://doi.org/10.1016/j.rse.2011.11.020

Food and Agriculture Organization, Applied Systems Analysis, ISRIC—World Soil Information, Institute of Soil Science, Chinese Academy of Sciences, & Joint Research Centre of the European Commission. (2012). *Harmonized World Soil Database (v1.2)*. Retrieved from http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/en/

Ganasri, B. P., & Ramesh, H. (2016). Assessment of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi Basin. *Geoscience Frontiers*, *7*(6), 953–961. https://doi.org/10.1016/j.gsf.2015.10.007

Gassman, P. W., Reyes, M. R., Green, C. H., & Arnold, J. G. (2007). The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions. *Transactions of the ASABE*, *50*(4), 1211–1250. https://doi.org/10.13031/2013.23637

Gavrilović, S. (1979). Hipsometrija površine reljefa Kopaonika [Hypsometry of the Kopaonik relief surface]. *Collection of papers of the Geographical Institute of the Faculty of Sciences – University of Belgrade*, *26*, 93–103.

Goyal, M. K., Singh, V., & Meena, A. H. (2015). Geospatial and hydrological modeling to assess hydropower potential zones and site location over rainfall dependent Inland catchment. *Water Resources Management, 29*(8), 2875–2894. https://doi.org/10.1007/s11269-015-0975-1

Japan Aerospace Exploration Agency. (2017). *ALOS Global Digital Surface Model "ALOS World 3D - 30m (AW3D30)"* [Data set]. Retrieved from http://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm

Jha, M., Arnold, J. G., Gassman, P. W., Giorgi, F., & Gu, R. R. (2006). Climate change sensitivity assessment on upper Mississippi river basin streamflows using SWAT. *Journal of the American Water Resources Association 42*, 997–1015. https://doi.org/10.22004/ag.econ.18419

Jović, N. (1968). Vertikalni raspored zemljišnih tvorevina na Kopaoniku [Vertical disposition of the soil formations on the Kopaonik Mt.]. *Šumarstvo, 21*(1-2), 7–16.

Kostadinov, S., Dragović, N., Zlatić, M., & Todosijević, M. (2008). Uticaj protiverozionih radova u slivu reke Toplice uzvodno od brane „Selova" na intenzitet erozije zemljišta [Impact of erosion control works on soil erosion intensity in the upper part of the river Toplica drainage basin]. *Vodoprivreda, 40*, 115–126. Retrieved from https://www.vodoprivreda.net/wp-content/uploads/2014/08/uticaj1.pdf

Kostadinov, S., Zlatić, M., Dragićević, S., Novković, I., Košanin, O., Borisavljević, A., Lakićević, M., & Mladjan, D. (2014). Anthropogenic influence on erosion intensity changes in the Rasina river watershed - Central Serbia. *Fresenius Environmental Bulletin, 23*(1), 254–263. Retrieved from https://www.prt-parlar.de/download_feb_2014/

Kumar, S., Singh, A., & Shrestha, D. P. (2016). Modelling spatially distributed surface runoff generation using SWAT-VSA: a case study in a watershed of the north-west Himalayan landscape. *Modeling Earth Systems and Environment, 2*(1), 1–11. https://doi.org/10.1007/s40808-016-0249-9

Lakušić, D. (1993). *Visokoplaninska flora Kopaonika – ekološko-fitogeografska studija* [Highland flora of Kopaonik Mountain – ecological-phytogeographical study]. (Master´s thesis). Faculty of Biology, University of Belgrade, Belgrade, Serbia.

Lazarević, R. (2009). *Erozija u Srbiji* [*Erosion in Serbia*]. Belgrade, Serbia: Želnid.

Li, J., Liu, C., Wang, Z., & Liang, K. (2015). Two universal runoff yield models: SCS vs. LCM. *Journal of Geographical Sciences*, *25*(3), 311–318. https://doi.org/10.1007/s11442-015-1170-2

Mas, J. F., & Flores, J. J. (2008). The Application of Artificial Neural Networks to the Analysis of Remotely Sensed Data. *International Journal of Remote Sensing*, *29*(3), 617–663. https://doi.org/10.1080/01431160701352154

Mausbach, M. J., & Dedrick, A. R. (2004). The length we go: Measuring environmental benefits of conservation practices. *Journal of Soil and Water Conservation, 59*(5), 96A–103A. Retrieved from https://www.jswconline.org/content/59/5/96A

Milivojević, N., Simić, Z., Orlić, A., Milivojević, V., & Stojanović, B. (2009). Parameter Estimation and Validation of the Proposed SWAT Based Rainfall-Runoff Model – Methods and Outcomes. *Journal of Serbian Society for Computational Mechanics, 3*(1), 86–110. Retrieved from http://www.sscm.kg.ac.rs/jsscm/downloads/Vol3No1/Parameter_Estimation_and_Validation_of_the_Proposed_SWAT_Based4.pdf

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., & Williams, J. R. (2011). *Soil and Water Assessment Tool, Theoretical Documentation*. Texas, USA: Texas Water Resources Institute.

Pavićević, N., Antonović, G., & Nikodijević, V. (1968). Razvojni stadijumi zemljišta na Kopaoniku [Developmental stages of soils on Kopaonik Mountain]. *Zbornik radova Instituta za proučavanje zemljišta, 1*, 31-61.

Potić, I. (2018). *Geosistemska analiza višestrukih stresova životne sredine u valorizaciji malih hidroelektrana Srbije* [Geosystem Analysis of Multiple Environmental Stresses in the Evaluation of Small Hydro Power Plants in Serbia]. (Doctoral Dissertation). University of Belgrade - Faculty of Geography, Belgrade, Serbia.

Potić, I., & Potić, M. (2017). Remote Sensing Machine Learning Algorithms in Environmental Stress Detection – Case Study of Pan-European South Section of Corridor 10 in Serbia. *The University Thought - Publication in Natural Sciences, 7*(2), 41–46. https://doi.org/10.5937/univtho7-14957

Potić, I. M., Ćurčić, N. B., Potić, M. M., Radovanović, M. M., & Tretiakova, T. N. (2017). Remote Sensing Role in Environmental Stress Analysis: East Serbia Wildfires Case Study (2007–2017). *Journal of the Geographical Institute "Jovan Cvijić" SASA, 67*(3), 249–264. https://doi.org/10.2298/IJGI1703249P

Rallison, R. E., & Miller, N. (1981). Past, present and future SCS runoff procedure. In V. P. Singh (Ed.), *Rainfall runoff relationship* (pp. 353–364). Littleton, CO: Water Resources Publication.

Republic Hydrometeorological Service of Serbia. (1981–2010). *Meteorološki godišnjak - klimatološki podaci* [Meteorological Yearbook - climatological data]. Retrieved from http://www.hidmet.gov.rs/ciril/meteorologija/klimatologija_godisnjaci.php

Ristić, R., Kašanin-Grubin, M., Radić, B., Nikić, Z., & Vasiljević, N. (2012). Land degradation at the Stara Planina ski resort. *Environmental Management, 49*(3), 580–592. https://doi.org/10.1007/s00267-012-9812-y

Ristić, R., Vasiljević, N., Radić, B., & Radivojević, S. (2009). Degradation of landscape in Serbian ski resorts – aspects of scale and transfer of impacts. *Spatium, 20*, 49–52. https://doi.org/10.2298/SPAT0920049R

Rospriandana, N., & Fujii, M. (2017). Assessment of small hydropower potential in the Ciwidey subwatershed, Indonesia: a GIS and hydrological modeling approach. *Hydrological Research Letters, 11*(1), 6–11. https://doi.org/10.3178/hrl.11.6

Schmid, S. M., Bernoulli, D., Fügenschuh, B., Matenco, L., Schefer, S., Schuster, R., Tischler, M., & Ustaszewski, K. (2008). The Alpine-Carpathian-Dinaridic orogenic system: correlation and evolution of tectonic units. *Swiss Journal of Geosciences, 101*(1), 139–183. https://doi.org/10.1007/s00015-008-1247-3

Setyorini, A., Khare, D., & Pingale, S. M. (2017). Simulating the impact of land use/land cover change and climate variability on watershed hydrology in the Upper Brantas basin, Indonesia. *Applied Geomatics, 9*(3), 191–204. https://doi.org/10.1007/s12518-017-0193-z

Simić, Z., Prohaska, S., Milivojević, N., & Orlić, A. (2004). Modeliranje procesa padavine-oticaj na podslivovima sliva Drine metodom SWAT [Modeling of the precipitation/runoff process in sub-catchments of the Drina river basin by the SWAT method]. *Vodoprivreda, 36*, 113–122. Retrieved from https://www.vodoprivreda.net/wp-content/uploads/2014/08/modeliranje-2.pdf

Singh, V., & Goyal, M. K. (2017). Unsteady high velocity flood flows and the development of rating curves in a Himalayan Basin under climate change scenarios. *Journal of Hydrologic Engineering, 22*(8), 04017023 https://doi.org/10.1061/(ASCE)HE.1943-5584.0001530

Skijališta Srbije. (2020). *Ski centar Kopaonik – o centru* [Ski center Kopaonik – about the center]. Retrieved on May 5, 2018 from http://www.skijalistasrbije.rs/sr/o-centru-kopaonik

Ski regions in Davos Klosters. Facts & figures: transportation & slopes. (2021). Retrieved on August 1, 2018 from https://www.davos.ch/en/activities/snowsports/ski-snowboard/ski-regions-in-davos-klosters

Statistical Office of the Republic of Serbia. (2014). *Comparative overview of the number of population in 1948, 1953, 1961, 1971, 1981, 1991, 2002 and 2011 – data by settlements*. Retrieved from https://pod2.stat.gov.rs/ObjavljenePublikacije/Popis2011/Knjiga20.pdf

Statistical Office of the Republic of Serbia. (2019). *Opštine i regioni u Republici Srbiji, 2019* [Municipalities and Regions in the Republic of Serbia, 2019]. Retrieved from https://publikacije.stat.gov.rs/G2019/Pdf/G201913046.pdf

Statistical Office of the Socialist Republic of Serbia. (1985). *Opštine u SR Srbiji 1984. Statistički podaci* [Municipalities in SR Serbia 1984. Statistical data]. Retrieved from http://publikacije.stat.gov.rs/G1985/Pdf/G19852002.pdf

Stevanović, V., Vukojičić, S., Šinžar-Sekulić, J., Lazarević, M., Tomović, G., & Tan, K. (2009). Distribution and diversity of Arctic-Alpine species in the Balkans. *Plant Systematics and Evolution, 283*(3–4), 219–235. https://doi.org/10.1007/s00606-009-0230-4

Tadono, T., Nagai, H., Ishida, H., Oda, F., Naito, S., Minakawa, K., & Iwamoto, H. (2016). Generation of the 30 m-mesh Global Digital Surface Model by ALOS PRISM. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 41-B4*, 157–162. https://doi.org/10.5194/isprs-archives-XLI-B4-157-2016

United States Geological Survey, Earth Resources Observation and Science Center. (2018). *Landsat Missions. Landsat 5*. Retrieved from https://www.usgs.gov/core-science-systems/nli/landsat/landsat-5?qt-science_support_page_related_con=0#qt-science_support_page_related_con

United States Geological Survey, Earth Resources Observation and Science Center. (2019a). *Landsat 5 Thematic Mapper C1 Level-1* [Data set]. Retrieved from https://doi.org/10.5066/F7N015TQ

United States Geological Survey, Earth Resources Observation and Science Center. (2019b). *Landsat 8 OLI/TIRS C1 Level-1* [Data set]. Retrieved from https://doi.org/10.5066/F71835S6

University Corporation for Atmospheric Research, & National Centre for Environmental Prediction. (2018). *NCEP Climate Forecast System Reanalysis*. Retrieved from https://rda.ucar.edu

University of Belgrade - Faculty of Mining and Geology. (2010). *Osnovne geološke karte Srbije 1:100000* [Basic geological maps of Serbia 1:100000]. Retrieved from http://geoliss.mre.gov.rs/OGK/RasterSrbija/

Urošević, M., Pavlović, Z., Klisić, M., Karamata, S., Malešević, M., Stefanović, M., Marković, O., & Trifunović, S. (1973). *Osnovna geološka karta 1:100000, Tumač za list Novi Pazar K34-30* [Basic Geological Map 1:100,000, Interpreter for sheet Novi Pazar K34-30]. Belgrade, Serbia: Savezni geološki zavod.

Urošević, M., Pavlović, Z., Klisić, M., Malešević, M., Stefanović, M., Marković, O., & Trifunović, S. (1973). *Osnovna geološka karta 1:100000, Tumač za list Vrnjci K34-18* [Basic Geological Map 1:100,000, Interpreter for sheet Vrnjci K34-18]. Belgrade, Serbia: Savezni geološki zavod.

Vasović, M. (1988). *Kopaonik*. Belgrade, Serbia: Serbian Geographical Society.

Vigiak, O., Malagó, A., Bouraoui, F., Vanmaercke, M., & Poesen, J. (2015). Adapting SWAT hillslope erosion model to predict sediment concentrations and yields in large Basins. *Science of the Total Environment, 538*, 855–875. https://doi.org/10.1016/j.scitotenv.2015.08.095

Williams, J. R. (1995). The EPIC Model. In V. P. Singh (Ed.), *Computer Models of Watershed Hydrology* (pp. 909–1000). Highlands Ranch, USA: Water Resources Publications.

Williams, J. R., & Hann, R. W. (1978). *Optimal Operation of Large Agricultural Watersheds With Water Quality Constraints*. Texas, USA: Texas Water Resources Institute.

Wishmeier, W. H., & Smith, D. D. (1978). *Predicting Rainfall Erosion Losses – A Guide to Conservation Planning*. Maryland, USA: US Department of Agriculture.

Yang, Q., & Zhang, X. (2016). Improving SWAT for simulating water and carbon fluxes of forest ecosystems. *Science of the Total Environment*, *569–570*, 1478–1488. https://doi.org/10.1016/j.scitotenv.2016.06.238

Zakon o nacionalnim parkovima [The law on National Parks]. Službeni glasnik Republike Srbije br. 84/2015-15, 95/2018-267 - dr. zakon (2018).

Zlatic, M., & Vukelic, G. (2002). Economic and Social Revival of a Degraded Region in Serbia. *Mountain Research and Development, 22*(1), 26–28. https://doi.org/10.1659/0276-4741(2002)022[0026:EASROA]2.0.CO;2