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INITIAL RESULTS OF COMPARATIVE ASSESSMENT OF SOIL EROSION INTENSITY USING THE WIntErO MODEL: A CASE STUDY OF POLIMLJE AND SHIRINDAREH DRAINAGE BASINS

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Abstract: This work aims to determine the current state of sediment production and propose land use measures that will affect the reducing the intensity of soil erosion for the areas of the Polimlje drainage basin on the territories of Montenegro and Serbia, and the small Shirindareh sub-basin of Iran. The approach is based on field and laboratory methods, which are processed by Web-based Intensity of Erosion and Outflow (WIntErO) model used to calculate erosion intensity. By using the computer-graphical method of the "WIntErO" software, in the study of erosion intensity, surface values (watershed surface, surface between isohypsies, etc.) and length, i.e. deviations from the map (length of the main watercourse, length of the watershed line, etc.) is processed very precisely, which was not the case before when using mechanical instruments, planimeters and curvimeters. The new WIntErO model is an integrated computer-graphic program package of the third-generation method based on the earlier generations of the modelling tools "River basins", and IntErO and calculates the amount of sediment, the intensity of soil erosion, as well as the maximum runoff from the basin, according to the EPM model of Gavrilović. During the procedure, an accuracy assessment is conducted with measurements of reservoir sediment deposition. These measurements were performed in April 2017 using professional hydrographic recording equipment, following the same methodology as in 2012. The measurement of point locations was conducted using a GPS receiver and a Trimble R6 base station. The reservoir's depth was measured using a single-frequency portable echo sounder, specifically the Odom Hydro Track. The initial assessment shows fairly acceptable results of the implemented WIntErO modelling for both study areas. Z coefficient values ranging from 0.01 to 1.00 for the observed period indicate that the river basins delineate areas with varying levels of susceptibility to water erosion processes—ranging from very low to moderate and high risk—within the studied drainage basins. Based on the analysis, we found that the average erosion intensity in Polimlje is 331.78 m^3 km^{-2} $year^{-1}$ per square kilometer. For the Shirindareh sub-basins, the average actual soil losses per square kilometer are 201 m^3 $year^{-1}$ km^{-2}. Given these findings, it is evident that these basins require prompt implementation of soil conservation measures.

Key words: drainage basins, WIntErO, erosion, Polimlje Basin, Shirindareh Basin, hydro-climatic factor

1. INTRODUCTION

The process of soil erosion is a phenomenon affecting the ground constantly and gradually. Influenced by water and wind, it separation of soil particles, their transport and further deposition. However, this process is rather insignificant when there is a certain balance between the striking force of water and various factors on the soil surface that provide resistance to water power (Spalević, 2011). In a general sense, nature generates soil through processes that involve water carrying it away; in essence, nature continually replenishes the soil. However, this equilibrium in nature is frequently disrupted by human activities. These actions involve the continuous degradation of vegetation cover and the upper soil layer through activities such as deforestation, clearing land for cultivation, and plowing meadows. These practices amplify the impact of water's erosive force and expedite the erosion process (Vančetović, 1971). These processes, in certain cases, result in creating specific forms of landscape (Alewell et al., 2015).

Soil erosion is the most widespread form of land degradation worldwide. The United Nations Convention to Combat Desertification (UNCCD) has recognized soil erosion by water and wind as a major cause of land degradation globally. It represents a major global environmental problem threatening agricultural productivity, water quality, infrastructure, etc. (Efthimiou, 2018). Major policy responses should reverse the impact of soil erosion in degraded areas by taking into account population growth, climate change trends and the crisis of water shortages (Panagos et al., 2020; Borrelli et al., 2023). During the past decade, the problem of soil erosion has become part of the environmental protection program in the European Union (EU) due to its impact on food production, drinking water quality, ecosystem services, flooding, eutrophication, reduction of biodiversity and carbon emissions. The EU soil thematic strategy, adopted by the European Commission in September 2006, pointed accelerated soil erosion as the main threat to European soils. The Common Agricultural Policy of the European Union recognizes the importance of protecting our soils and addresses the issue of reducing erosion and maintaining organic carbon on European farmland. It was determined that the average rate of soil loss in the countries of the European Union was 2.46 t ha^{-1} $year^{-1}$, which results in total soil losses of 970 million tons per year; equal to an area the size of Berlin at a depth of one meter (Borrelli et al., 2023).

Watersheds (i.e. drainage basins) are in fact often affected by natural hazards, above all floods, overflows, inundations, erosion processes, landslides and pollution (Tazioli et al., 2015). The estimation of the erosion in a drainage basin is therefore essential to encompass a numerous environmental problem and to evaluate the amount of sediment moved, transported and deposited in and out of the basin respectively.

Comparative analysis of the data obtained by processing the WIntErO model in the area of Polimlje and selected sub-basins of the Shirindareh basin in Iran is made. Based on this data, it is possible to determine the influence of land use on the intensity of erosion in the selected drainage basins of Polimlje and sub-basins of the Shirindareh drainage basin. Based on the estimated intensity of soil erosion and runoff from the basins, in the region of Polimlje and in the sub-basins of the Shirindareh basin, the studied basins were grouped into regions with high, moderate and low priorities for soil and water conservation. Proposals for variants of usage for selected basins were given, all with the aim of determining and protecting critical areas for taking measures to preserve soil and water, respecting the ideas of sustainable management in basins. Finding the optimal structure of land use for the relevant drainage basins will value biological and ecological laws and principles of preservation of the environment.

Soil erosion is an important environmental hazard worldwide and is one of the most significant land degradation patterns, especially in developing countries (Eswaran et al., 2001). According to Morgan (2005), the occurrence of the erosion process, distribution and time of occurrence are closely related to anthropogenic factors. The most common side effects of erosion that represent a serious problem for human sustainability are: loss of soil fertility, change in hydrological systems, land use and land cover changes, environmental pollution and reduced water quality (Dragićević & Milevski, 2010; Tošić et al., 2019).

Assessment of soil erosion is usually done for small research areas in the field (in-situ), and sampling of sediments and water is expensive and time-consuming (Spalević et al., 2020). Various models are currently used to assess the risk of water erosion and the production of erosion deposits. They can be divided into empirical or regression conceptual and physical models (Renschler & Flanagan, 2002). According to another classification, they can be divided into qualitative, quantitative and semi-quantitative (Kostadinov & Marković, 1996). Some of the semi-quantitative are: Erosion Potential Method – EPM (Gavrilović model), Pacific Southwest Inter-Agency Committee – PSIAC (Ndomba, 2013), Modified Pacific Southwest Inter-Agency Committee – MPSIAC (Bagherzadeh & Daneshvar, 2013), Fleming & Kadhimi Scoring Model – FKSM (de Vente & Poesen, 2005), Wallingford Scoring Model (WSM) and etc. (Milevski et al., 2007; Morgan, 2005; Dragičević et al., 2016).

According to Micić Ponjiger et al., (2023), all erosion maps of former Yugoslav countries were prepared in the 1980s based on the expert judgment of field data and maps generated via the erosion potential method (EPM) (Gavrilović, 1972) as one of the most widely accepted and applied empirical models in the Balkan region, South, South-East, and Central Europe, as well as the Middle East, North Africa and parts of South America. In the Western Balkans, the Erosion

Potential Method (EPM) for mapping the intensity of water erosion at the country scale is the preferred model. The model is based on the long-term research of the soil erosion process in the Morava River catchment area (Serbia), led by professor Gavrilović (1972). The Intensity of Erosion and Outflow (IntErO) of Spalević (2011) is a program package with the EPM integrated into the algorithm for Windows Operating System. It was tested on the territory of Montenegro. The newer generation of the software is the WIntErO model (Vujačić, 2019). It is important to highlight that the EPM (along with the more widely used USLE and RUSLE models), has also been tested in catchment areas all over the world: Montenegro (Spalević et al., 2020), Serbia (Dragićević et al., 2009; Perović et al., 2013; Manojlović et al., 2018; Kostadinov et al., 2018; Gocić et al., 2020), Bosnia and Herzegovina (Lazarević, 1985a,b; Tošić et al., 2012; Lovrić & Tošić, 2018; Tošić et al., 2019; Golijanin et al., 2022; Micić Ponjiger et al., 2023), Croatia (Dragičević et al., 2017a,b), North Macedonia (Milevski et al., 2007, 2011, Aleksova et al., 2023), Italy (Tazioli, 2009), Slovenia (Zorn & Komac, 2011), Greece (Efthimiou & Lykoudi, 2016), Chile (Kazimierski et al., 2013), Brazil (Tavares et al., 2019), Iraq (Ali et al., 2016), and in Iran (Behzadfar et al., 2014; Barović et al., 2015; Hazbavi et al., 2020; Poornazari et al., 2021). Efthimiou et al., (2016) conducted a study evaluating soil erosion and its spatial distribution using two empirical models, namely the erosion potential model (EPM), also known as the Gavrilović method, and the RUSLE model. The study focused on the Venetikos River catchment, the largest tributary of Aliakmonas River, located in northern Greece. Both models demonstrated a satisfactory simulation of the phenomenon, exhibiting acceptable precision and enabling the identification of areas most susceptible to erosion and land degradation. Although both models performed quite similarly and attributed underestimated results in comparison to the “actual” (measured) values of mean annual sediment discharge and yield, the core of the EPM approach was used in this study as well in order to generate potentially comparable data with neighboring and Middle East countries where the same approach was applied.

Thus, the EPM model has been extensively implemented across the Balkans and in other countries worldwide, and its application has provided reliable results for assessing water erosion severity, estimating mean annual soil loss and sediment yield, and implementing erosion control measures and torrent regulation at a regional scale.

Therefore, the main objectives of this study are to: (1) perform systematic and comparative assessment of soil erosion intensity (hydro-meteorological hazards) in the study areas by applying a modified erosion assessment model WIntErO and joint systematic approaches; (2) in-depth hazard risk and susceptibility analysis, and (3) identify places of greatest erosion risks as the starting point for defining and implementing suitable mitigation measures.

2. STUDY AREA

To determining reliability of the selected approach of soil erosion modelling, two geographically distinct areas are taken into account: Polimlje drainage basin on the territories of Montenegro and Serbia, and the small Shirindareh sub-basin of Iran.

The Lim basin from Lake Plav to the dam of HPP "Potpeć", as one spatial-functional unit, which extends over the territories of the east and north-east of Montenegro, and south-west Serbia on an area of 2900 km^2 (Spalević, 2011). From a mathematical-geographic point of view, the investigated area is located between 42°37' and 43°30' north latitude and 17°10' and 17°23' east longitude (Figure 1).

The altitude of the riverbed of the Lim River, which traverses the examined region, varies between 907 m (Plavsko Lake) and 436 m (Potpeć reservoir). Likewise, the elevation of the watershed area spans from 2461 m (Tromeđa, Prokletije) to 436 m (the lowest point - the summit of HPP Potpeć). The slope of the watershed, Isr, is 30.05%, which categorizes this watershed in the group of those with very steep slopes.

The studied basin is of a tectonic-erosive origin and steeply descends from the slopes of the mountains that border it, into the valley bottoms of Lim and its tributaries, covering a part of the Plav valley, as well as the basins of Andrijevica, Berane, Bijelo Polje, the composite valley and the extensions around Brodarevo and Prijepolje (Bakić, 2005).

About 157,422 inhabitants live in this area, of which 109,463 live in the municipalities of Berane, Bijelo Polje, Plav, Andrijevica and Mojkovac, which belong to the Republic of Montenegro (Monstat, 2011), and 47,959 in the municipalities of Prijepolje and Nova Varoš, which belong to the Republic of Serbia. (Preliminary results of the 2022 population census). The Shirindareh river basin is located in the northeast part of Iran, in the province of North Khorasan (pers. Ostan-e Khorasan-e Shomali). The watershed is located in the area of the Hezar-Masjed mountain group, which represents the southeastern part of the Kopeh Dag mountains (Amini et al., 2010).

The Shirindareh River is the right tributary of the 530 km long Atrak (Atrek) River, a tributary of the Caspian Sea, whose basin covers 33,500 km^2, 79% of which is located in the territory of Iran, and 21% in Turkmenistan (Figure 2 and 3).

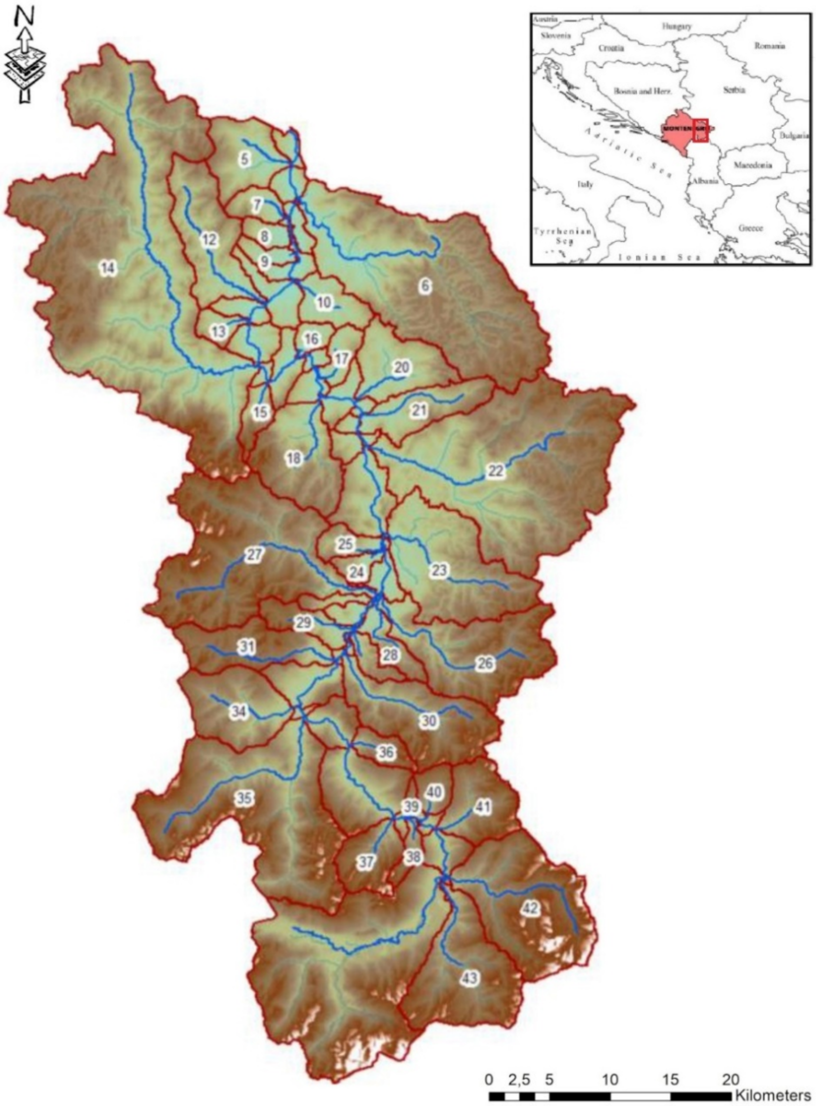


Figure 1. Map of Polimlje studied area - the codes/nomenclature on the map correspond to the ID numbers of the sub-basins within the study area according to Spalević (2011) (Author of the map: Duško Vujačić)

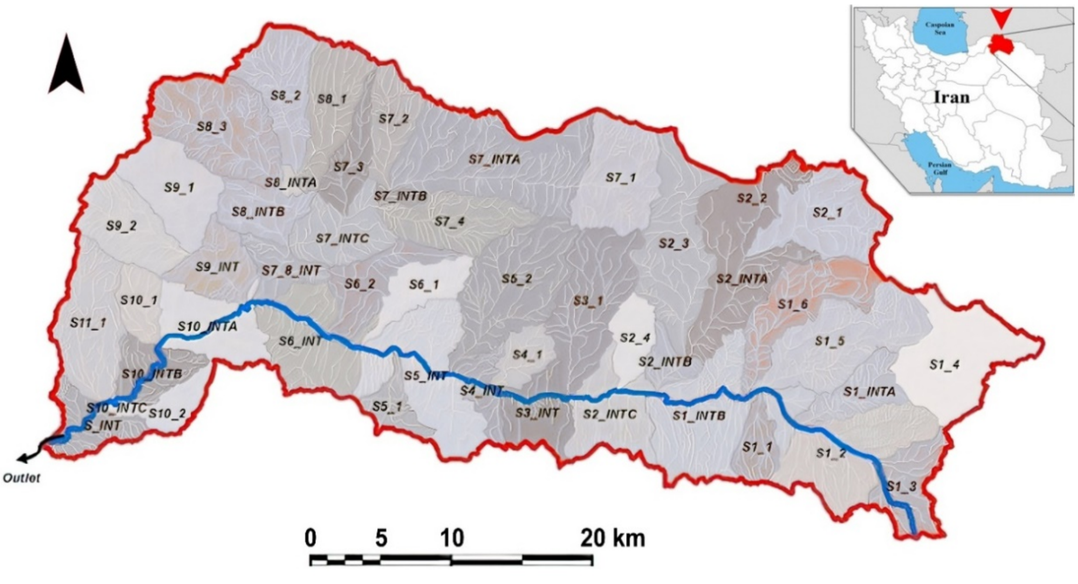


Figure 2. Map of Shirindareh River Basin - the codes/nomenclature on the map correspond to the ID numbers of the sub-basins within the study area according to Behzadfar et al., (2014)

Figure 3. Aerial view of the dam on the "Shirindareh" reservoir (photo: Morteza Behzadfar)

Table 1. Comparative presentation of the main data pertaining to the specified study areas

River Catchment	Catchment Area	Stream Length	Highest/Lowest Elevation
Lim*	4857 km^2	149,2 km	2534/437 m
Shirindareh*	1612 km^2	84,12 km	2687/697 m

Note (*): to the reservoir "Potpeć"/"Shirindareh"

The part of the river from the source to the dam of Shirindareh reservoir is 84.12 km long, while its catchment area is 1612 km^2. It is elongated and placed in the east-west direction, with a length of about 70 km, while it is up to 20 km wide. The highest elevation in the basin is 2687 m, and the reservoir is located at 696 m (Table 1).

3. MATERIALS AND METHODS

The following parameters were processed using this methodology, as well as the additional data processing with the new computer graphic model WIntErO: 1) Area of the watershed; 2) The length of the watershed line; 3) Natural length of the primary watercourse's source; 4) The length of the basin measured by a series of parallel lines; 5) The area encompassing the majority of the watershed; 6) Area of a minor part of the basin; 7) Total length of the main watercourse with tributaries; 8) Altitude of initial isohypse; 9) Equidistance; 10) Length of isohypsies; 11) Surfaces between adjacent isohypses; 12) The lowest elevation in the basin; 13) The highest elevation of the basin; 14) Part of the watershed surface that is made up of highly permeable rock formations (limestone, sand, gravel); 15) The part of the watershed surface that is composed of rocks of medium water permeability (shales, marls, sandstones); 16) Part of the basin's surface that is composed of rocks with poor permeability (heavy clay, igneous rocks); 17) Part of the area of the watershed under forest cover; 18) Part of the catchment area under grass, meadows, pastures and orchards; 19) Part of the watershed surface dominated by bare trees, arable land and land without grass vegetation; 20) The shortest distance between the source and the mouth; 21) Height of torrential rain; 22) Mean annual air temperature; 23) Mean annual amount of precipitation; 24) Types of soil formations and related species; 25) Basin management coefficient; 26) Numerous equivalents of visible and clearly expressed land erosion processes.

The total sediment production is calculated according to Gavrilović's (1972) analytical equation for calculating the total annual sediment production:

$$Wyear = T * Hyear * \pi * \sqrt{Z^3} * F$$

Where, Wyear – total sediment production (m3/year), T – temperature coefficient, Hyear – average annual precipitation in mm, Z – erosion coefficient, F – basin is in km^2.

To determine the annual amount of sediment in the hydrographic network (Wp), Gavrilović penned the equation (1972):

$$Ru = \frac{\sqrt{O} * D}{0{,}2(L + 10)}$$

Where, O stands for the volume of the basin (km), D for the average altitude of the basin (km), and L for the length of the basin (km).

Annual production of the sediment in the basin (G) is calculated as follows:

$$Gyear = Wyear * Ru$$

The utmost reliability in data arises when obtained through direct measurements, yet regrettably, such data is often lacking. In such instances, planners are compelled to resort to empirical techniques to establish yearly sediment transportation. Among these practices, the assessment of soil erosion dynamics methods finds frequent application for such computations (Zakerinejad & Maerker, 2015).

This research in the area of Polimlje, and later in the basins of Iran, were carried out following the Gavrilović's EPM method applied to estimate the intensity of erosion and production of sediments, and newly developed WIntErO model. The Erosion Potential Method (EPM) (Gavrilović, 1972). The method is based on the quantitative classification of erosion (Method for the Quantitative Classification of Erosion - MQCE), which was developed in 1954. During the research, Gavrilović discovered the possibility of further development of the MQCE method, which was used to determine the intensity of erosion. This method includes erosion mapping nowadays, as well as the estimation of erosion sediment production and classification of torrents and has been intensively applied since 1968 in solving problems related to erosion and torrents in all Balkan countries (Gavrilović et al., 2008).

3.1. Modifications of Gavrilović's method.

One of the first upgrades of this method was proposed by Lazarević (1985b), mostly regarding the values of coefficient Y. Later on, Aleksova et al., (2023), Milevski (2011), and Globevnik et al., (2003) proposed GIS-based implementation of the EPM method, where most of the parameters are calculated from digital elevation models, satellite images and CORINE Land Cover models. Tošić & Dragićević (2012) proposed approach for determining the erosion coefficient (Z) in a GIS environment. The essence of their work is the use of a PDA (Personal Digital Assistant) device with a GPS (Global Positioning System) receiver. Another modification was suggested by Furthermore, Fanetti & Vezzoli (2007) suggested a change in the categorization of the coefficient of land protection by vegetation cover X, which is based on different categories of ways of use, and were the first to consider urban areas as potential areas of erosion. The most recent advancement of EPM has been implemented across a global spectrum, spanning regions from Montenegro to Serbia, Croatia, Slovenia, Italy, North Macedonia, Bosnia and Herzegovina, Iran, and Chile (e.g., Dragičević et al., 2016; Aleksova et al., 2023). Furthermore, its application extends to Morocco, Brazil (e.g., Globevnik et al., 2003), and Nepal (Chalise et al., 2019). For the purposes of assessment, the soil erosion intensity in Polimlje (Montenegro and Serbia) and Shirindaher (Iran), the "WIntErO" platform was developed respectively. It represents an integrated and modern variant of the "IntErO" program (Spalević, 1999) including "Surface and distance measuring” and the program “Basins” (Spalević et al., 2000).

The data from the Institute for Hydrometeorology and Seismology of Montenegro for the meteorological stations Plav, Berane and Bijelo Polje and data from the Republic of Serbia Hydrometeorological Institute from the meteorological station Sjenica were used to obtain the climatic characteristics of the Lim drainage basin. The layout and number of stations as well as the climate elements used during processing, were determined by the length, i.e. the series of data, as well as the rank of the stations themselves. In previous studies, the Velička River basin was identified as one of the areas endangered by these processes that should be adequately protected, and therefore the basin of this river was taken under protection and research. Also, the period 2018 - 2048 was taken as a reference period of the study, with the aim of improvement during the period of 30 years.

The hydrographic characteristics of the river Lim are the results of the climatic, geological and geomorphological characteristics of the terrain. To analyze the water regime of the Lim basin, data from hydrological stations (HS) Plav (as an input profile) and HS Bijelo Polje (as an output profile on the territory of the Republic of Montenegro) and data from HS Brodarevo (as an input profile on the territory of the Republic of Serbia) were used and HS Prijepolje as the last (exit) profile before the Potpeć reservoir, as the final destination for analysis.

During the procedure, an accuracy assessment is conducted with measurements of reservoir sediment deposition. These measurements were performed in April 2017 using professional hydrographic recording equipment, following the same methodology as in 2012. The measurement of the points location was carried out with a GPS receiver and a Trimble R6 base station; the depth of the reservoir was measured with a single-frequency portable echo sounder Odom Hydro track. The surveying of the bed of the river Lim in the field was carried out by the construction maintenance group of the "Drinsko-Limska" branch of Bajina Bašta HPP, Limska HPP Nova Varoš in the period from April 11, 2017, until April 26, 2017. The operational team consisted of Milosav Vranić, Aleksandar Bjelić, and the team was joined by Velibor Spalević and Duško Vujačić, from the Department of Geography within the Faculty of Philosophy of the University of Montenegro, who collected necessary field data for the validation of the WIntErO analytical model for the purposes of research study.

Testing the consistence of the WIntErO model was made through comparison of the results in Polimlje with these in Shirindareh basin, northeastern Iran. This is an area with severe erosion, endangering fertile agricultural lands. Actually, almost 35 million hectares of Iran are affected by various types of water erosion (Zakerinejad & Maerker, 2015).

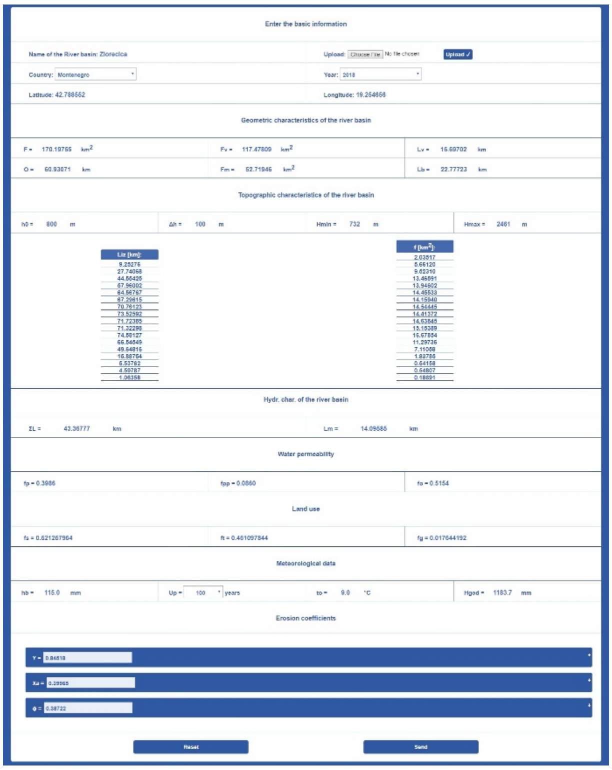
Furthermore, bathymetric recording of the Potpeć reservoir was made. With the comparison of these recordings with previous ones, the actual intensity of sedimentation is calculated. This step was necessary to validate the WIntErO platform and EPM model as well. The identical methodology is employed for the broader expanse of the Shirindareh watershed, seeking to assess the feasibility of employing the WIntErO platform and EPM within this global region as well.

ESRI Land Cover maps were used for the purposes of prediction. Furthermore, the analysis and visualization of areas with diverse erosion potential in this study were performed using the geographic information system (GIS) open-source software Quantum Geographical Information System- QGIS 3.32.1 'Lima' (QGIS Development Team, Gossau, Zürich, Switzerland).

The research on the impact of land use practices on runoff and erosion intensity in Polimlje and the sub-basins of the Shirindareh watershed consisted of collecting and processing data about land use practices; collecting and processing data about the physical-geographical characteristics of the selected Velička River watershed and the sub-basins S1-2, S2-1, S5-2, S7-1 & S2-2 of the Shirindareh watershed; analyzing changes in land use practices of the selected watersheds using the WIntErO model, projected over time profiles from 2018 to 2048.

Additionally, a field survey was conducted among the local population in the village of Velika, municipality of Plav, in the northeastern part of Montenegro, and data prepared by the MENARID team in Iran for the sub-basins of the Shirindareh watershed in Iran were utilized. The aim of the survey was to investigate and confirm previously obtained data regarding historical and current land use practices, which were gathered from various sources such as documents from the Real Estate Administration, Statistical Office, Forestry Administration, and the University of Montenegro. Data for the sub-basins of the Shirindareh watershed were obtained through personal field research and the analysis of reports by the MENARID team in Iran (standing as a control factor in this research). After examining the current situation, proposed measures of land use practices were suggested to gradually reduce soil erosion intensity and runoff from 2018 to 2048 by using the WIntErO model (Figure 4 and 5).

Figure 4. WIntErO, layout of the home page on the WIntErO platform



Enter the basic information

Name of the River basin: Zlorecica

Upload: Choose File No file chosen

Country: Montenegro

Year: 2018

Latitude: 42.788552

Longitude: 19.254656

Geometric characteristics of the river basin

F = 170.19755 km^2

Fv = 117.47809 km^2

Lv = 15.69702 km

O = 60.93071 km

Fm = 52.71946 km^2

Lb = 22.77723 km

Topographic characteristics of the river basin

h0 = 800 m

Δh = 100 m

Hmin = 732 m

Hmax = 2461 m

Liz [km]:	f [km^2]:
9.25276	2.03517
27.74068	5.66120
44.66425	9.62310
67.96002	13.46591
64.56787	13.94602
67.29815	14.45533
70.78123	14.15940
73.52592	14.54445
71.72385	14.41372
71.32298	14.63845
74.88127	15.15389
66.54649	16.67854
49.54816	11.29736
16.88764	7.11068
6.53782	1.83786
4.59787	0.64158
1.06358	0.64807
	0.18891

Hydr. char. of the river basin

ΣL = 43.36777 km

Lm = 14.09585 km

Water permeability

fp = 0.3986

fpp = 0.0860

fo = 0.5154

Land use

fs = 0.621267964

ft = 0.461097844

fg = 0.017644192

Meteorological data

hb = 115.0 mm

Up = 100 years

to = 9.0 °C

Hgod = 1183.7 mm

Erosion coefficients

Y = 0.84618

Xa = 0.39965

φ = 0.38722

Figure 5. Overview of data entry on the WIntErO platform

4. RESULTS

Building on the erosion investigations conducted in previous Polimlje studies (Spalević, 2011) that focused on erosion processes in Polimlje based on basin analysis, this analytical approach has been extended to certain sections within Polimlje and the sub-basins of the Shirindareh basin in Iran. The calculation results obtained were integrated into the worldwide basin database of WIntErO, which was established during the course of this research.

Furthermore, the slight difference between the data obtained from field research and modeling indicates the justification of the application of the

WIntErO model for the calculation of erosion intensity.

The river Lim in the studied area extends at an elevation between 436 m (Potpeć reservoir) and 907 m (Plavsko Lake), while the catchment area elevation range between 436 m and 2461 m. Thus, the average elevation of the catchment is 2025 m.

A series of graphic displays were created as a comparative analysis of the following data:

1. Sub-basin areas of Shirindareh Basin, Iran;
2. Natural length of the main watercourse, Lv, of Shirindareh sub-basins, Iran (km);
3. The highest elevation of the catchment, Hmax, of the sub-basins of the Shirindareh basin (m);
4. The mean altitude of the catchment, Hmean, of the sub-basins of the Shirindareh basin (m);
5. Mean height difference of the catchment, D, of the sub-basins of the Shirindareh basin (m);
6. Mean decline of the basin, Isr, sub-catchment of Shirindareh basin (%);
7. Maximum runoff from the basin, Qmax, sub-catchment of the Shirindareh basin ($m^3 s^{-1}$);
8. Production of erosion material, Wyr, sub-catchment of Shirindareh basin (m^3 $year^{-1}$) ;
9. Sediment retention coefficient, Ru, of the sub-catchment of the Shirindareh basin;
10. Actual soil losses, Gyr, sub-catchment of Shirindareh catchment (m^3 $year^{-1}$);
11. Actual losses per km^2, Gyr km^2, Shirindareh sub-catchment (m^3 $year^{-1}$ km^{-2}).

According to WIntErO calculations, the average area of the basin (Figure 6) of the sub-basins of the Shirindareh basin is 35.9 km^2. By area of the sub-catchment, the largest are the basins S2-3 (61.0 km^2), S5-2 (60.3 km^2), S1-4 (59.1 km^2), S8-3 (59.1 km^2), S1-5 (57.3 km^2), and S1-2 (56.1 km^2). The S2-3 catchment has the largest natural length of the main watercourse, Lv, of 20.5 km, while the average value for the Lv of the Shirindareh sub-catchment is 11.4 km (Figure 7). The highest elevations of the basin (Figure 8), Hmax, of the sub-catchment of the Shirindareh basin were recorded in the upper part of the Shirindareh catchment near the basins S1-4 (2687 m), S1-5 (2484 m), S1-6 (2515 m), S2-1 (2514 m). In the central part of the Shirindareh basin, it is important to note that the S7-1 catchment has the highest elevation of the basin at 2448 m. This is followed by the mean altitudes of the sub-basins: S1-4 (1983 m), S1-5 (1694 m), S1-6 (1681 m), S2-1 (1913 m) and S7-1 (1824 m) (Figure 9 and 10).

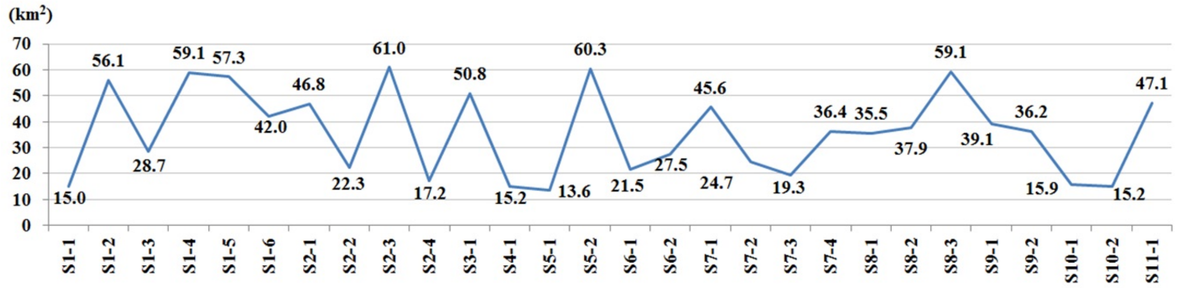


Figure 6. Overview of sub-basin surface areas of Shirindareh Basin, Iran (areas in km^2 on y-axis)

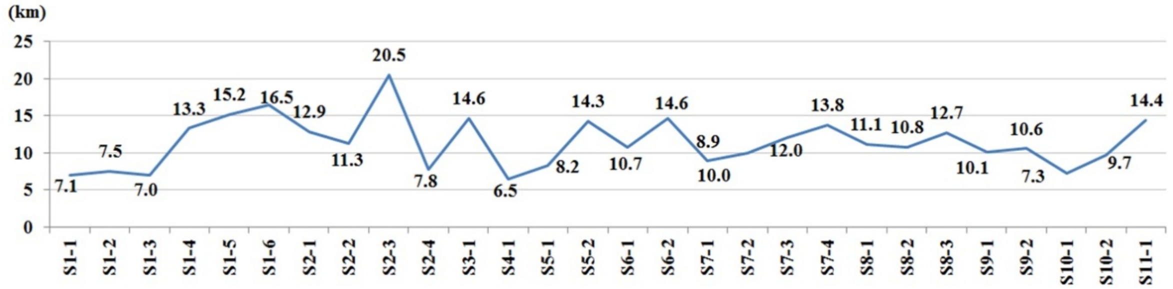


Figure 7. Natural length of the main watercourse, Lv, Shirindareh Basin, Iran (km values on y-axis)

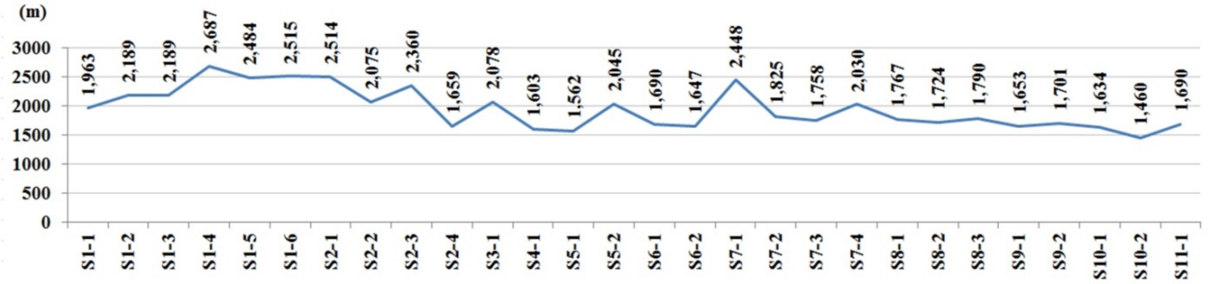


Figure 8. The highest elevation of the basin, Hmax, of the sub-basins of the Shirindareh Basin (m values on y-axis)

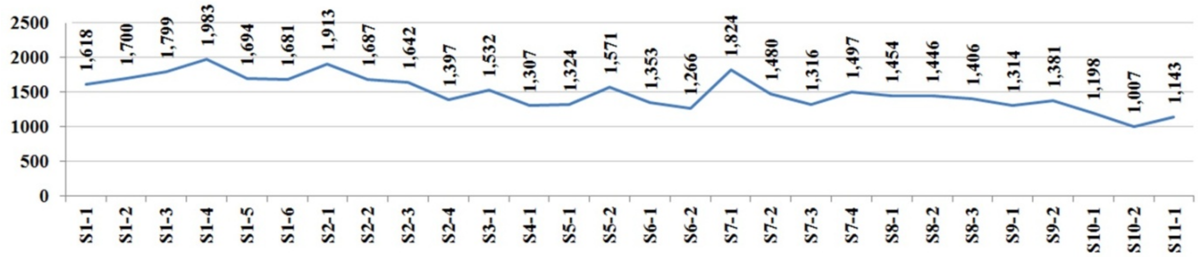


Figure 9. Mean elevation of the basin, Hmean, of the sub-basins of the Shirindareh Basin (m values on y-axis)

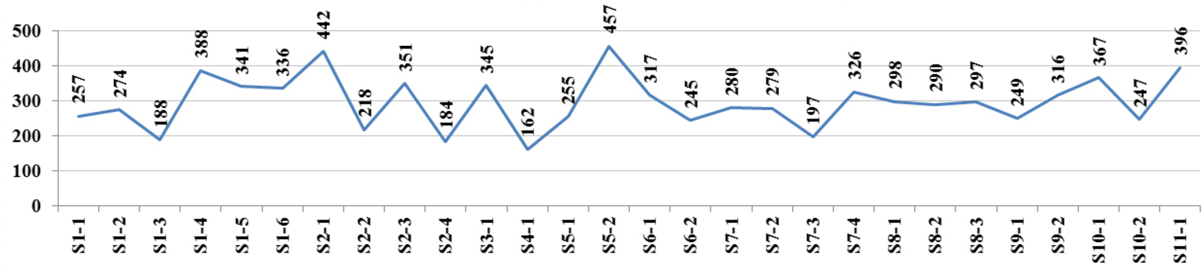


Figure 10. Mean elevation difference of the basin, D, of the sub-basins of the Shirindareh Basin (m values on y-axis)

The average catchment gradient ranged from 16% to 45%. Using the WIntErO model, we calculated that in the sub-basins of the Shirindareh catchment, the largest average drop of the basin, Isr, is in the S1-4 sub-catchment (45%); the smallest in sub-basin S2-2 (16%). The mean value for Isr of the Shirindareh sub-catchment is 29.6% (Figure 11).

By analyzing catchment areas, the mean height difference and the shape of individual basins, the water permeability of the area, vegetation cover, water retention in the catchment area, the energy potential of water flow during torrential rains, with the use of the WIntErO model tool, we obtained the calculation of the maximum runoff from all sub-basins of the Shirindareh basin.

Calculations of the WIntErO model showed that the maximum runoff from the basin, Qmax, of 209 m^3 s^{-1} can be expected in the sub-catchment S1-2 (return period of 100 years). The mean value for Qmax of the Shirindareh sub-catchment is 73 m^3 s^{-1}. With a more detailed analysis for this sub-basin, the WIntErO model calculations showed that the expected maximum runoff from the S1-2 basin is about 87 m^3 s^{-1} for a return period of 5 years and 341 m^3 s^{-1} for a return period of 1000 years (Figure 12). The production of erosion material, Wyr, of the sub-basins of the Shirindareh basin is presented in Figure 13.

The production of erosion material, according to the calculations of the WIntErO model, is the highest in the basin S1-2 (53.821 m^3 $year^{-1}$), followed by S1-5 (43797 m^3 $year^{-1}$), S2-3 (43471 m^3 $year^{-1}$), S7-1 (41805 m^3 $year^{-1}$), S5-2 (41602 m^3 $year^{-1}$), S1-4 (41475 m^3 $year^{-1}$), S8-3 (35983 m^3 $year^{-1}$), and S2-1 (35668 m^3 $year^{-1}$).

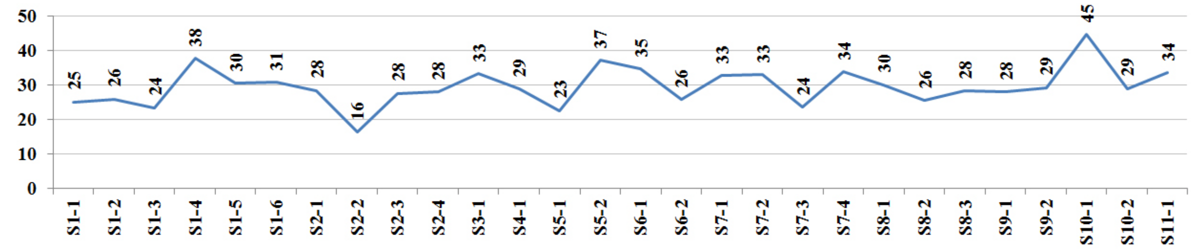


Figure 11. Average gradient of the basin (Isr), and sub-basins of the Shirindareh Basin (% values on y-axis)

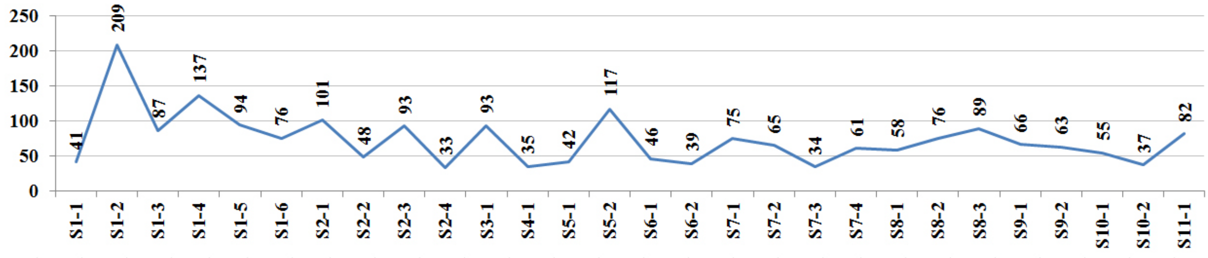


Figure 12. Maximum runoff from the basin, Qmax, sub-basins of the Shirindareh Basin (m^3 s^{-1} values on y-axis)

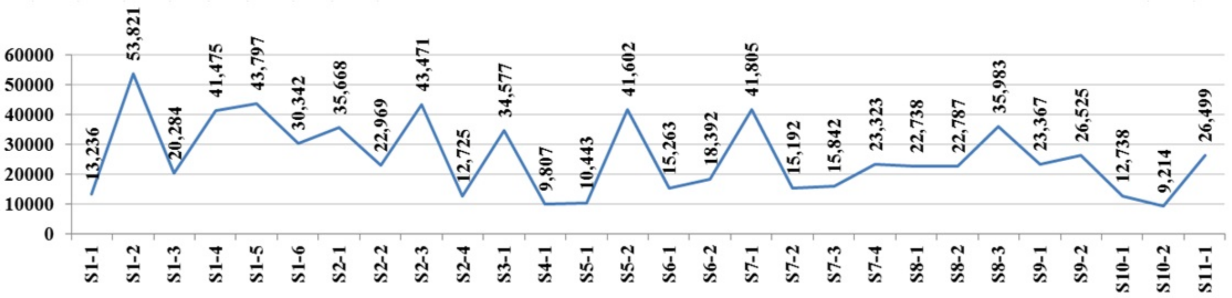


Figure 13. Production of erosion material, Wyr, sub-basins of the Shirindareh Basin (m^3 $year^{-1}$ values on y-axis)

However, all the erosion material produced in the basins (Wyr) does not reach the lowest point in the basin but is retained in the lower positions of the respective basins. In order to obtain the actual soil losses in the basin (Gyr), the value of the produced erosion material should be reduced by multiplying this value with the coefficient of retention of erosion sediments (Ru) (Figure 14). This coefficient is a factor that reduces the general amount of deposits produced on average per year. Reducing the quantity of deposits from the source to the mouth of the basin is a natural process.

The highest values of real soil losses, Gyr, of the sub-basins of the Shirindareh basin (m^3 $year^{-1}$), according to the calculations obtained from the WIntErO model (Figure 15), were recorded in the following sub-basins: S1-2 (20404 m^3 $year^{-1}$), S5-2 (14584 m^3 $year^{-1}$), S1-5 (13228 m^3 $year^{-1}$), and S2-1 (12493 m^3 $year^{-1}$).

The highest values of actual soil losses per square kilometer, Gyr km^{-2}, of the sub-basins within the Shirindareh basin (m^3 $year^{-1}$ km^{-2}), according to the calculations of the WIntErO model, were recorded for the following sub-basins: S1-2 (364 m^3 $year^{-1}$), S2-1 (267 m^3 $year^{-1}$), S5-2 (242 m^3 $year^{-1}$), S7-1 (242 m^3 $year^{-1}$), and S2-2 (240 m^3 $year^{-1}$).

The results show that soil erosion is primarily controlled by topography, and sediment recharge in basins is related to land use and plant cover (Čurović et al., 2020). At higher elevations. Identified regions of high priority for soil and water conservation, with calculated highest values of actual soil losses, Gyr (G_{yr}), sub-basins of Shirindareh basin (m^3 yr^{-1}), are according to WIntErO model calculation: S1-2 (20404 m^3 $year^{-1}$), S5-2 (14584 m^3 $year^{-1}$), S1-5 (13228 m^3 $year^{-1}$), S2-1 (12493 m^3 $year^{-1}$), and by real land losses per square kilometer: S1-2 (364 m^3 $year^{-1}$ km^{-2}), S2-1 (267 m^3 $year^{-1}$ km^{-2}), S5-2 (242 m^3 $year^{-1}$ km^{-2}), S7-1 (242 m^3 $year^{-1}$ km^{-2}), and S2-2 (240 m^3 $year^{-1}$ km^{-2}) (Figure 16). The average value of actual soil losses per square kilometer for the Shirindareh sub-basins is 201 m^3 $year^{-1}$ km^{-2}. According to the given findings, these basins require a prompt response by establishing and implementing proper soil conservation measures.

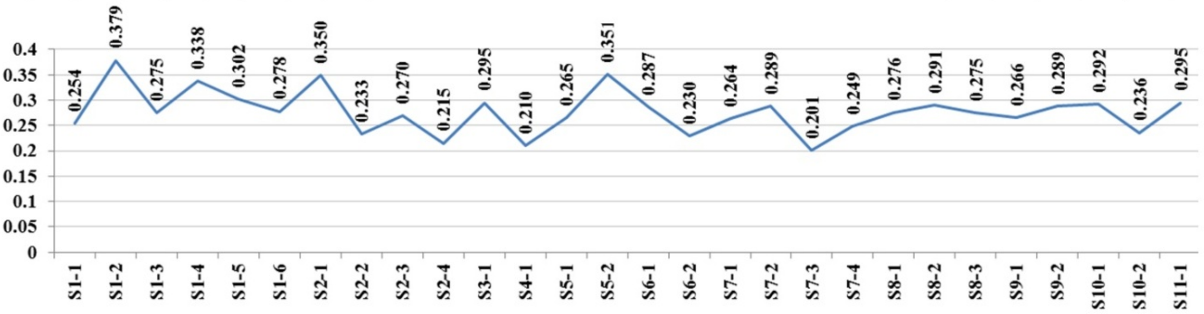


Figure 14. Sediment retention coefficient, Ru (values on y-axis), of the sub-basins within the Shirindareh Basin

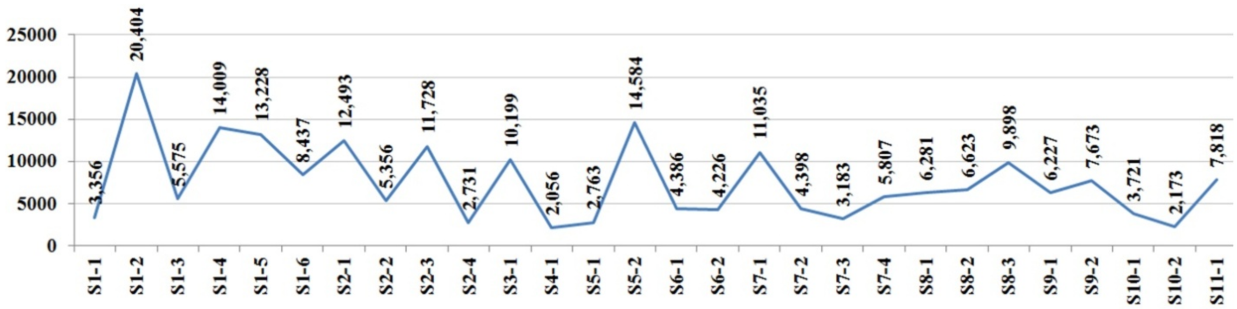


Figure 15. Actual soil losses, Gyr, sub-basins within the Shirindareh Basin (m^3 $year^{-1}$ values on y-axis)

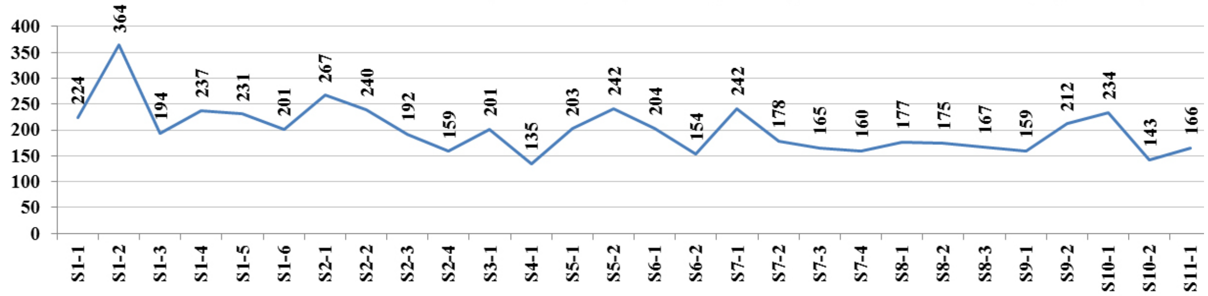


Figure 16. Actual soil loss in sub-basins within the Shirindareh Basin (m^3 km^{-2} $year^{-1}$ values on y-axis)

Using the inputs of the Polimlje research (Spalević, 2011, Spalević et al, 2017) and according to the calculations of the WIntErO model, in order to establish a new database, high-priority regions for soil and water conservation were identified, with the highest values of actual soil losses, Gyr, of the Lim sub-basins calculated (in m^3 $year^{-1}$) (Nikolić et al., 2019). Within the Polimlje basins, the computation of real soil losses per square kilometer (in m^3 km^{-2} $year^{-1}$) was executed for all 57 primary tributaries of the Lim River within Montenegro's territory. Subsequently, through the utilization of the WIntErO model, a recalculation was performed, leading to the presentation of the ensuing actual soil loss values, depicted in Figure 17 and 18.

Starting from the fact that understanding the problem of soil erosion and runoff in the basin is of key importance for the preservation of soil and water resources, the influence of land use on the intensity of erosion in Polimlje and selected sub-basins of the Shirindareh basin with proposals for variants of the use method was carried out on the basins with the most critical values of real soil losses in the case study Velička River in Polimlje in the territory of Montenegro and in the following sub-basins of the Shirindareh basin: S1-2, S2-1, S5-2, S7-1, S2-2 in the territory of Iran.

In their research on the impact of changes in land use and landscape patterns on soil erosion in basins, Amini et al., (2010) pointed out that it is very important to have a good understanding of the relationship between soil erosion and landscape patterns, so that soil and water conservation in river basins can optimize. The relationship between soil erosion and land use, as well as landscapes themselves, is important for water management and land management. Processes of soil erosion and reduction of runoff from basins can be reduced by strengthening the control function of land

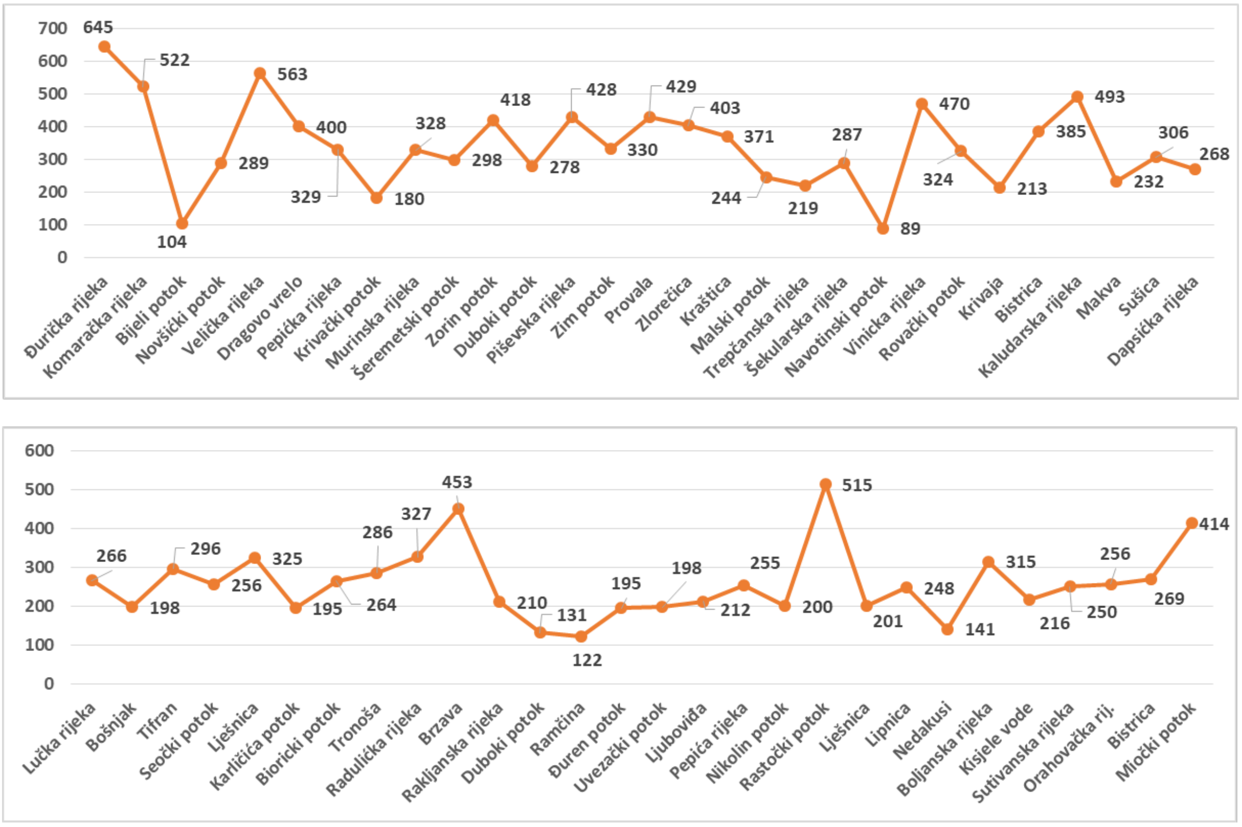


Figure 17. Results of the recalculation investigation of the Lim tributaries in Polimlje

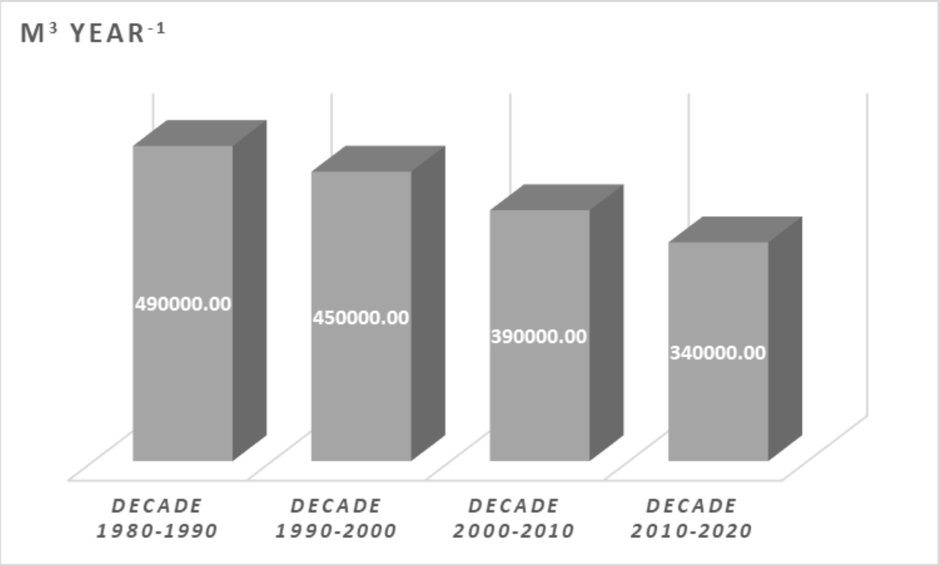


Figure 18. Overview of the intensity of soil erosion in Polimlje by decades

use, improving the diversity of landscape types, enriching landscape types, while taking into account the increase in the degree of aggregation in the landscape.

With serious land use planning, these measures can contribute to the improvement and optimization of soil and water conservation in river basins.Research into the impact of land use on runoff and erosion intensity in Polimlje and the sub-basins of the Shirindareh Basin consisted of collecting and processing data on land use; Data collection and processing of physical-geographic features of selected Velička River basins and sub-basins S1-2, S2-1, S5-2, S7-1 and S2-2 within the Shirindareh basin; Analysis, with the use of the WIntErO model, of changes in land use in selected basins with projections on time profiles from 2018 to 2048.

As a result of the aforementioned analyses and simulations, so-called "sustainable" land use proposals were obtained in the basins in question with analyses of their impact on the intensity of erosion, i.e. on actual soil losses per square kilometer. In addition to the standard research methods mentioned in the Material and methods chapter, for the purposes of these analyses, a survey of the population in the village of Velika, municipality of Plav, in the north-east of Montenegro, was carried out, and the data prepared by the MENARID team in Iran for the sub-basins of the Shirindareh basin in Iran. The aim of the survey was to establish (discover) the way land was used in the past and at the present using the data of the Real Estate Administration, the Bureau of Statistics, the Forestry Administration, and the University of Montenegro.

Data for the sub-basins of the Shirindareh basin were acquired through field-based investigations and by scrutinizing reports produced by the MENARID team in Iran. Conclusively, subsequent to a comprehensive review of the present circumstances, land use strategies were suggested. These measures are intended to progressively diminish the soil erosion intensity and runoff over the span from 2018 to 2048.

The anthropogenic factor, in interaction with other natural factors, has a direct influence on the parameter of the structure of land use from the equation on runoff from basins (Spalević, 2011). The coefficients fs (areas under forest cover), ft (areas under grass cover), and fg (areas under barrens), from the equation on maximum runoff from basins, according to Gavrilović approach, quantitatively describe the way of land use (barrens, arable fields, orchards and vineyards, mountain pastures, meadows, degraded forests, well-structured forests) of those structures that man directly manages, changing their percentage occurrence in the basins respectively (Gavrilović, 1972).

By processing all input data from the selected watersheds covered by this study: Velička River in Polimlje and the sub-basins of the Shirindareh watershed in Iran, which were identified as critical in the initial analyses, results regarding runoff and erosion intensity were obtained by using the WIntErO model. Data for the watersheds were further analyzed and processed, forming the basis for proposed land use practices – i.e. the structure of land use practices for the selected watersheds. Calculated values are referring to the current state (2018) and projected state (2048) of land use practices. These proposals, when implemented into practice, can lead to reduced erosion intensity to around 200 $m^3/year^{-1}/km^2$ for the Iranian sub-basins; reduced by 50% for the selected critical sub-basin of the Velička River in the Polimlje watershed within Montenegro's territory. Also, the obtained results, presented as the erosion coefficient (Z), reveal a significant presence of areas with diverse erosion potential in both analyzed watersheds. The figures

(Figure 19 and 20), as well as range of erosion coefficient values (Z) (given in the Table 2), illustrate high, moderate, low, and very low-risk areas susceptible to water erosion processes.

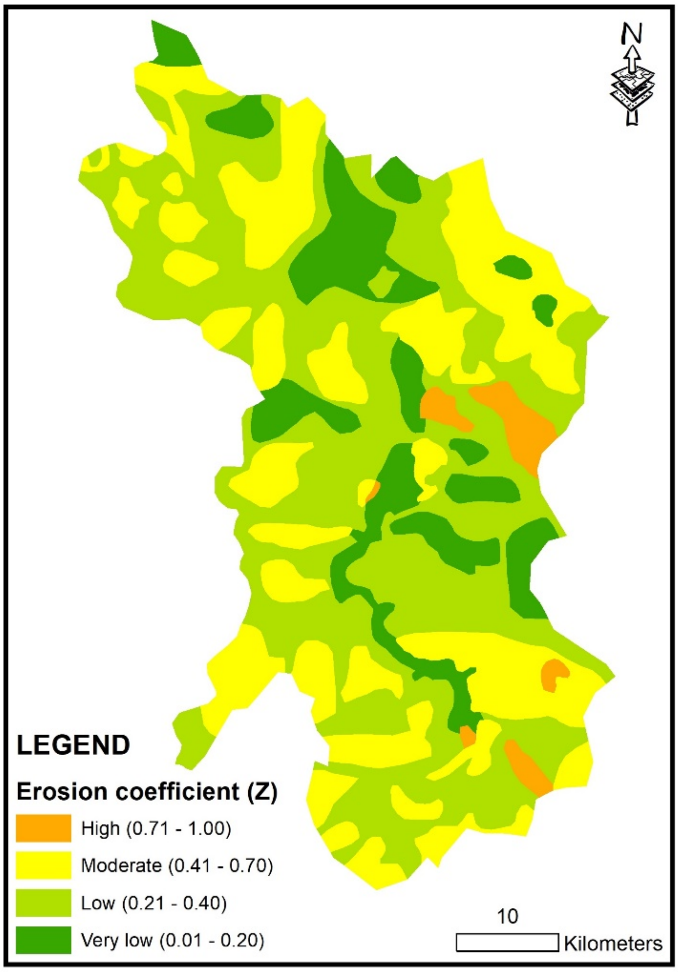


Figure 19. Erosion coefficient (Z) for Polimlje basin

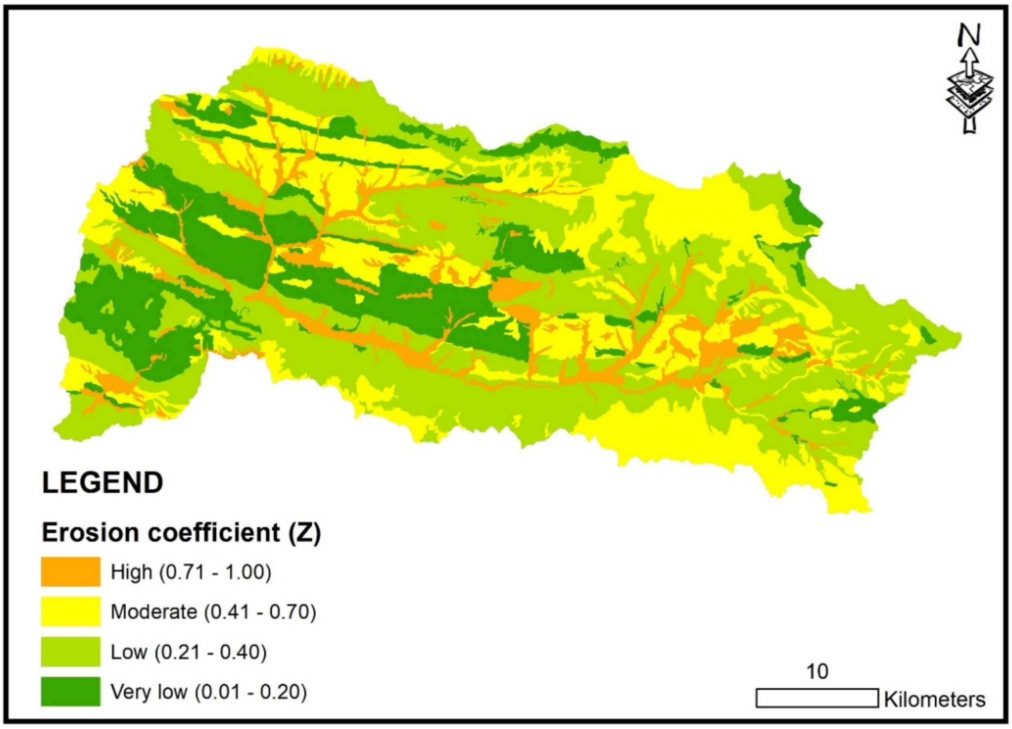


Figure 20. Erosion coefficient (Z) for Shirindareh basin

Table 2. Range of erosion coefficient values (Z)

Qualitative name of erosion category	Range of erosion coefficient (Z)
Very high erosion	1.00 - 1.50 > 1.50
High erosion	0.71 - 1.00
Medium erosion	0.41 - 0.70
Low erosion	0.21 - 0.40
Very low erosion	0.01 - 0.20

5. DISCUSSION

A comparison of the two independent watersheds was made to test the given river basin model for assessing runoff and soil erosion in areas with specific morphology, land use, a continental climate characteristics, and highly pronounced pluvial contrasts. In mountainous areas such as most of northern Montenegro and southwestern Serbia, river catchments are often affected by natural hazards, including floods, soil erosion and landslides (Spalević et al., 2017). Excess soil erosion is one of the most widespread and dangerous environmental threats that reduce agriculture production and affect water quality (Tazioli, 2009). The most prominent forms of water erosion for such mountainous areas include surface, sheet, rill, gully and bank erosion. Negative effects on soil potency and fertility, plant cover, runoff coefficient and flood risk can be extremely significant; especially in regions where soil and water resources are very vulnerable. The implementation of adequate actions against this globally widespread environmental problem is often not in the focus of government administrations compared to some other prominent concerns, such as dealing with climate change challenges (Tangestani, 2005; Lukić et al., 2019, 2021; Micić Ponjiger et al., 2021, 2023).

A clear understanding and quantification of erosion intensity at the basin surfaces level is essential for solving many environmental problems caused by the impact of sediment transport and its deposition outside the river basin.

Previous research has identified the Velička River basin as one of the areas affected by these processes that should be adequately protected (Petraš et al., 2003). The Velička River is the right tributary of the Lim River in the northeast of Montenegro. The basin includes the villages of Velika, Volujak and Radeviće. It is located 5.3 km north of Plav; 9 km south of Šekular, Spalevići settlement; 15 km southeast of Andrijevica.

The basin, which is characterized by very steep slopes, extends from the lowest elevations (Hmin 879 m.a.s.l.) all the way to the peaks of Prijedolska Glava (Hmax, 2077 m.a.s.l.) over a length of 5.2 km. The length of the main watercourse is 6.9 km. The shortest distance between the source and the mouth is 5.4 km; the length of the basin, measured by a series of parallel lines, Lb, is 8.9 km. The average altitude of the basin is 1455 m above sea level, and the average height difference is 576 m.

Calculation of the WIntErO model showed that the actual soil losses in the Velička River basin are 18148 $m^3 km^2 yr^{-1}$; while actual soil losses per km^2 attain 562 $m^3 km^2 yr^{-1}$.

The proposal for changes in land use in the Velička River basin aimed to achieve a structural change through management by converting grasslands (2018 - 59%; 2048 - 30%) into forested areas (2018 - 39%; 2048 - 69%) using soil conservation measures. This measure was suggested due to calculations indicating that the erosion intensity in this watershed is twice as high as the average values in the Polimlje basin, from the source of Lim in Montenegro to the Potpeć dam in Serbia as presented by this study. The projected impact of this measure would result in a 50% reduction in erosion intensity. By implementing this proposal, projected real soil losses are expected to decrease from 18148 $m^3 yr^{-1}$ (in 2018) to 9049 $m^3 yr^{-1}$ (in 2048). Reducing the area under grass in favor of increasing the area under forests would not be at the expense of the livestock farming of the local population respectively. Afforestation interventions would take place at higher elevations in the watershed, far from settlements, on land - slopes with a greater incline. Furthermore, the expanses of pastures and meadows are sufficient even with this reduction proposal for the further development of animal husbandry in this area. Here in the analysis, we took into account that the local population also owns properties on the slopes of Čakor and towards the Mokri Mountain. The large areas under the pastures that are used for the seasonal ascents to the mountain are more than enough for the needs of livestock farming, which is practiced by the local population. On the other hand, an increase in the area under forests (fs 0.39 - 2018; 0.69 - 2048) would reduce the problems that can be caused by soil erosion, and the forest fund would be strengthened, where later, through proper forest management, the local population would also have significant economic gains in exploitation of areas under newly established forests in the period after three decades. According to Hartel et al. (2013), land use change represents a major threat to global biodiversity. The positive aspect of this proposal is that it takes into account that forest species are facing the threat of deforestation, and this would lead to a reversed process of reforestation of previously cleared areas under forests. In their research, they highlight numerous benefits of protecting areas where forests are endangered, by establishing long-term stable silvo-pastoral management practices.

Calculations of the WIntErO model showed that, apart from impacting erosion intensity, the land use practices had a positive effect on the reduction of the maximum runoff from the basin. The value of Qmax 2018 was reduced from 295.01 $m^3 s^{-1}$ to Qmax 2048 in the value of 269.86 $m^3 s^{-1}$, for a return period of 100 years for Velička River (Figure 21).

Hence, it proves valuable to introduce this approach as a concept to managers overseeing watershed surface management within forestry administrations, as well as decision-makers within relevant ministries and local governing bodies. These stakeholders then extend their efforts to the local populace. This endeavor is aimed at formulating region-specific economic development plans accurately, all aligned with the objective of attaining the region's economic development goals, while upholding the principles of sustainable basin management.

A change in land use was also proposed for the S1-2 sub-basin of the Shirindareh basin. By establishing the structure of land use with percentage participation, the maximum runoff from the basin, Qmax, decreased from 209.29 $m^3 s^{-1}$ (2018) to 184.45 $m^3 s^{-1}$ (2048). The production of erosion material in the basin, Wyr, decreased from 53820 m^3 $year^{-1}$ to 30279 m^3 $year^{-1}$. Actual soil losses, Gyr, decreased from 20404 m^3 $year^{-1}$ to 11479 m^3 $year^{-1}$. Actual soil losses per square kilometer decreased from 363.98 m^3 $year^{-1}$ km^{-2} to 204.78 m^3 $year^{-1}$ km^{-2}.

The land use change analysis proposed for the S2-1 sub-basin of Shirindareh indicated that there was a slight decrease in the maximum runoff from the basin, Qmax, from 101.32 $m^3 s^{-1}$ (2018) to 101.4 $m^3 s^{-1}$ (2048). The production of erosion material in the basin, Wyr, decreased from 35667 m^3 $year^{-1}$ to 26904 m^3 $year^{-1}$. Actual soil losses, Gyr, decreased from 12493 m^3 $year^{-1}$ to 9423 m^3 $year^{-1}$. Actual soil losses per square kilometer decreased from 267.12 m^3 $year^{-1}$ km^{-2} to 201.49 m^3 $year^{-1}$ km^{-2}.

The analysis of land use change proposed for S5-2 sub-basin Shirindareh, indicated that there was a decrease in the maximum runoff from the basin, Qmax, from 116.62 $m^3 s^{-1}$ (2018) to 112.98 $m^3 s^{-1}$ (2048). The production of erosion material in the watershed, Wyr, decreased from 41601 m^3 $year^{-1}$ to 34732 m^3 $year^{-1}$. Actual soil losses, Gyr, decreased from 14584 m^3 $year^{-1}$ to 12175 m^3 $year^{-1}$. Actual soil losses per square kilometer decreased from 241.74 m^3 $year^{-1}$ km^{-2} to 201.82 m^3 $year^{-1}$ km^{-2}.

The analysis of land use change proposed for S7-1 sub-basin Shirindareh, indicated that there was a decrease in the maximum runoff from the basin, Qmax, from 75 $m^3 s^{-1}$ (2018) to 72.41 $m^3 s^{-1}$ (2048). The production of erosion material in the basin, Wyr, decreased from 41805 m^3 $year^{-1}$ to 34778 m^3 $year^{-1}$. Actual soil losses, Gyr, decreased from 11034 m^3 $year^{-1}$ to 9179 m^3 $year^{-1}$. Actual soil losses per square kilometer decreased from 242.04 m^3 $year^{-1}$ km^{-2} to 201.36 m^3 $year^{-1}$ km^{-2}.

Furthermore, the analysis of land use change proposed for S2-2 sub-basin Shirindareh, indicated that there was a decrease in the maximum runoff from the basin, Qmax, from 47.86 $m^3 s^{-1}$ (2018) to 46.16 $m^3 s^{-1}$ (2048). The production of erosion material in the basin, Wyr, decreased from 22968 m^3 $year^{-1}$ to 19305 m^3 $year^{-1}$. Actual soil losses, Gyr, decreased from 5355 m^3 $year^{-1}$ to 4501 m^3 $year^{-1}$. Actual soil losses per square kilometer decreased from 240.17 m^3 $year^{-1}$ km^{-2} to 201.86 m^3 $year^{-1}$ km^{-2}.

The presented methodological approach using the WIntErO model identified potential risks of soil erosion in the case study of the Velička River in Polimlje on the territory of Montenegro and in the following sub-basins of the Shirindareh basin: S1-2, S2-1, S5-2, S7-1, S2-2 on the territory of Iran.

Gaining insight into the erosion process holds specific significance when its practical application is considered. This insight can be harnessed to enhance the planning of various human activities within natural settings, all while adhering to the principles of sustainable land and water management.

Based on the presented findings, it has been demonstrated that the WIntErO model serves as a practical tool for assessing the influence of land use on erosion intensity within watersheds. This model's applicability can extend to other regions sharing similar ecological and socioeconomic conditions.

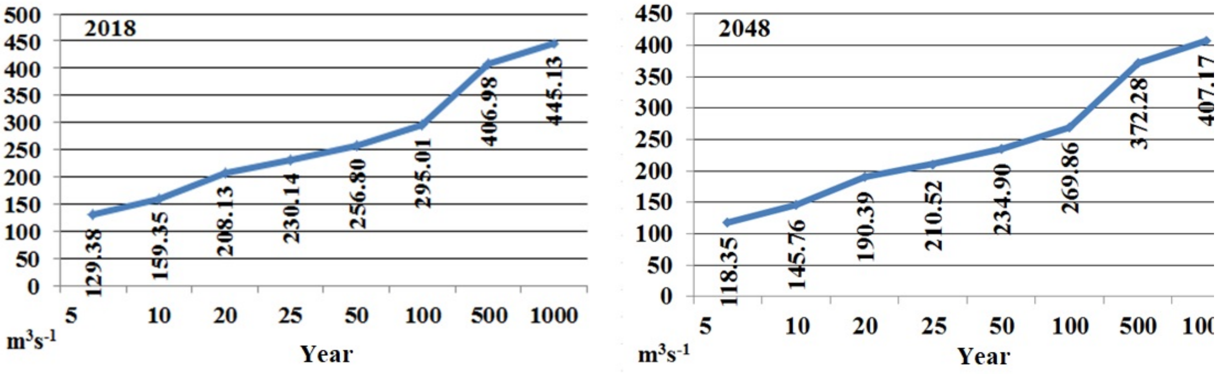


Figure 21. Value of Qmax 2018 and Qmax 2048 for Velička River

6. CONCLUSIONS

The WIntErO model is a computer-graphic method based on the earlier generations of "River basins" (Spalević et al., 2000; Mohammadi et al., 2021) and IntErO (Spalević, 2011) and calculates the amount of sediment, the intensity of soil erosion, as well as the maximum runoff from the basin, based on Gavrilović approach, and has widely found its application in the study of hydro-meteorological hazards in the Polimlje (Montenegro and Serbia) and Shirindareh (Iran) basins. In the aforementioned basin surfaces, Spalević and his co-workers used computer-graphic methods for calculating surfaces and distances ("Surface and Distance measuring"; (Spalević, 1999), as well as the programs IntErO (Spalević, 2011) and "Basin surfaces" (Spalević et al., 2000; Nikolić et al., 2019) for calculating runoff and erosion intensity in the 57 basin surfaces. Tangestani (2005), Sadeghi et al., (2008) and Sadeghi et al., (2009) compared the results of the Gavrilović model with the results of the PSIAC model and observed a better reliability of the PSIAC model in determining areas of very strong erosion potential. A visual inspection of the terrain in combination with a GPS device confirmed a good estimate for areas of medium and strong erosion obtained by Gavrilović's method and a lower accuracy for areas of weak erosion potential. Thus, the value of the measurement of annual backfilling for the year 2017 (data on total backfilling and the percentage of backfilling since the beginning of the measurement) is 0.34 million m^3, which is 340,000 m^3 per year. The value obtained by WIntErO modeling is 340,000 m^3 per year. This coincidence of only 0.5% of the difference between measurement and calculation indicates that further use of the WIntErO model is acceptable for the preparation of land use scenarios and the impact of climate change on the intensity of erosion and runoff in the Polimlje watershed, i.e. in similar watersheds in the region. Another comparison with the PSIAC method showed the same pattern for the predicted values of erosion sediment for both methods with a correlation coefficient of 0.95, which confirmed the applicability of both methods in moderately arid and arid watersheds compared Gavrilović's method with PSIAC and MPSIAC and concluded that the MPSIAC method gives better results of erosion sediment production than Gavrilović's method. It should be noted that respective authors used a simplified formula for estimating the retention coefficient of erosive sediment (Spalević et al., 2020). The results obtained through comparison of the RUSLE method and the Gavrilović method with field measurements led to the conclusion that the RUSLE method aligns more closely with the field measurements conducted at the Abrami test fields. These comparisons should be made with the WIntErO model calculations in the future research. Compared to some other methods, Gavrilović's method does not investigate the physics of erosion processes and, as such is suitable for areas where a smaller range of information is available and where there is a lack of previous erosion research. As such, the method can provide insight not only into the total production of erosion deposits but also into the intensity of erosion as a preliminary result and indicator of areas potentially endangered by erosion.

Various improved models were employed in the preceding period, and diverse iterations of the model continue to be utilized in the present day. Those model variants pertain to estimating the annual quantities of transported, dragged and suspended sediment by the river network. The analysis showed somewhat better results and agreement with measurements in the field when applying the modified formula for the retention coefficient of the erosion deposit. The modified erosion sediment retention coefficient utilizes the river network density as the ratio between the total length of the main watercourse and all secondary watercourses to the basin area. If a simpler (original) formula is employed and the formula is substituted with a constant, the outcomes derived from the model's application might exceed the projected values for the overall annual production of eroded sediment, specifically the yearly quantity of displaced soil particles. Dragičević et al., (2016, 2017a,b), recommend the application of the formula for the density of the river network, which was applied in this paper and integrated into the WIntErO model, in order to avoid inaccurate results that give higher values for the annual amounts of transported erosion sediment by the river network compared to the total annual production of erosion sediment. It is worth outlining that the Gavrilović EPM method is integrated into the algorithms of the IntErO and WIntErO models respectively. Therefore, the model utilized in this study represents a semi-quantitative approach for assessing sediment yield on a catchment scale for the two independent basins. However, the approach proposed in this study still requires comparison with other models and more intricate erosion estimators (e.g. RUSLE, RUSLE2) for successful validation and assessment in the broader Balkan (Micić Ponjiger et al., 2021, 2023; Lukić et al., 2019) and Middle East region (Mohammadi et al., 2021). Similar studies in neighboring and eastern countries are essential to delineate the environmental limitations of the model's application, which is significantly influenced by the land use factor and demographic changes. The WIntErO model calculates sediment yield comprehensively for the entire basin, making it effective in estimating the severity of erosion. The data generated using this approach is presented through detailed values of the factors employed in the intensity of erosion and outflow WIntErO/EPM method. However, there is a notable drawback: the absence of geospatial representation within the model itself. Future research efforts should aim to incorporate the k-means clustering algorithm. This addition would help elucidate spatial patterns of soil erosion intensity and enhance compatibility with various visualization modules, thus improving the overall quality of the model itself. Also, it is generally accepted that both sediment discharge series and soil erosion measurements are only available in a few small to medium-sized experimental catchments. Due to varying sediment data availability in the case study areas, further research is necessary to address model limitations and reduce the uncertainty of model results. Direct measurements of erosion in a watershed are feasible through multi-year measurements of solid transport in the closing section (which is a significant constraint of this study). Hence, these stated issues strongly impacts the inability to generate precise and high-resolution erosivity maps, which are valuable tools for water erosion assessment and control, especially for agricultural and land use planning. Therefore, this matter needs to be tackled in future regional-based studies.

According to the above stated, it can be pointed out that the following factors have the greatest influence on soil erosion in Montenegro, Serbia and Iran, that is, in the areas of Polimlje (Montenegro and Serbia) and Shirindareh watersheds from the northeast parts of Iran:

- Natural conditions;
- High sensitivity of natural resources;
- Irregular and inadequate development activities;
- Changes in land use and illegal exploitation of resources;
- Lack of adequate marketing of soil protection and conservation;
- Technical factors.

Despite many serious issues related to soil erosion in Montenegro, Serbia and Iran, a comprehensive strategy to solve this problem has not yet been established. Numerous basin surface management activities have been slow to be implemented in Iran and Serbia; in Montenegro was reduced to individual activities of several researchers from the Department of Geography of the Faculty of Philosophy of the University of Montenegro, with the support of researchers from the Faculty of Sciences at the University of Novi Sad.

The effectiveness of watershed management activities has not yet been scientifically or precisely assessed. However, teams of Montenegrin, Serbian and Iranian experts, according to available literature (Spalević et al., 2020; Mohammadi et al., 2021; Čurović et al., 2020) propose the following approaches to soil erosion control and mitigation in these three countries:

- Establishing a proper understanding and conceptualization of the system that leads to adaptive management;
- Limiting the development of unnecessary infrastructures and activities;
- Control of changes in land use and stopping illogical and irrational exploitation of resources;
- Establishment of constant monitoring of the hydrological behavior of river basins;
- Establishment of special, specific protection measures against soil erosion for different purposes of individual agro-ecological regions.

On the basis of the presented observations from domestic and foreign literature, we conclude that the negative processes of soil erosion, in the Western Balkans and in the world, are intensified by the influence of anthropogenic factors and climate variability and that the studies of runoff and the intensity of soil erosion in Polimlje (Montenegro and Serbia) and in the Shirindareh watersheds (Iran) are justified.

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