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ASSESSMENT OF SOIL EROSION AND SEDIMENT YIELD USING EROSION POTENTIAL METHOD: CASE STUDY - VRBAS RIVER BASIN (B&H)

Abstract: Soil erosion is one of the most significant forms of land degradation in the Bosnia and Herzegovina. The mapping of soil erosion in B&H, as in the study area, was realized 30 years ago (1979-1985). The past decades has been marked by the changes which retained visible tracks and caused numerous changes in the intensity of erosion processes. In this paper, the mapping of the recent state of erosion intensity was performed, and then an analysis of changes was made in relation to the state of 30 years ago. The erosion potential method (EPM) was used for mapping the soil erosion and calculation of gross annual erosion and sediment yield. Erosion Map of the Vrbas river basin was made in the scale of 1:25,000. This Erosion Map counts a total of 69 topographic sections and 4,524 erosion polygons (plots). According to the Erosion Map of the Vrbas river basin, 5,666.88 km^2 of the study area is affected by erosion, while 621.71 km^2 are accumulating sediments. Annual gross erosion in the Vrbas river basin is 1,223,989.60 m^3/year, while sediment yield is 366,088.10 m^3/year. These research results are important because this is the first soil erosion map for the Vrbas river basin with EPM methodology for the whole river basin on territory of Bosnia and Herzegovina. The results can be applied in the field of spatial and urban planning, water and soil management on the local and regional level.

Key words: soil erosion, intensity, EPM, Vrbas river basin, Bosnia and Herzegovina

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Introduction

Soil erosion is a global problem, with severe consequences for the environment, human society and economy. In most cases, this process is caused by natural factors, but some human activities also contribute to soil erosion intensity (Lal, 1990; Chen et al., 2002; Ananda & Herath, 2003; Morgan, 2005; Sharma et al., 2011; Khaledian et al., 2017). Recently, there were many models for soil erosion estimation as well as deposition rate in the world, but the results of those models provided different possibilities for functional usage.

Empirical models are frequently used in preference to more complex models. They can be implemented in situations when data and parameter inputs are limited and for these reasons empirical models for soil erosion and sediment yield prediction are still widely in use many countries (Walling & Web, 1996; Van Oost et al., 2005; de Vente et al., 2005; 2006; 2007; 2008), including the Republic of Srpska/B&H (Tošić et al., 2011; 2012; 2013).

Gavrilović (1962; 1970; 1970a; 1972) created and developed an empirical EPM (Erosion potential method) model for the analytical determination of erosion coefficients, quantification of gross erosion and average annual sediment yield. This model is a result of experimental research on a station that was located in Serbia. Regarding examinations from experimental stations in Serbia, Bosnia and Herzegovina, Croatia, Slovenia and Montenegro, as well as from the work on the erosion mapping in former Yugoslavia, Lazarević (1985) made certain adjustments of the empirical methodology of S. Gavrilović through changes of the tables for determination of the coefficients Φ, X, Y, and the tables for determining the mean value of the erosion coefficient (Z). By the use of the above mentioned methodology, the Erosion map of Bosnia and Herzegovina was made (1980-1985) and Erosion map of Republic of Srpska (2012) (Lazarević, 1985; 1985a; 2004; Tošić et al., 2012).

The chosen methodology has been used for more than 40 years, and today it is a leading methodology both in our country, but also in the countries of the region and around of the world (Globevnik et al., 2003; Fanetti & Vezzoli, 2007; Haghizadeh et al., 2009; Bagherzadeh & Daneshvae, 2011; Deilami et al., 2012; Barmaki et al., 2012; Tošić et al., 2012; Zarei & Mokarram, 2016; Dragičević et al., 2017).

Since the period when mapping of erosion processes in Vrbas river basin was carried out, some significant changes in this area have occurred due to the anthropogenic influences. The civil war left serious consequences and made important impact on decrease in population and households, population migration, land use, but also on gross erosion and sediment yield changes (Dragićević & Stepić, 2006; Mustafić, 2007; Tošić, 2008; Dragićević et al., 2009; Tošić et al., 2012b; Manojlović et al., 2018). All those changes point to a justified need for the mapping of soil erosion in the Vrbas river basin. It is particularly important to note that this is the first soil erosion map in Bosnia and Herzegovina that covers the whole river basin, the river basin area in Republic of Srpska and the Federation of Bosnia and Herzegovina.

The main aim of this study is the mapping of soil erosion and calculation of the amount of gross soil erosion and sediment yield for the Vrbas river basin. These results are the basis for all integral water management projects, soil protection, forest ecosystems and environmental protection, spatial planning, agriculture and other human activities.

Study area

The Vrbas river basin, situated in the western part of Bosnia and Herzegovina, has a flow length of 235 km and basin area of 6,288.59 km^2. The average altitude of the river basin is 690 meters above sea level (Tošić et al., 2018). The Vrbas River Basin is surrounded by the Bosna river basin in the east, the Una and Sana river basins in the west, and in the southeast to the Neretva river basin (Fig. 1).

The geological structure of the basin mainly consists of carbonate rocks of the Mesozoic, Paleozoic and Tertiary periods. Igneous rocks and Paleozoic carbonates are less common. Quaternary sediments are least represented and they mainly cover the karst poljes and alluvial valleys along the river.

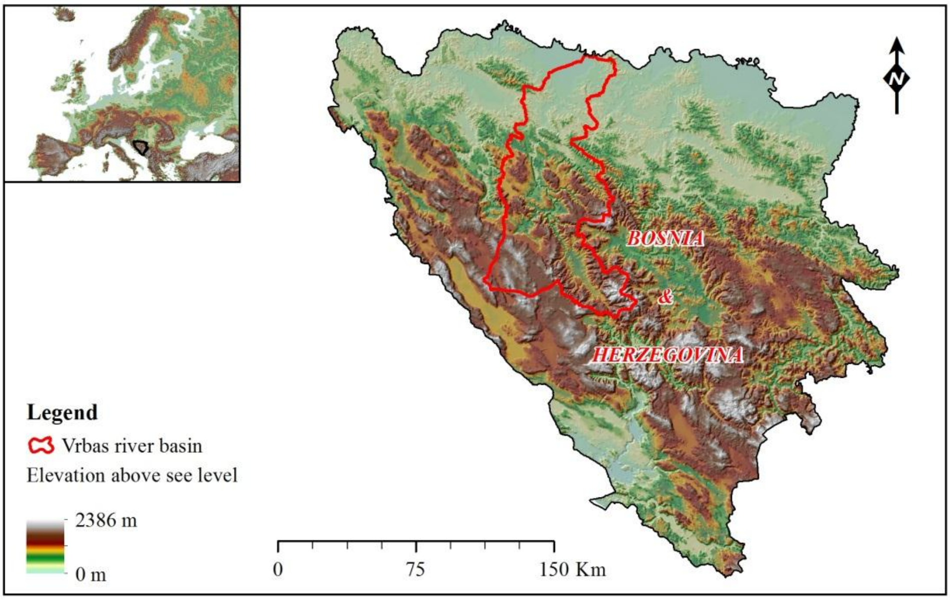

Fig. 1. Location of study area - Vrbas river basin

In the physical-geographical sense, the basin belongs to two morphotectonic units: Pannonian and mountain/valley. The first morphotectonic unit includes low depressions originating from tectonic activities and accumulation processes. The second morphotectonic unit, apart from the significant karst areas that are scattered around and divided by smaller isolated massifs and mountains, includes the Manjača massif in the central part, which covers an area of about 200 km^2. In the area between the mountains, there are tectonic depressions or valleys. The valleys are connected to the gorges and canyons cut into older and more resistant rocks that dominate this morphotectonic unit (Čičić, 2002; Hrvatović, 2006).

Geomorphologically view, the Vrbas river basin is a mountain - hilly relief, while in the geotectonic sense, it is a part of the western zone of young fold mountains (Dinaric mountain area) and the Pannonian depression. In geomorphological terms, the headwater of the Vrbas belongs to the main highest range of the Dinaric Mountains. The rest is mostly developed on the northeastern slope of the Dinaric Mountains. The lower part of the basin is on the edge of the Pannonian Basin and in its accumulative plain.

Data from 53 precipitations stations were analyzed for daily precipitation for the period 1950-2017, and the data from the Banja Luka, Bugojno and Jajce stations that are currently operating in the basin. This analysis concluded that the average precipitations in the Vrbas river basin are about 800 mm per year in the north, and about 1,500 mm per year in the south. The average potential evaporation is 700-750 mm, which in the summer months exceeds the precipitation. The average annual air temperatures are mostly conditioned by the altitude and geomorphological characteristics of the basin. In the Vrbas river basin they range from 10.8°C to 9.4°C in the area with temperate continental climate, and from 9°C to 6°C in the areas with sub-mountain and mountain climates.

The hydrographic network in the Vrbas river basin has a close and direct dependence on the geological structure of the land and the hydrogeological function of the rock masses. The complex river network of the basin has a number of minor and major tributaries. The main tributaries of the river Vrbas are on the left the Dragočaj, Crna Rijeka and Pliva rivers and on the right the Turjanica and Vrbanja rivers, and the Ina. In an average year with 1,050 mm of precipitations, the total precipitation volume is $6{,}704.3 \cdot 10^6$ m^3 and the total runoff is $4{,}062 \cdot 10^6$ m^3. This gives an average runoff coefficient for the entire basin of 0.60 and an average discharge of 128.8 m^3/s. Hydrological data (mean daily discharges) from 16 hydrological stations in the Vrbas river basin were analyzed for this research.

The soils of the Vrbas river basin belong to the order of automorphic and hydromorphic soils (Burlica & Vukorep, 1980). Across the vertical profile of the Vrbas river, from the confluence to the highest peaks, vegetation differs according to the ecological conditions of habitats, with different types of forest and grass ecosystems and agro ecosystems (Stefanović et al., 1983).

The general characteristic of agricultural land is that it is dominated by areas under the pastures in the mountainous area of the basin, and meadows in the areas of karst poljes and river valleys. The most important arable land is located along the watercourses. The main characteristic of the agricultural land are large areas of pastures and meadows that are located in the hilly and mountainous area. The exception is a smaller percentage of artificial and natural meadows in wetlands, which are fragmented across the basins of smaller watercourses. The area of the Vrbas river basin is dominated by forest vegetation. However, there are significant areas with other categories of land use.

Methodology

In recent time there are numerous methodologies and models for soil erosion mapping and developing erosion maps. Empirical models are more focused on modeling erosion and sediments transport at the basin scale. Therefore, when the aim of the research is the intensity of the erosion process and the sediment transport in a small area or a surface of a certain inclination, it is better to use physically based or conceptual methods. Empirical methods are more effective in determining the production and transport of sediments in a larger basin area because they show far greater precision and reliability in defining the final results (Merritt et al., 2003; Lenhart et al., 2005; Morgan, 2005; de Vente et al., 2005; 2006; Tošić et al., 2012a).

Tab. 1. Descriptive factors used in the EPM model (Lazarević, 1985).

Soil protection coefficient	**X**
Mixed and dense forest	0.05-0.20
Thin forest with grove	0.05-0.20
Coniferous forest with little grove, scarce bushes, bushy prairie	0.20-0.40
Damaged forest and bushes, pasture	0.40-0.60
Damaged pasture and cultivated land	0.60-0.80
Areas without vegetal cover	0.80-1.00
Soil erodibility coefficient	**Y**
Hard rock, erosion resistant	0.1-0.3
Rock with moderate erosion resistance	0.3-0.5
Weak rock, schistose, stabilized	0.5-0.6
Sediments, moraines, clay and other rock with little resistance	0.6-0.8
Fine sediments and soils without erosion resistance	0.8-1.0
Coefficient of type and extent of erosion	**Φ**
Little erosion on watershed	0.1-0.2
Erosion in waterways on 20–50% of the watershed area	0.3-0.5
Erosion in rivers, gullies and alluvial deposits, karstic erosion	0.6-0.7
50–80% of watershed area affected by surface erosion and landslides	0.8-0.9
Whole watershed affected by erosion	1.0

Mapping the intensity of erosion in the Vrbas river basin was carried out using the empirical methodology developed by S. Gavrilović (1962; 1972) and R. Lazarević (1985). The EPM method uses a scoring approach for three descriptive variables: soil protection coefficient (X), soil erodibility coefficient (Y) coefficient of type and extent of erosion (Φ) (Tab. 1). Watersheds with strong spatial variability in these descriptive factors should be divided in smaller and more homogenous sub-watersheds.

The basic EPM value of the quantitative erosion intensity is the erosion coefficient (Z). The soil erosion coefficient (Z) for erosion polygon can be estimated using corresponding tables (Tab. 2) or calculated from equation:

$$Z = Y \cdot X \cdot \left(\Phi + \sqrt{I_{sr}}\right)$$

In which, Y is the soil erodibility coefficient, X is soil protection coefficient, Φ is coefficient of type and extent of erosion, and I_{sr} is average slope steepness of the watersheds in angle. The quantitative values of the erosion coefficient (Z) have been used to separate erosion intensity to classes or categories.

Tab. 2. EPM erosion qualitative categorization and range of erosion coefficients (Z)

Erosion category	Qualitative name of erosion category	Range of erosion coefficient (Z)
I_3 - I_1	Excessive erosion	1.00 - 1.50 > 1.50
II_2 - II_1	Intensive erosion	0.71 - 1.00
III_2 - III_1	Medium erosion	0.41 - 0.70
IV_2 - IV_1	Slight erosion	0.21 - 0.40
V_2 - V_1	Very slight erosion	0.01 - 0.20

Source: Lazarević, 1985

According to Gavrilović (1972), the analytical equation for calculation of the average annual gross erosion W (m^3/year):

$$W_{year}=T \cdot H_{year} \cdot \pi \cdot \sqrt{Z^3} \cdot F$$

Where, W_{year} is the total annual erosion (m^3/year), T is the temperature coefficient:

$$T=\sqrt{\frac{t}{10}+0.1}$$

Where, t is average annual air temperatures (°C), H_{year} are the precipitations (mm), F is the watershed area (km^2), and Z is the erosion coefficient.

Gavrilović (1972) has suggested the following equation for determination of the sediment delivery ratio:

$$R_u=\frac{\sqrt{O \cdot D}}{0.2(L+10)}$$

Where, O is perimeter of watershed (km), D is average elevation of the watershed (km) and L is length of the watershed (km).

The annual watershed sediment yield (G) was calculated as:

$$G_{year} = W_{year} \cdot R_u$$

Described methodology for mapping soil erosion intensity is advanced by usage the geographic information systems (GIS). These methods and techniques can be recognized through several phases: (1) phase of collecting data on Map of erosion of Bosnia and Herzegovina from 1980s, (2) phase of collecting data, geo-referencing and preparation of topographic maps in 1:25,000 scale, digital orthographic and satellite images, (3) analytical phase of main physical geographic factors which determinate soil erosion intensity, (4) phase of field research mapping and determination of parameters, (5) phase of Map of erosion intensity creation and (6) phase that contains analysis of character and spatial distribution of erosion processes and calculation of amount of gross soil erosion and sediment yield for the Vrbas river basin. All data are organized in a Personal Geodatabase and presented as an attribute table with the following data: Object ID, Shape, Basin, Entity, Section_TK, Fi, I_mean, Z, Category, Erosion Strength, Area_F_km², Shape_length, Shape_area.

Results and Discussion

The first quantitative indicators of soil erosion intensity in the Vrbas river basin were presented in the Study "State, Problems and Contemporary Methods for the Erosion and Torrential Streams Control" in 1970. According to the data from this Study, from the total area of the Vrbas river basin, 5,400 km^2 was affected by erosion (Lazarev & Lubardić, 1969; 1970). The results presented in this Study did not arise from the mapping of erosion.

Quantitative indicators on the erosion state of the larger basins were published in the Erosion Map of the Republic of Bosnia and Herzegovina (1979-1985). According to this map, 5,634 km^2 of the Vrbas river basin was affected by erosion, while 625 km^2 was under sediment accumulation (Lazarević, 1985).

In this study, the intensity of erosion in the Vrbas river basin was mapped to a scale of 1:25,000. The following was determined: erosion coefficients (Z) for each erosion plot, erosion categories, mean gradients, erosion process strengths, and the mean erosion coefficient (Zm) for the total Vrbas river basin. The erosion map in the scale of 1:25,000 was plotted on a topographic map in the scale of 1:25,000, having a total of 69 topographic sections and 4,524 erosion polygons (plots).

Mapping and processing of data also defined erosion coefficients for certain categories. The coefficient for the category I_1 is 1.59, for I_2 is 1.3, for I_3 is 1.15, for II_2 is 0.76, for III_1 is 0.58, for III_2 is 0.46, for IV_1 is 0.34, for IV_2 is 0.25, for V_1 is 0.17, and for V_2 is 0.09.

According to the data of the coefficients and categories of erosion, the intensity of erosion processes in the Vrbas river basin has a moderate character; very poor erosion with mean erosion coefficient (Z_m) for the total basin of 0.18, which is V_1 category of the strength of erosion processes.

Tab. 3. Areas of erosion categories and erosion coefficients per category for the Vrbas river basin according to the Erosion Map of the Vrbas river basin in the scale of 1:25,000

Erosion category	**Intensity of erosion**	**Basin area F (km^2)**	**Z_m**
I_1	Excessive erosion	3.44	1.59
I_2	Excessive erosion	9.24	1.38
I_3	Excessive erosion	8.56	1.15
II_2	Strong erosion	5.56	0.76
III_1	Medium erosion	49.83	0.58
III_2	Medium erosion	187.60	0.46
IV_1	Low erosion	269.53	0.34
IV_2	Low erosion	428.50	0.25
V_1	Very low erosion	3,006.33	0.17
V_2	Very low erosion	1,698.27	0.09
Alluvium		621.71	
			Z_m= 0.18
		F_e =5,666.88	
		F_a =621.71	

In terms of defining the spatial distribution of the erosion intensity processes, it is evident that the dominant category is V (very low erosion) on 74.81% of the basin area.

Category IV (low erosion) is on 11.10% of the basin area, category III (medium erosion) is on 3.78%, category II (strong erosion) is on 0.09% of the basin area, category I (excessive erosion) is on 0.34%, while the process of sediment accumulation covers 9.89% of the total area of the Vrbas river basin (Fig. 2).

Erosion processes in the Vrbas river basin occur in the form of surface and linear erosion, weathering, chemical erosion and other forms of erosion processes. In river basins, washing processes are manifested in the form of washing and denudating rocks, while the processes of undermining occur in the form of linear shapes such as hairline cracking, cracks, gullies and ravines. Medium, low and very low erosion dominate in the Vrbas river basin in the territory of the Republika Srpska, or in its upper and middle part. This whole area is characterized by a population decrease caused by the war, but also little arable land. Areas that were once intensively cultivated today are abandoned fields. Agricultural production is preserved only in places that were not affected by the war (beyond the demarcation line), or in places where was significant return of displaced population. Low and very low erosion processes are present in large areas on the right side of the Vrbas between Jajce and Bugojno. Some areas, usually along the alluvial part or on the first river terrace, are covered with raspberry orchards. In the Rika basin, the erosion processes have reduced as a result of displacement of the population. The situation regarding erosion processes in the Oborovačka Rijeka basin is similar, although the demographic situation is somewhat better. The areas which are under stronger intensity of erosion processes are mainly arable areas and plots with raspberry plants. The right side of the valley from Bugojno to the river source of the Vrbas has no significant agricultural activity except for the raspberry orchards on the river terraces.

The erosion processes in this part of the basin are of medium, low and very low intensity. The state of erosion on the left valley side of the Vrbas in the same region is exactly the same as on the right side. Of course, it should not be forgotten that there are also large areas of forests and karst, which in terms of the strength of erosion processes fall into the category of very low erosion.

Changes in the intensity of erosion processes in this part of the Vrbas valley have a predominantly anthropogenic character. In areas that were dominated by strong and excessive erosion the intensity is now reduced to medium and low erosion. However, it must not be forgotten that in areas of past strong and excessive erosion, there are still preserved erosion forms, especially linear, along which, due to changes in some of the primary physical and geographical factors, erosion processes of high intensity can be rapidly activated.

Low, medium and strong erosion still dominate in the area around Čelinac and the suburbs of Banja Luka in the Vrbas river basin. This is due to anthropogenic impact. This part of the Vrbas river basin was not affected by the war. During the migration of the population in Bosnia and Herzegovina, some refugees and displaced persons settled here, which preserved and only partially modified the structure of land use. Stronger erosion processes are still present in the Jošavka basin which has all the characteristics of a torrential basin, as well as in the area of the Kruševica's river source.

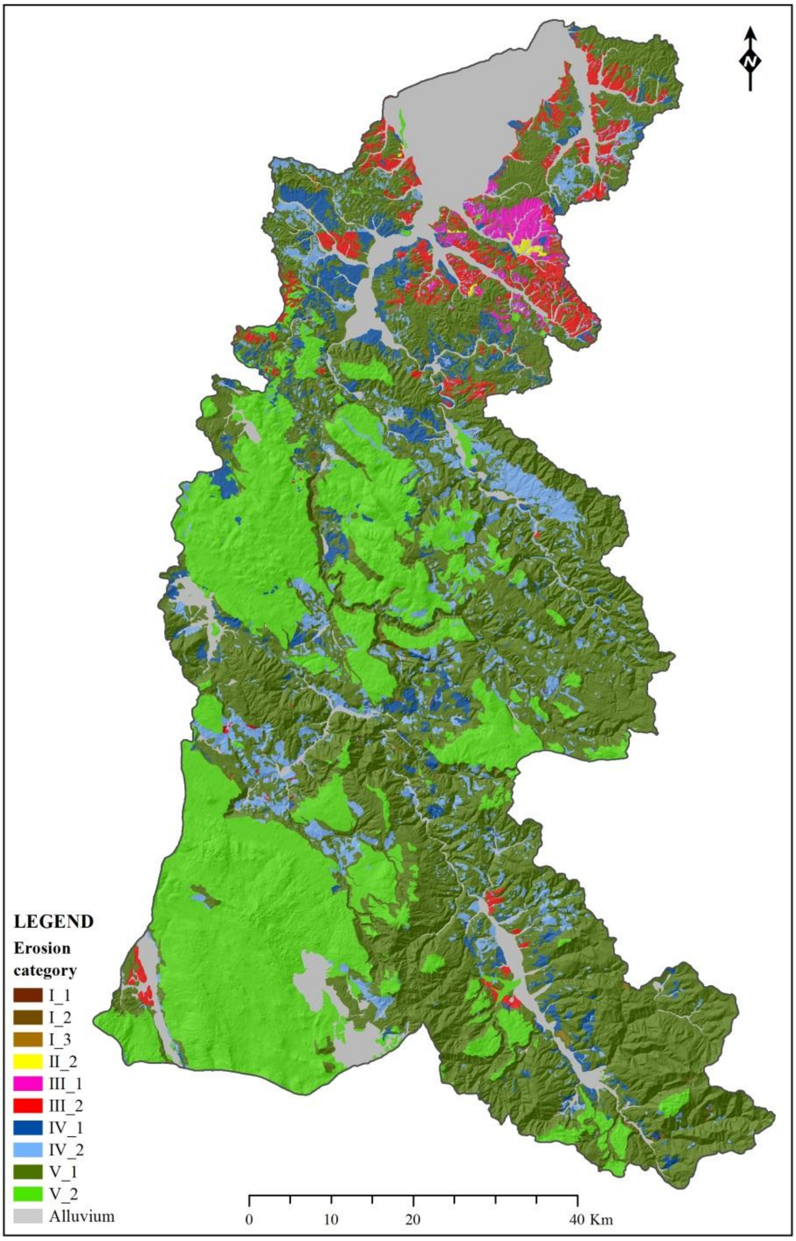

Fig. 2. Erosion map of the Vrbas river basin (overview map)

The part of the Vrbas river basin in the vicinity of Banja Luka is the most densely populated with the largest number of households. Because of this, a large area is under the influence of strong and medium erosion. In addition to this, there is some very low and low erosion. The land use in the Vrbas river basin around Banja Luka and in the direction of the Sana basin remained the same. In the areas near the Entity line, which was a demarcation area during the war, there have been significant changes in the intensity of erosion processes. Arable areas that were affected by medium and strong erosion are today under the influence of weak and very weak erosion because agricultural production ceased.

Mapping erosion in the Turjanica basin indicates that erosion processes have a moderate character of low erosion, but it is also possible to determine the functional dependence of the primary erosion factors and the intensity of erosion processes. Overall, erosion processes in the Turjanica basin consist of low surface and linear erosion with areas where sediments accumulate. The presence of phytogenic erosion was noted during the mapping, particularly in those areas which are heavily tilled and which have larger inclination of the ground surface.

The lower part of the Vrbas river basin, i.e. its valley sides, has relatively well-preserved structure of land use (agriculture), since this area was not directly affected by the war. Erosion processes in this area are of strong, medium, low and very low intensity. Erosion plots (crop fields) often retained stronger erosion process on drainage divides and infrequently on the valley sides. The land no longer dominated by agricultural production has converted into meadows and pastures, and, in some places, abandoned fields have been slowly overgrown by vegetation. This state of erosion was recorded in the following basins: Povelič, Husrpovačka Rijeka, Crkvena, Osorna, Borna, etc.

Overall, erosion processes in the Vrbas river basin are diminishing, especially in the parts of the basin where agricultural production ceased and where there has been population and household decrease (upper and middle part of the basin). However, in the areas that used to be dominated by strong or excessive erosion, although the intensity of erosion processes lessened, there are still linear erosion forms which can become places of pronounced sediment production only by a change of one primary factor of erosion processes.

The general estimate is that the present state of erosion processes in some parts of the basin is more favorable, primarily due to emigration from mountainous areas, which reduces anthropogenic impact on the environment. This led to the restoration of vegetation, but only on those areas on which the productive soil layer was not destroyed.

However, in some parts of the Vrbas river basin (mountain areas) where logging was carried out in an ecologically unacceptable way, the situation worsened. The damage caused by the uncontrolled logging in places close to the former demarcation lines that were not mined, but also in the vicinity of settlements, resulted in further degradation and devastation of forests. The unplanned logging and fires that often occurred due to negligence wiped away huge forest complexes, which weakened their protective function from erosion. This increased the intensity of erosion processes, the production of sediments and their transport through rivers to the lower local base levels.

According to Gavrilović (1972) analytical equation for calculation of the average annual gross erosion and sediment yield, annual gross erosion in the Vrbas river basin is 1,223,989.60 m^3/year, and sediment yield is 366,088.10 m^3/year.

Conclusion

The first task in this research was to create a map of the intensity of erosion in the Vrbas river basin. Erosion Map of the Vrbas river basin was made in the scale of 1:25,000 using topographic maps (TK_25). This Erosion Map counts a total of 69 topographic sections and 4,524 erosion polygons (plots). According to the Erosion Map, 5,666.88 km² of the Vrbas river basin are affected by erosion, while 621.71 km² are accumulating sediments.

According to the Erosion Map of the Vrbas river basin we can conclude that soil erosion process diminishes, especially in the parts of the basin where agricultural production ceased and where there has been population and household decrease. However, in the areas that used to be dominated by strong or excessive erosion, although the intensity of erosion processes lessened, there are still linear erosion forms which can become places of pronounced sediment production only by a change of one primary factor of erosion processes.

Mapping erosion has one vital goal – getting knowledge and information on how much land is endangered with erosion. Using cartographical representation of intensity of soil erosion it is plausible to notice intensity of erosion process, to identify character of erosion process and to define relevant protective measures as well as measures for restoration of degraded soil. Mapping intensity of soil erosion is very important for agriculture, water management, environmental protection, spatial planning and other human activities.

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ПРОЦЈЕНА ЕРОЗИЈЕ ЗЕМЉИШТА И ТРАНСПОРТА НАНОСА КОРИШЋЕЊЕМ МЕТОДА ПОТЕНЦИЈАЛА ЕРОЗИЈЕ: СТУДИЈА СЛУЧАЈА – СЛИВ РИЈЕКЕ ВРБАС (БИХ)

Резиме: Ерозија је један од најзначајнијих облика деградације земљишта у Босни и Херцеговини. Картирање интензитета механичке водне ерозије на територији Босне и Херцеговине није у потпуности спроведено већ тридесетак година. Стога се наметнула потреба за картирањем појединих физичко-географских цјелина, као што је то случај и са сливом ријеке Врбас, а у којем су новонастале физичко-географске и социоекономске промјене имале знатан одраз на интензитет ерозионих процеса. У раду је анализирано и приказано стање ерозије земљишта у сливу ријеке Врбас, на основу новоизвршеног теренског картирања ерозије у размјери 1:25.000. При анализи је коришћења Метода потенцијала ерозије (ЕПМ) уз помоћ које је процијењена годишња продукција и транспорт наноса у поменутом сливу. Добијени резултати могу се користити у области просторног и урбанистичког планирања, управљања водама и земљиштем, како на локалном, тако и на регионалном нивоу.