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DETERMINATION OF EROSION INTENSITY IN BRKA WATERSHED, BOSNIA AND HERZEGOVINA

SUMMARY

The Bosnia and Herzegovina (BiH) erosion map was made in 1985, however, over a period of 35 years, there has been a substantial change in the values of most erosion factors, resulting in the change of the erosion intensity. Changes relate to demographics, urbanization and land use as well as climate. The increase in temperature and the occurrence of extremes caused significant environmental and economic consequences (May 2014 floods). This situation is more pronounced in the northern part of the country, especially in the lower parts of the larger basins. Risk assessment procedures using modern software and hardware solutions can help decision-makers to recognize sites where forest should not be cut down, certain crops should not be grown or soil conversation measures are necessary. Therefore, the aim of this research is to estimate the intensity of erosion processes in one such watershed in BiH - the Brka watershed, taking into consideration current conditions and using modern hardware and software solutions. To calculate erosion intensity the Gavrilovic method supported with GIS techniques was used. The soil protection (x), soil erodibility (y) and type and extent of erosion (ϕ) coefficients were calculated using digital maps: CORINE 2018 (grid size 100 m x 100 m) land cover, soil map of BiH and open-source satellite images. The slope was calculated from the BiH digital elevation model (25 m x 25 m). The Brka watershed area (184.09 km^2) was divided into four basins: Maočka Rijeka (51.56 km^2), Rahička Rijeka (24.26 km^2), Zovičica (75.30 km^2) and direct basin of Brka (32.94 km^2). The highest average erosion intensity was determined for Zovičica basin, where Z=0.56. The calculated mean annual production of sediment per basin varies from 5,746 for Rahička Rijeka to 57,089 m^3 year^{-1} for Zovičica, with total Brka river watershed sediment yield of 120,754 m^3 year^{-1}.

Keywords: Gavrilovic method; Erosion intensity; Brka watershed; CORINE; GIS

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INTRODUCTION

Soil erosion has been considered as the primary cause of soil degradation and loss. Lately, erosion has become a growing problem when it comes to environmental and biodiversity protection in the Balkans (Spalevic et al., 2015). In Bosnia and Herzegovina (BiH), soil erosion intensifies with the negative effects of man from the time of the ancient Illyrians, Romans, Slavs, etc. to this day. Logging and burning of forests and converting these areas to arable land resulted in the occurrence of excessive soil erosion (Šarić et al., 1999). Soil water erosion is one of the most important causes of soil degradation in BiH, this is especially true for agricultural land and smallholder farms that are often located in marginal areas, where the soil quality is poor and the topography is complexed (J. Žurovec et al., 2017a). With its complex relief, geological and pedological structure, hydrography, precipitation regime and land use, BiH is highly vulnerable to destructive processes of erosion and floods, especially in the northern part of the country (Čadro et al., 2019; O. Žurovec et al., 2017b). According to Lazarević (1985b), as much as 83% of the total area of BiH is threatened by water erosion.

When it comes to the analysis of erosion processes in BiH in addition to local surveys at the parcel level (J. Žurovec & Čadro, 2008; J. Žurovec et al., 2017a) the Gavrilovic method (Gavrilović, 1972) was used to map and analyze erosion at the larger-areas. An erosion map of the FR of Bosnia and Herzegovina was made in the period 1980-1985 (Lazarević, 1985b). Recently, in 2012 an erosion map of the Entity Republika Srpska in scale 1:25,000 (Radislav Tošić et al., 2012a; Radislav Tošić et al., 2012b) was made as well as in 2018 the erosion map of the Vrbas River Basin at a scale of 1:25,000 (Lovrić & Tošić, 2018).

Latterly, there has been a substantial change in the values of most erosion factors, resulting in the change of erosion intensity. Changes relate to demographics, urbanization and land use as well as climate (Čadro et al., 2018; Čadro et al., 2019; Popov et al., 2018; Trbic et al., 2017; O. Žurovec et al., 2017b). The increase in temperature and the occurrence of extremes caused significant environmental and economic consequences (May 2014 floods). This situation is more pronounced in the northern part of the country, especially in the lower parts of the larger watersheds.

A map of the spatial distribution of the intensity of erosion processes should be the first step towards a better understanding of the situation in an area of a basin, as well as a more realistic view of the risks of natural disasters, especially erosion, floods and landslides. Such a map is essentially a measure for disaster risk reduction (DRR), a systematic approach to identifying, assessing and reducing the risks of disaster (Jamieson, 2016).

Therefore, the main objective of this study was to analyze the basic soil erosion factors and estimate the intensity of erosion processes in the River Brka watershed, taking into consideration current conditions and using modern hardware and software solutions.

MATERIAL AND METHODS

Study area and data collection

The Brka River Basin is located in the northeast of BiH, it covers the northern slopes of mountain Majevica and part of the Bosnian Posavina (Figure 1). The total watershed area is about 184.09 km^2. The highest point is the Okresanica peak, 815 meters above sea level, while the lowest point is the delta of the Brka River at 84 meters above sea level. Most of the watershed area is located within the Brcko District, and only a small part to the south is in the Federation of Bosnia and Herzegovina (FBiH), the municipalities of Srebrenik and Čelić.

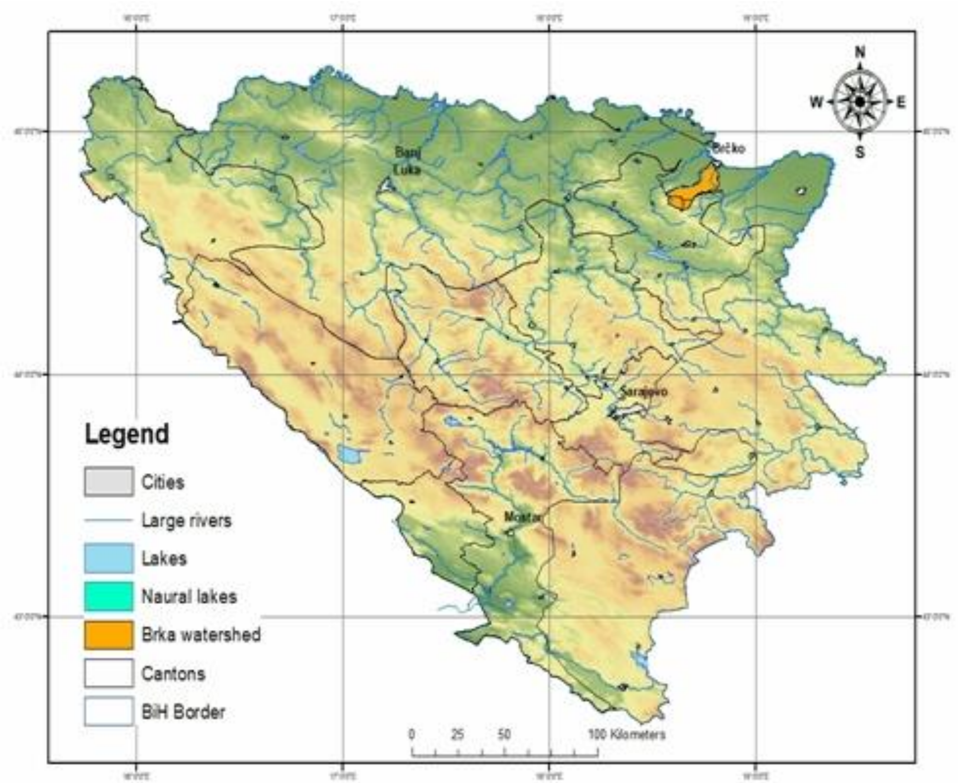

Figure 1. Geographical location, a digital elevation map of Bosnia and Herzegovina and location of Brka River watershed.

The Brka watershed belongs to the temperate continental climate zone. The characteristics of this climate are quite cold winters and warm summers. The average air temperature is 11.12^{o}C and the average precipitation is 780 mm (Table 1). In the south, due to the increase in altitude, average temperatures are decreasing and precipitation is increasing (Majstorović, 2000).

This is an area of great potential for the development of the economy, due to favorable population density, significant areas of arable land, developed road infrastructure and favorable position towards the three major regional centers, Belgrade, Zagreb and Sarajevo (Čardaklija, 2015; Smajlović, 2014).

Table 1. Average monthly climatic parameters from the Brčko weather station, period 1961 – 1990.

BRČKO	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Ann.
T_{max} [1]	2.8	6.3	12.0	17.5	22.5	25.4	27.5	27.4	23.5	17.8	10.4	5.2	16.52
T_{mean} [2]	-0.5	2.3	6.5	11.6	16.4	19.7	21.3	20.6	16.8	11.4	5.8	1.5	11.12
T_{min} [3]	-4.0	-1.7	1.3	5.9	10.2	13.5	14.5	13.7	10.6	5.9	1.9	-1.7	5.83
RH_{mean} [4]	86	83	77	73	73	74	72	75	77	79	83	86	78
$u_{(2)}$ [5]	1.49	1.42	1.80	2.00	1.80	1.52	1.67	1.55	1.39	1.38	1.42	1.47	1.57
PRCP[6]	53	50	56	67	76	95	73	70	55	47	70	69	780

[1] T_{max} – Maximum average air temperature; [2] T_{min} – Minimum average air temperature; [3] T_{mean} – Average air temperature; [4] RH_{mean} – Average relative humidity in %; [5] $u_{(2)}$ – Average wind speed in m s^{-1}; [6] PRCP – Average sum of precipitation in mm.

Erosion intensity calculation method

In this research, the Gavrilovic method (Gavrilović, 1972) also known as the Erosion potential method (EPM) modified according to Lazarević (1985a) and adapted for use in the geographical information system environment - GIS (N. Dragičević et al., 2013; Mustafić, 2012; Radislav Tošić & Dragićević, 2012) was used to create maps and calculate erosion intensity (Z), mean annual production of sediment (Wyear) and basin sediment yield (Gyear).

The Gavrilovic method has been used for over 40 years, both in our country (Lazarević, 1985b; Lovrić & Tošić, 2018; Radislav Tošić et al., 2012a; Radislav Tošić et al., 2012b; Radoslav Tošić et al., 2019) and in the countries of the region Serbia (Dragićević et al., 2009; Kostadinov et al., 2012; Mustafić, 2012), Montenegro (Spalevic et al., 2017; Spalević et al., 2012), Croatia (Nevena Dragičević et al., 2016; Globevnik et al., 2003), Slovenia (Globevnik et al., 1998), Macedonia (Milevski et al., 2008), as well as around the world Italy (Ballio et al., 2010), Iran (Deilami et al., 2012; Spalević et al., 2016), Iraq (Ali et al., 2016), Chile (Kayimierski et al., 2013).

The soil erosion coefficient, or erosion intensity (Z) was calculated using the analytical method with following equation:

$$Z = Y \times X \times (\varphi + \sqrt{Jsr}) \tag{1}$$

Where:

Y - Coefficient of the resistance of the land to erosion (soil erodibility)

X-Coefficient of the protection of the land from the atmospheric impact, vegetation protection coefficient

φ - Coefficient of the type of erosion

$\sqrt{Jsr}$ -Average slope (inclination) in %

The quantitative values of the erosion coefficient (Z) have been used to separate erosion intensity to 5 classes: Excessive erosion (I), Z > 1.00; Intensive erosion, Z=0.71-1.00; Medium erosion (III), Z=0.41-0.70; Slight erosion (IV), Z=0.21-0.40; Very slight erosion (V). Z=0.01-0.20 (Lazarević, 1985a).
To calculate mean annual production of sediment per basin - W_{year} (m^3 $year^{-1}$) the following equations ware used:

$$T = \sqrt{\frac{t}{10} + 0.1} \tag{2}$$

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

Where:
T Temperature coefficient ($^{\circ}$C)
t Mean annual air temperature ($^{\circ}$C)
H_{year} Mean annual sum of precipitation (mm)
F Area of the basin (km^2)

Multiplying the mean annual production of sediment per basin (W_{year}) with Coefficient of the retention of sediment (R_u) we calculated the mean annual volume of suspended and transported sediment per basin, or the basin sediment yield – G_{year} (m^{-3} $year^{-1}$). To do so the following equations were applied:

$$D_d = \frac{I_p + I_a}{F} = \frac{L}{F} \tag{4}$$

$$R_u = \frac{\sqrt{O \cdot D}}{(I_p + 10)} \cdot D_d \tag{5}$$

$$G_{year} = W_{year} \cdot R_u \tag{6}$$

Where:
R_u Coefficient of the retention of sediment
O Basin perimeter (km)
D Average elevation difference of the basin (km)
I_p Length of the main watercourse (km)
D_d Density of the river network per basin (km km^{-2})
L Total length of basin watercourse (km)
I_a Length of the secondary watercourse (km)

The boundary of the basin area was determined using Digital terrain model (DEM: 25 m x 25 m) and Hydrographic network map of BiH; the soil protection coefficient (X) from CORINE 2018 (grid size 100 m x 100 m) land cover map based on the X values proposed by Globevnik et al. (2003). Soil erodibility (Y) was determined on the basis of the BiH soil map (scale 1: 50,000), while for the determination of type and extent of erosion (ϕ) coefficients open-source satellite images were used.

Esri® ArGIS 10.2.1 software was used to determine all required elements of the basin ($\sqrt{Jsr}$, F, O, D, I_p, D_d, L and I_a). The raster calculator tool was used to create Z and W_{year} maps.

Also, climate data from the Brčko weather station (period 1961 – 1990) was used to analyze the climatic conditions as well as the calculation of certain parameters within the EMP methods (T and H_{year}).

RESULTS AND DISCUSSION

Basic characteristics of the watershed and soil erosion factors

The Brka River watershed has an elongated shape and is characterized by a very small proportion of left tributaries, with almost all tributaries located on the right side of the Brka River. The total area of the Brka River watershed is 184.09 km^2. However, for precise observation of the basic watershed characteristics as well as a more accurate calculation of erosion intensity (Z), the watershed area is divided into 4 separate sub-basins (Figure 2):

- •Maočka River basin (51.57 km^2),
- •Rahička River basin (24.27 km^2),
- •Zovičica basin (75.31 km^2), and
- •Direct basin of the Brka river (32.95 km^2)

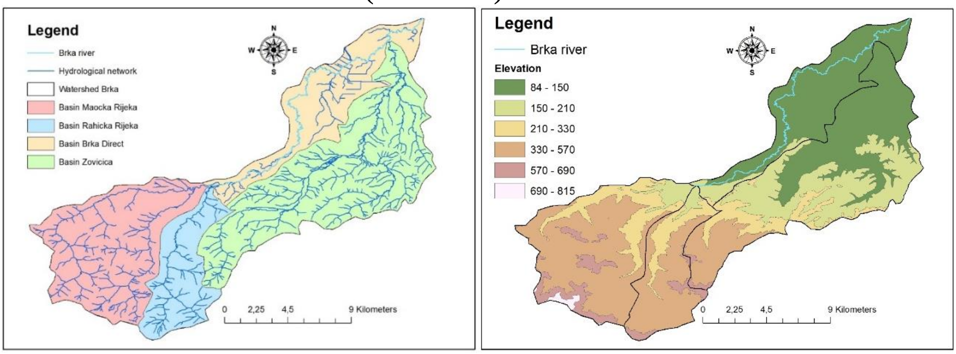

Figure 2. (a) Hydrological network and spatial distribution of the four Brka sub-basins; (b) Elevation map of Brka watershed.

The largest area is occupied by the Zovičica river basin, with about 41% of the total area, while the Rahička river basin occupies the smallest area or about 13% of the total watershed.

The direction of fall of the Brka River basin is southwest-northeast, which is the result of higher altitudes in the south (814 m.a.s.l.) that is, in the area of the Majevica Mountain and on the other side, low altitudes (84 m.a.s.l.) of the Posavina valleys in the north (Figure 2). The average basin elevation is 276 m, with an almost equal proportion of lowlands with elevations up to 150 m (33%) and elevations ranging from 330 to 570 m (31%). Less than 5% of the watershed area is located at an altitude of more than 570 m (Table 2).

Table 2. Share of different elevation categories for the Brka watershed.

Elevation (m)	Area (km^2)	Area (%)
84 - 150	61.04	33.15
150 – 210	32.81	17.82
210 – 330	23.21	12.61
330 - 570	57.89	31.44
570 - 690	8.31	4.51
690 – 814	0.88	0.48
84 - 814	184.09	100.00

An overview of the basic spatial and hydrological characteristics required for the EPM method calculation for the 4 defined sub-basins of the Brka River is given in Table 3.

Table 3. The river Brka sub-basin spatial and hydrological characteristics.

Sub-basin	F[1] (km^2)	O (km)	D_{max} (km)	D_{min} (km)	D (km)	l_p (km)	l_a (km)	L (km)	D_d (km km^{-2})	R_u
Maočka R.	51.57	34.15	0.81	0.15	0.66	12.48	97.26	109.74	2.12	0.45
Rahička R.	24.27	28.42	0.69	0.15	0.54	13.93	37.97	51.90	2.13	0.35
Zovičica	75.31	53.53	0.69	0.08	0.61	24.39	185.08	209.47	2.78	0.46
Brka direct	32.95	44.34	0.27	0.08	0.18	26.57	48.45	75.03	2.27	0.18
Brka	184.09	77.39	0.81	0.08	0.73	26.57	419.58	446.15	2.42	0.49

[1] F – Area; O – Perimeter; D_{max} – Maximum elevation; D_{min} – Minimum elevation; D – Average elevation difference; l_p – Length of the main watercourse; la – Length of the secondary watercourse, L - Total length of basin watercourse; D_d - Density of the river network per basin; R_u - Coefficient of the retention of sediment

The individual sub-basins are quite different, this is especially true for the Zovičica river basin, which occupies the largest surface area. The main watercourse, the river Brka is 26.57 km long. The Zovičica River is similar in length (24.39 km), however, the total length of its tributaries is more than 3 times greater. Also, the difference between the lowest and highest points of the Brka River is only 185 m, unlike the Maočka River where this difference is 661 m or Zovičica where it is 611 m. This situation results in high river network density (D_d) as well as a significant retention coefficient (R_u), which is especially true of the Zovičica River basin area.When it comes to soil type, the Dystric Kambisol occupies the largest area of the Brka watershed (Table 4). In most cases, this soil is covered with forest, but due to its favorable properties it is often used as agricultural land (Miljković, 2005; Resulović et al., 2008). Most of the areas under this type of soil are located in the southern part of the basin, respectively within the sub-basins of the Maočka and Rahiča rivers.

Table 4. Share of different soil types in the Brka watershed

Soil type, BiH Nacional classification	Area (km^2)	Area (%)
Dystric Kambisol	68.11	36.99
Pseudogley	52.53	28.53
Luvisol	29.75	16.16
Eutric Kambisol	17.46	9.48
Humofluvisol	13.06	7.09
Fluvisol	1.98	1.08
Eugley	1.25	0.68

Pseudogley and Luvisol are in second and third place, respectively. These are heavy soils, with poor permeability and high erodibility (Dugalić & Gajić, 2012; Resulović et al., 2008). These soils are very susceptible to erosion, especially if located on slopes greater than 12% (J. Žurovec, 2012). It is very important to note that these soils occupy 82 km^2 or 45% of the Brka watershed. They are mainly located in the north part of the basin, at altitudes less than 330 m.Based on the land use, the watershed can be divided into three zones, an urban zone in the far north that includes the city of Brčko itself, then an agricultural zone located in the middle part of the watershed, ie along the river Brka itself and within the Zovičica river basin. The third zone, the forest zone, is located in the south of the basin, that is, on the slopes of mountain Majevica, or sub-basins Maočka and Rahička Rijeka (Table 5).

Table 5. Share of different CORINE land use classes in the Brka watershed.

Land use classes	Area (km^2)	Area (%)
Discontinuous urban fabric	9.94	5.40
Industrial or commercial units	0.30	0.16
Non-irrigated arable land	19.54	10.61
Fruit trees and berry plantations	2.76	1.50
Complex cultivation patterns	42.83	23.36
Land principally occupied by agriculture	17.18	9.33
Broad-leaved forest	89.22	48.45
Mixed forest	0.43	0.24
Transitional woodland-shrub	1.91	1.04
Water courses	0.03	0.02

Nearly half (49%) of the watershed area is covered by forest vegetation, dominated by the broad-leaved forests. Agricultural production takes place at 82 km^2.Based on mentioned soil erosion factors in the Brka watershed, first, the individual land use and soil type categories were assigned with the values of the coefficients X and Y, then their spatial distribution was created in Esri® ArGIS

10.2.1 software (Figure 3). In this process, using the DEM and open-source satiate images, a slope map, as well as an ϕ map, were created (Figure 3).

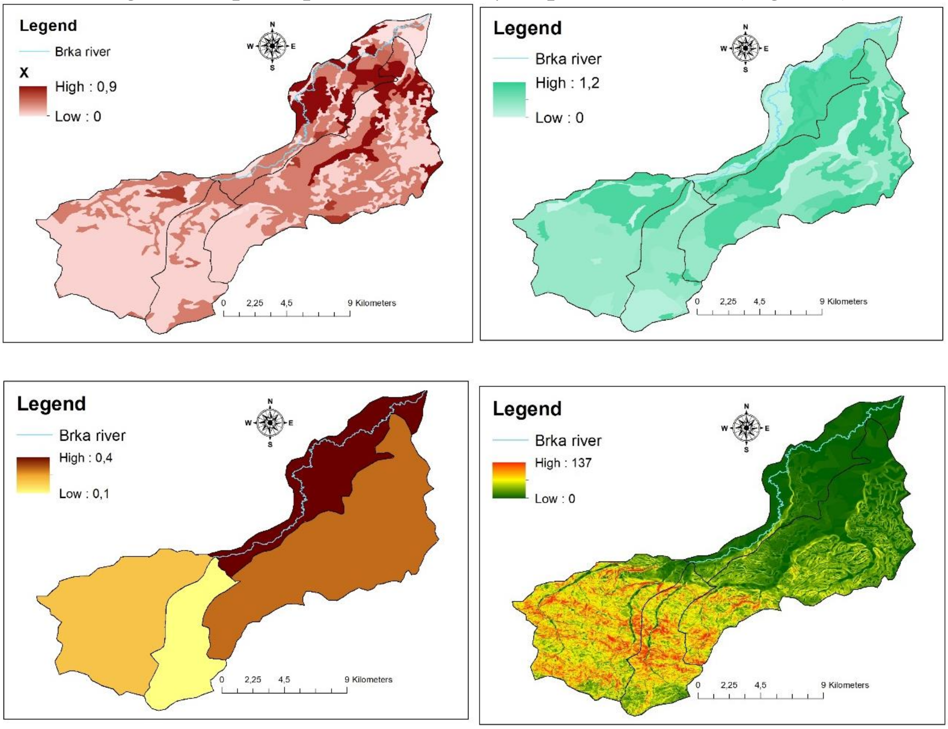

Figure 3. (a) Map of vegetation protection coefficient X; (b) Map of the resistance of the land to erosion, coefficient Y; (c) Map of the type of erosion coefficient ϕ; (d) Slope map

Based on the erosion categories 16.68% of the territory is affected by excessive erosion, 7.24% by intensive erosion, 7.31% by medium erosion, 12.66% by slight erosion, 48.85% by very slight erosion, and 7.72% has no erosion (Table 6).

Table 6. Share of erosion intensity categories in the Brka watershed.

Erosion category	Intensity of erosion	Basin area (km^2)	Percentage of the basin area (%)
-	No erosion	13.37	7.27
V2 - V1	Very slight erosion	89.85	48.85
IV2 - IV1	Slight erosion	23.29	12.66
III2 - III1	Medium erosion	13.44	7.31
II2 - II1	Intensive erosion	13.68	7.24
I3 - I1	Excessive erosion	30.68	16.68

In this way, all the maps necessary for the calculation (Equation 1) and spatial representation of the erosion intensity (Z) were obtained. The next step was use of the Raster calculator tool to calculate and create erosion intensity (Z) map of Brka watershed as shown in Figure 4.

The spatial distribution of erosion intensity (Figure 4) shows the highest intensity of erosion in the central part of the watershed. Although the upper part of the watershed has a higher slope, most of these areas are covered with forests, which very well protects the soil from erosion. This is not the case in the central and lower parts of the watershed, which are characterized by smaller slopes, but where intensive agricultural production is carried out on soils with poor water-physical characteristics. This means that soil characteristics and land use have a dominant influence on the intensity of erosion processes in the Brka watershed.

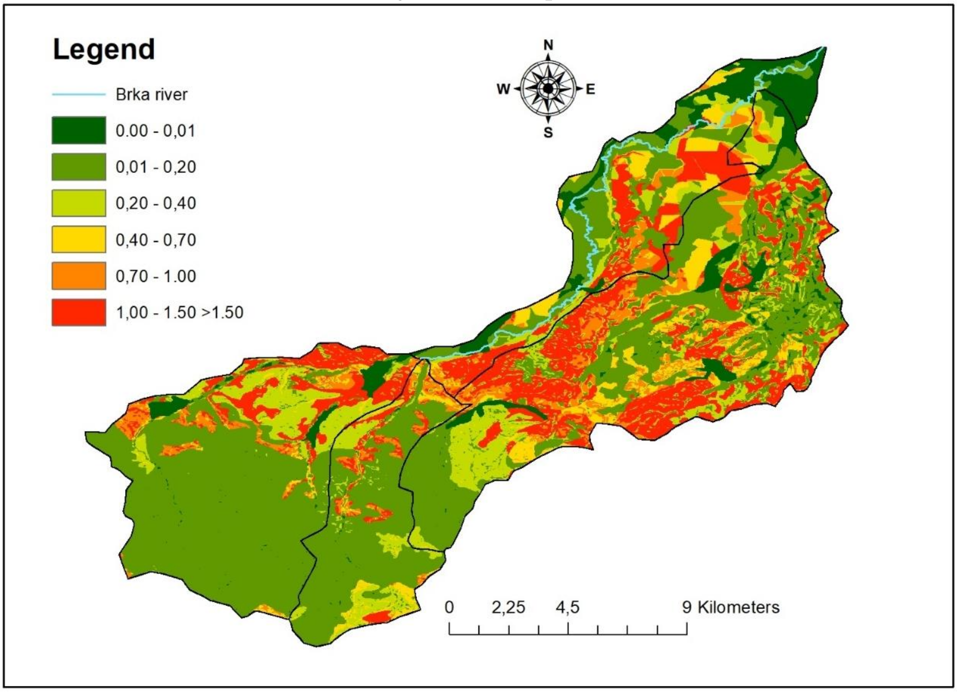

Figure 4. Erosion intensity (Z) map of the Brka watershed area

According to the results, the intensity of the erosion process in Brka watershed has a medium erosion character, with an average erosion coefficient of Z=0.46 (Table 7). In comparison, the average value of Z for the Vrbas basin is much smaller Z=0.18 (Lovrić & Tošić, 2018), as well as most of the other watersheds in BiH entity Republic of Srpska: Bosna Z=0.20; Drina=0.45; Sana=0.15 (Radislav Tošić et al., 2012a). This indicates the pronounced erosion processes in the Brka watershed. This is especially true for the Zovičica River sub-basin (Z=0.56) and the Brka River direct basin (Z=0.46). This situation is probably the result of the high prevalence of high erodibility soils (Pseudogley and Luvisol) that are mostly used for agricultural production.

Table 7. Summary of Gavrilovic method results for Brka watershed.

Sub-basin	Z[1]	Intensity of erosion	W_{year} (m^3 $year^{-1}$)	W_{year} (m^3 $year^{-1}$ km^{-2})	G_{year} (m^3 $year^{-1}$)
Maočka Rijeka	0.39	Slight erosion	58,810	1,140	26,442
Rahička Rijeka	0.29	Slight erosion	16,331	672	5,746
Zovičica	0.56	Medium erosion	123,459	1,639	57,089
Brka direct	0.46	Medium erosion	43,820	1,329	7,818
Brka	0.46	Medium erosion	242,421	1,316	120,754

[1] Z – Erosion intensity; W_{year} – mean annual production of sediment; G_{year} - basin sediment yield

The mean annual production of sediment per km^2 (W_{year}) varied between 672 and 1639 m^3 $year^{-1}$ km^{-2}. The calculated mean annual sediment yield (G_{year}) varies from 5,746 for Rahička Rijeka to 57,089 m^3 $year^{-1}$ for Zovičica, with total Brka river watershed sediment yield of 120,754 m^3 $year^{-1}$.

CONCLUSIONS

The average Z value of 0.46 (medium erosion intensity), 43.89% of the territory threatened by water erosion, and 16.68% affected by excessive erosion indicates that at the Brka watershed certain soil conservation measures are more than necessary.The upper part of the watershed is covered with forest vegetation and therefore well protected from erosion processes. This is especially true for the sub-basins of the Maočka and Rahička rivers. Most of the agricultural production in this watershed takes place in the central part of the basin. However, this production takes place on soils with poor water-physical characteristics (Pseudogley and Luvisol). Since land use is an erosion factor that humans can control, it is necessary to act in this direction and prevent erosion conducting agro-technical and biological soil conservation measures.

In these circumstances, the cultivated soil should not be left bare - not sown at any cost, especially when it is plowed in the direction of the slope. Additionally, special attention should be paid to the length of parcels located on higher slopes. Contour soil cultivation and contour sowing/planting are recommended whenever the size and shape of the plot allow it.

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