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ASSESSMENT OF THE SOIL LOSS CAUSED BY RIVERBANK EROSION IN SERBIA

Abstract: Riverbank erosion and lateral channel migration are important geomorphological processes which cause various landscape, socio-economic, and environmental consequences. Although those processes are present on the territory of Serbia, there is no available data about the soil loss caused by riverbank erosion for the entire country. In this study, the spatial and temporal dynamics of the riverbank erosion for the largest internal rivers in Serbia (Velika Morava, Zapadna Morava, Južna Morava, Pek, Mlava, Veliki Timok, Kolubara) was assessed using remote sensing and GIS. The aim of this paper is to determine the total and average soil loss over large-scale periods (1923-2020), comparing data from the available sources (aerial photographs, satellite images, and different scale paper maps). Results indicated that lateral migration caused significant problems through land loss (approximately 2,561 ha), especially arable land, and land use changes in river basins, but also economic loss due to the reduction of agricultural production. Total and average soil loss was calculated for five most representative meanders on all studied rivers, and on the basis of the obtained values, certain regularities about further development and dynamics of riverbank movement are presented. A better understanding of river channel migration in this area will be of a great importance for practical issues such as predicting channel migration rates for river engineering and planning purposes, soil and water management and land use changes, environment protection.

Key words: riverbank erosion, lateral channel migration, meanders, soil loss, Serbia

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Introduction

Riverbank erosion has become a common phenomenon and one of the major natural hazards in world. Every year this process directly or indirectly affects millions of people destroying natural and anthropogenic resources, agricultural lands, road networks, households, etc. (Tripathy & Mondal, 2019). The processes of riverbank erosion on the one and the accumulation of eroded material on the other side are the constituent elements or phases of the manifestation of the lateral channel migration. Alluvial plains are modified and different fluvial shapes are formed, such as eroded banks, cut-off meanders, and point bars. Many researches (Rusnak & Lehotske, 2014; Bertalan et al., 2018; Sylvester et al., 2019; Kiss et al., 2019) indicated that bank erosion is a very complex process with the interaction of numerous factors which can determine changes in the river course, bank erosion intensity, sediment regime, environment transformation, and land use changes (geological, climatological, hydrological, biogeographical, and anthropogenic factors).

Bank erosion process is an important component of channel evolution of river systems (Macfall et al., 2014). In addition, lateral channel migration is responsible for extensive destruction of arable lands and usually threatens human environment, especially agricultural areas (Bertalan et al., 2018). In general, consequences, caused by the processes of lateral channel migration and riverbank erosion, can be categorized into four groups: socio-economic (land loss and land use changes, impact on population, settlements and economic activities), natural (changes of different hydrological indicators and vegetation cover), ecological (impact on habitats) (Langović, 2020), geopolitical (when the meandering river represents the state border) (Dragićević et al., 2013; Palmer et al., 2014). Land loss due riverbank erosion is permanent, so the effect of this process is more significant (Yousefi et al., 2017). According to that, several scientific and practical studies, in which process of riverbank erosion is examined, has special emphasis on the economic consequences caused by soil loss (Dragicevic et al., 2012, 2013, 2017b; Baki, 2014; Das et al., 2014; Dekaraja & Mahanta, 2021). Productive and agricultural land on the concave part of the bank has been eroded, while on the other hand, the formed land on the point bars is mostly covered by bushy or woody vegetation, with no significance for agriculture development.

Lateral channel migration and bank erosion are the most important geomorphological processes of the alluvial plains in the southern part of the Pannonian Basin and its southern rim (Blanka & Kiss 2011; Zaharia et al., 2011; Floriou, 2011; Roksandić et al., 2011; Dragićević et al., 2012, 2013, 2015; Tošić et al., 2014; Lovrić & Tošić, 2016; Bertalan et al., 2019). In accordance, on the territory of Serbia, bank erosion is singled out as a very dynamic and intensive fluvial process, which has a significant impact on the various aspects of society, economy, and environment (Langović, 2020). Determination of the riverbank erosion rates and their impact on the surrounding area does not have a broad research past on the territory of Serbia. Therefore, the consequences of this process have not been studied for the entire territory of Serbia. However, it is possible to single out scientific papers (Roksandic et al., 2011; Dragićević et al., 2013, 2017a; Langović, 2020) that manage the mentioned issue on the examples of certain rivers.

The main objective of this study was to assess the amount of land loss by the process of riverbank erosion of different watersheds in Serbia using remote sensing and GIS. By determination of the spatial and temporal variability of riverbanks a base was created for quantification of the total and average land loss around the investigated rivers.

Material and methods

Study area

The river network on the territory of Serbia is relatively dense and includes a large number of watercourses of different sizes, ranging from small creeks to very big rivers such as the Danube River. The greatest part of the territory of Serbia belongs to the Danube River Drainage Basin (92.46%) (Blagojevic et al., 2020). The most important tributaries of the Danube River in Serbia are Tisa, Sava, Velika Morava, Tamiš, Mlava, Pek, and Timok.

For the purpose of this study, the following rivers are taken into consideration: Velika Morava, Zapadna Morava, Južna Morava, Timok, Pek, Mlava, and Kolubara (Fig. 1). The most important internal river in Serbia is the Velika Morava River (L = 185 km) which begins near Stalać, below the confluence of the Južna and Zapadna Morava rivers. Higher amount of water the Velika Morava River receives from the Zapadna Morava River (HS Jasika - 102.29 m^3/s for the period 1946-2019) than the Južna Morava River (HS Mojsinje - 91.93 m^3/s for the period 1946-2019). An average river discharge close to the confluence of the Velika Morava and Danube rivers is 227.7 m^3/s (HS Ljubičevski most, for the period 1946-2020). Downstream from the mentioned point, another significant right-sided tributaries flow into the Danube River, Mlava River (L = 78 km; HS Veliko Selo - 9.13 m^3/s), Pek River (L = 129 km; HS Kusiće - 8.7 m^3/s), and Timok River, which is also known as Veliki (Great) Timok River (L = 202 km) (Гавриловић & Дукић, 2014; Blagojevic et al., 2020). There are no available discharge data for the Veliki Timok River, for a longer period of time (HS Čokonjar started to register discharge data from 2005), so the mean annual discharge value was obtained by summing the mean annual discharge values registered on the main stations of its components, just before the confluence – HS Gamzigrad on Crni Timok River and HS Zaječar on the Beli Timok River (Q = 20.2 m^3/s). The Kolubara River has length of 86.4 km and presents one of the major right tributary of the Sava River (Dragicevic et al., 2017a). At the hydrological station Beli Brod on the Kolubara River the mean annual river discharge of 15.76 m^3/s (1946-2020) has been registered (RHMSS, 1946-2020).

In this research representative river sectors, which are characterized by increased natural lateral channel migration and soil loss on the territory of Serbia, were identified and singled out (Fig 1). It is necessary to emphasize that sectors, affected by river regulations and intensive anthropogenic activities, were excluded from this study. The majority of mentioned rivers had been intensively regulated in the 20th century, especially during the 1960s (Velika Morava, Južna Morava, Zapadna Morava). However, there are reaches, which remained in relatively natural state. The main rivers flowing through the Pannonian Plain and its rim (Danube, Tisa, Sava and Drina River) were excluded from this study for several reasons – they are characterized with very intensive lateral channel migration which monitoring requires shorter time intervals (Lower Drina) (Schwarz, 2016), there are no sectors characterized by recent lateral migration of riverbanks, extensive regulatory work had been carried out through modern history (Tisa River), and they do not represent internal river flows.

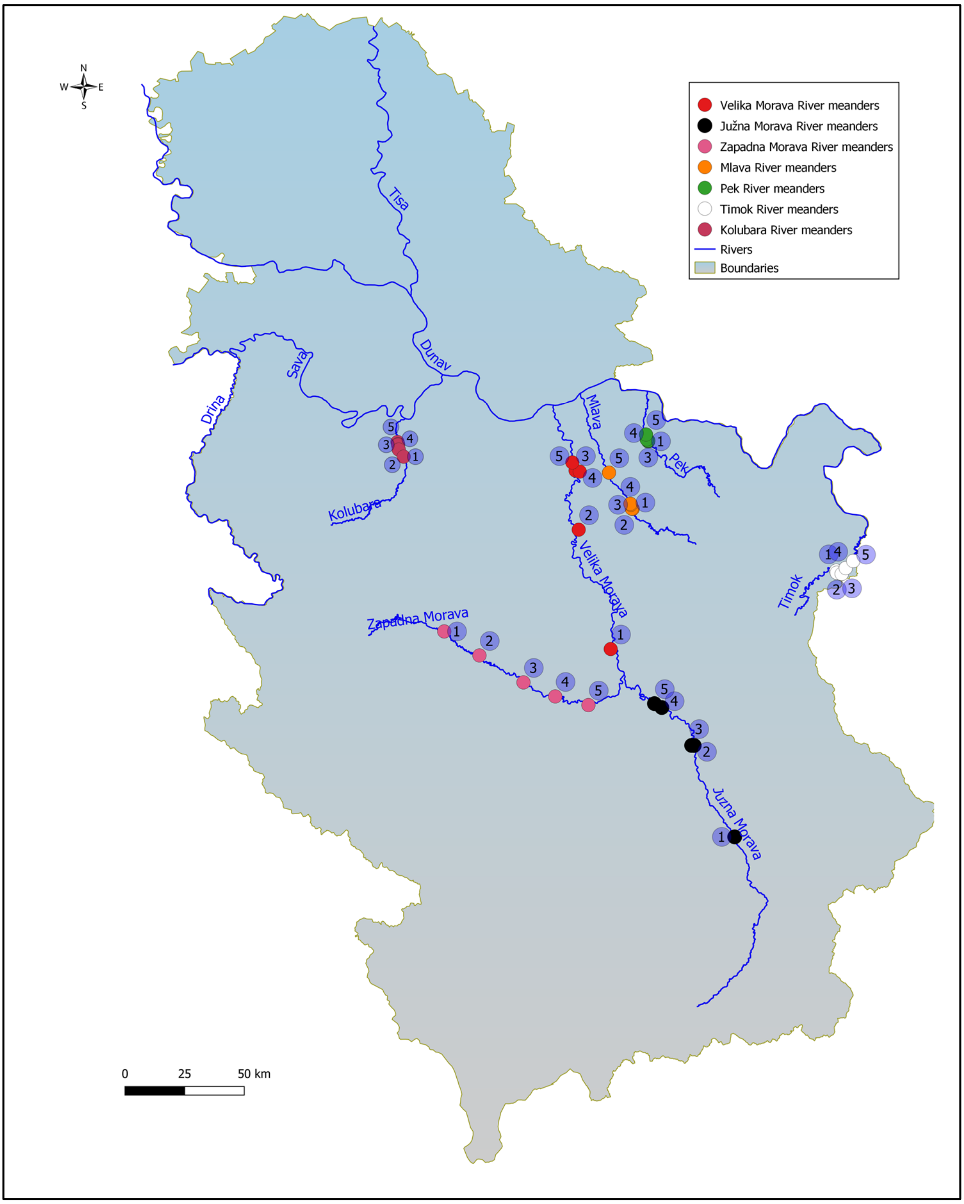

Fig. 1. Locations of the selected rivers and representative meanders on the territory of Serbia

Methodology

Investigation of riverbank erosion and lateral channel migration is based on different methodological procedures connected to the spatial and temporal approach. The qualitative and quantitative understanding of these processes, and the perception of the fluvial relief transformation under their influence, is of a particular interest (Giardino & Lee, 2011). The availability of aerial photography, orthophoto images, and GIS software has opened up the possibility to research riverbank erosion, process of accumulation and lateral channel migration (Sekac & Jana, 2014; Rosli et al., 2021). Worldwide, several different techniques have been used to quantify these processes and different time span, 1 to 10 years for field measurements and 10 to 200 years for maps and aerial photographs (Hooke 1979, 1980, 2003; Hooke & Redmond 1989; Duan 2005). In recent years, there has been an increase of the usage of aerial and terrestrial photogrammetry in fluvial process studies (Yang et al., 2018; Hemmelder et al., 2018; Binh et al., 2020).

For the purposes of this study, comparative analyses have been made based on the topographical maps (1:50,000 and 1:25,000) and satellite images from different periods. The evolution and development of the major rivers in Serbia have been investigated for almost 100 years (1923-2020). The selection of the 100 years threshold for evaluating river changes at the reach scale was motivated by the data sources required for assessing these changes. Depending on the availability of data, different time-series datasets were used, in order to determine total and average soil loss. Although the length of periods and the initial year were different among the studied rivers, the year 2020 was defined as a final year of observation on all sectors.

Comparing the data from various periods, the evolution of the river channel position over different time series was defined. In the QGIS software, a continuous polygon which represent the river channel in each year was created using the available data. Both shorelines at the start of each period were digitalized, the left shorelines of different years were copied into a single layer, and using the GIS software were processed to create polygons that represented difference between the two positions. River shorelines were digitalized using the water boundary because it is clearly defined in the topographical maps and orthophoto images. Using explained methodology, and comparing the data from different periods, total area of land loss (ha) for each river in the observed period was determined and calculated. Afterwards, the average annual land loss (ha/year) was calculated also for each river in order to compare obtain results among rivers. Further in this analysis, representative river sectors, which are characterized by increased natural lateral channel migration and soil loss, were identified. They were graphically presented, and quantification of their total and average land loss was performed.

Given the fact that hydrological factors are the most important among natural factors that have influence on the intensity and dynamics of the riverbank erosion process, the connection between different indicators of each process was determined. Regression analysis was performed on the two variables - the average annual discharge (m^3/s), and the average annual land loss (ha/year) in certain periods, and their dependence was determined. Regression reflects the effect of interdepended variable changes on a change of the dependent variable. The applied regression can indicate on whether the evolution of a certain meander is mostly dependent on one factor (in this case, changes of river discharge values) or whether it is equally affected by other natural and anthropogenic factors.

Results and Discussion

In this study for the analyzed rivers, it was identified that the value of the total land loss caused by bank erosion, is approximately 2,561 ha (25.6 km^2). Analyzing the data in the Tab. 1, it can be concluded that the processes of riverbank erosion and soil loss are noticeable on all of the studied rivers. The total amount of land loss is proportional to the morphometric and hydrological characteristics of river courses. Results indicated that the biggest amount of land was lost along the banks of the Velika Morava River (950.3 ha) in the period 1923-2020, Južna Morava River (611.1 ha) in the period 1924-2020, and Zapadna Morava River (547.2 ha) in the period 1923-2020 (Tab. 1). The defined periods for three major rivers are around 100 years, in which occurred changes of the riverbanks were very significant. For other rivers, researched periods are shorter due to lack of available data (around 50 years). Registered values vary from 62.3 ha (Mlava River), to 152.3 ha (Timok River). On the Kolubara River, for the period of 90 years the amount of total land loss was approximately 125.7 ha. Due to unequal period's durations, the more significant results are determined, by calculating another indicator, the average annual land loss (ha/year). The values in Tab. 1 show that around 9.79 ha (or 0.11 km^2) of land is directly lost every year from the Velika Morava River bank erosion process. Similar results were registered for the Južna and Zapadna Morava rivers, on average about 6 ha/year, while on the other researched rivers obtained values were much lower (on average from about 3 ha/year - Timok River, to 1.22 ha year, Mlava River).

Tab. 1. Total and average land loss by process of riverbank erosion for the studied rivers

River	Period	Total area lost (ha)	Average area lost (ha/year)	Mean annual discharge (m^3/s)
Velika Morava	1923-2020	950.3	9.79	227.71
Južna Morava	1924-2020	611.1	6.36	91.93
Zapadna Morava	1923-2020	547.2	5.64	102.29
Kolubara	1930-2020	125.7[2]	1.41	15.76
Mlava	1969-2020	62.3	1.22	9.13
Pek	1968-2020	112.6	2.16	8.7
Timok	1968-2020	152.3	2.99	20.2

For each river, five most representative sectors characterized by the highest value of soil loss due to riverbank erosion were presented (Tab. 2, Fig. 2). In case of the Velika Morava River, 97-year long period (1923-2020) was analyzed, yielding maximal soil loss of 102 ha (Meander 4). It is followed by meanders along which the determined land loss was 76 ha (Meander 1), 74 ha (Meander 5), 67 ha (Meander 3) and 64 ha (Meander 2). In order to emphasize the intensity of the erosive process in the second half of the research period (1971-2020), and especially in the last decade (2010-2020) in Tab. 2 are shown values of total and annual average land loss for these periods. Based on the analysis of the land loss values from different periods, the current state and tendency of further evolution of a certain meander can be determined. While meanders 1, 4 and 5 show an equable trend of land loss during the whole studied period, specifics occur on the example of Meander 2, which is in a stagnant phase of evolution, given the fact that in the last 10 years, riverbank erosion caused loss of 1.25% of the total land loss for the entire period. In

[2] The value refers to the lower part of the Kolubara River, for which there are available sources and data.

contrast, nowadays the most active is Meander 3, on which a land loss of 15.6 ha (1.9 ha/year) has been registered in the last 10 years, i.e., about 25% of the total loss in the entire research period.

Tab. 2. Total (TAL) and average area lost (AAL) by the process of riverbank erosion for the representative meanders (M)

River	M	Period	TAL (ha)	AAL (ha/y)	River	M	Period	TAL (ha)	AAL (ha/y)
Velika Morava	M1	1923-2020	76.0	0.8	Kolubara	M1	1930-2020	5.2	0.1
		1971-2020	26.7	0.5			1959-2020	3.2	0.1
		2010-2020	7.1	0.7			2010-2020	0.3	0.03
	M2	1923-2020	64.2	0.7		M2	1930-2020	4.2	0.1
		1971-2020	7.6	0.5			1959-2020	3.8	0.1
		2010-2020	0.8	0.1			2010-2020	0.3	0.03
	M3	1923-2020	67.1	0.7		M3	1930-2020	2.3	0.03
		1971-2020	31.9	0.7			1959-2020	1.8	0.03
		2010-2020	15.6	1.6			2010-2020	0.1	0.01
	M4	1923-2020	102	1.1		M4	1930-2020	3.5	0.04
		1971-2020	33.9	0.7			1959-2020	1.5	0.02
		2010-2020	15.9	1.6			2010-2020	0.3	0.03
	M5	1923-2020	74.1	0.8		M5	1930-2020	10.1	0.1
		1971-2020	44.8	0.9			1959-2020	6.4	0.1
		2010-2020	4.2	0.4			2010-2020	0.6	0.1
Južna Morava	M1	1924-2020	26.6	0.3	Mlava	M1	1969-2020	1.2	0.02
		1969-2020	12.6	0.2			2010-2020	0.1	0.01
		2010-2020	0.8	0.1		M2	1969-2020	1.2	0.02
	M2	1924-2020	51.5	0.5			2010-2020	0.2	0.02
		1969-2020	2.1	0.04		M3	1969-2020	1.8	0.01
		2010-2020	1.0	0.1			2010-2020	0.3	0.03
	M3	1924-2020	37.8	0.4		M4	1969-2020	1.9	0.03
		1969-2020	1.0	0.01			2010-2020	0.7	0.1
		2010-2020	0.5	0.05		M5	1969-2020	1.1	0.02
	M4	1924-2020	25.4	0.3			2010-2020	0.4	0.04
		1969-2020	11.2	0.21	Pek	M1	1968-2020	2.4	0.05
		2010-2020	4.1	0.4			2010-2020	0.2	0.02
	M5	1924-2020	13.2	0.1		M2	1968-2020	5.0	0.1
		1969-2020	0.3	0.05			2010-2020	1.3	0.1
		2010-2020	0.2	0.02		M3	1968-2020	2.6	0.05
Zapadna Morava	M1	1923-2020	21.0	0.2			2010-2020	0.03	0.003
		1970-2020	13.2	0.3		M4	1968-2020	2.8	0.05
		2010-2020	0.5	0.05			2010-2020	0.1	0.05
	M2	1923-2020	11.1	0.1		M5	1968-2020	1.9	0.03
		1970-2020	4.7	0.1			2010-2020	0.2	0.02
		2010-2020	0.6	0.1	Timok	M1	1968-2020	4.5	0.1
	M3	1923-2020	38.5	0.4			2010-2020	0.1	0.01
		1970-2020	20.3	0.4		M2	1968-2020	4.4	0.1
		2010-2020	4.1	0.4			2010-2020	0.1	0.01
	M4	1923-2020	30.9	0.3		M3	1968-2020	2.6	0.1
		1970-2020	2.5	0.05			2010-2020	0.1	0.01
		2010-2020	1.6	0.2		M4	1968-2020	5.5	0.1
	M5	1923-2020	17.8	0.2			2010-2020	0.1	0.01
		1970-2020	6.3	0.2		M5	1968-2020	7.8	0.2
		2010-2020	1.0	0.1			2010-2020	0.1	0.01

Similar results were achieved by observing the soil loss along the riverbanks of the two main components of the Velika Morava River. For both rivers, the sectors with the most intensive land loss in the last 100 years (average per meander 30.9 ha of land loss –

Južna Morava River and 23.4 ha of land loss - Zapadna Morava River) have been singled out. However, certain regularities can be determined here as well, if the first and second half of the entire research period are observed separately. On most of the meanders of the Južna Morava River (2,3,5), intensive land loss was finished in the first interval (1924-1969), while the only sector in which an intensive process has been recorded in the last 10 years is Meander 4 (approximately 16% of the total land loss). On the Zapadna Morava River, Meanders 1 and 3 can be singled out due to average land loss of 60% of the total land loss in the second interval (1969-2020).

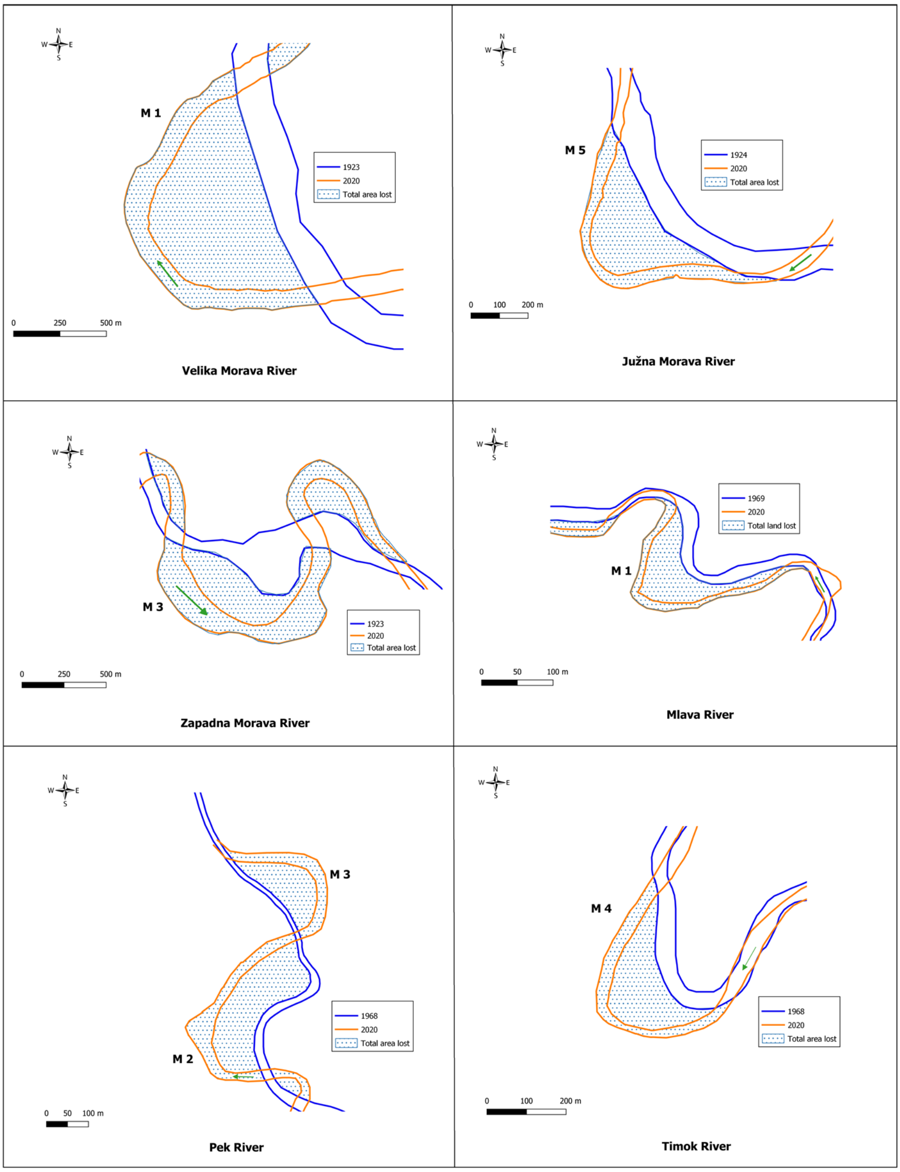

Fig. 2. Examples of representative meanders for each river course

On the other watercourses, the observation periods are shorter, (around 50 year), but the last decade has been re-emphasized in order to see the further tendency of the soil loss by riverbank erosion. On the representative sectors of the Mlava River, more intensive land loss was registered on three meanders (3,4,5) in the last decade (on average 37% of the total value of the entire research period). On the Pek River, only one meander recorded a more intensive process of land removal in the last segment of the investigated period (Meander 2), while on the Timok River there were no highlighted land loss in the same interval. On the Kolubara River, Meander 5 is characterized with the most intensive river bank erosion for the period 1930-2020 which caused land loss of approximately 10.1 ha or 0.1 ha/year. In the last period 2010-2020 the most active meanders on the Kolubara River were meanders 2 and 4 (approximately 8% of the total land loss for the entire studied period).

The results shown that among the meanders with the biggest amount of land loss in the researched period are those that are less active or inactive nowadays, which indicates on the existence of variations of the different factors that have major influence on riverbank erosion. Variations of the hydrological indicators, which imply an increase in the frequency of occurrence of extremely high or low discharge values, are the most important natural causes that regulates the intensity of the riverbank erosion and soil loss. On the other hand, anthropogenic factors and regulatory works on rivers (meander cutting, gravel and sand exploitation, dams' construction, etc.), but also in the river basins of the observed rivers, had a significant impact on variations of the intensity of riverbank erosion. On certain meanders, the process of riverbank erosion has been reduced or stopped in the last few years due to anthropogenic activities (using riverbank stabilization measures – bank revetment, such as on M5 on the Južna Morava River) or on the banks covered with woody vegetation which density and root depth have major effect on the river bank stabilization (M1 on the Zapadna Morava River, M1 on the Pek River).

Observing the use of land which is lost due to riverbank erosion, it can be determined that arable land is dominant, which makes the economic consequences especially pronounced. Areas covered by arable land are followed by areas covered with forest and shrubby vegetation, areas with sand extraction, and other land (anthropogenic formations, roads, etc.). The possibility of using the Historical Imagery tool of the Google Earth, enabled formation of views presented on Fig. 3 (position of the riverbanks of two meanders which indicate their evolution in the last period). These are especially active meanders: M1 on the Velika Morava River (2006-2020) and M3 on the Zapadna Morava River (2004-2020).

In the observed periods, the total land loss was estimated at 8.805 ha on the first and 10.948 ha on the second meander. Observing the land use, results indicated that on the first meander of the total lost areas, 91.71% was arable land, 4.59% areas covered with forest and shrub vegetation, 3.42% sand and gravel formations and 0.28% other types. Similar results were obtained for the second meander with a slightly higher share of land covered with forest and shrub vegetation (13.2%) and other (rural roads, isolated agricultural buildings - 5.02%), while agricultural land was again dominant (8.953 ha or 81.78%). For other meanders and rivers, the same regularity occurs when it comes to the land use, except for examples where there are certain local characteristics (on meanders along the middle course of the Mlava and Pek rivers next to arable land is land covered with meadows which is not used in agricultural purposes). Also, besides mentioned meanders, in the last 30 years, new sectors can be registered in which the process of more intensive land loss is presented (especially on the examples of the South Morava and Timok rivers).

Fig. 3. Examples of two meanders with intensive river bank erosion and land loss: M 1 Velika Morava River (2006-2020) and M 3 Zapadna Morava River (2004-2020)

The results in this study are in accordance with the results of other scientific and practical studies that deal the topic of riverbank erosion on the examples of individual rivers in Serbia. Roksandic et al. (2011) studied the consequences of the riverbank erosion in the Lower Kolubara Region and determined that the total soil loss along the banks of the Kolubara River were 67.3 ha for a period of 43 years (1967-2010) which had a significant economic consequence for the Obrenovac Municipality. Dragicevic et al. (2017a) using topographical maps, remote sensing, GIS, and field measurements, determined the land loss along the six most characteristic meanders of the Kolubara River (on the most downstream active meander they calculated the total land loss of 9.5 ha for the period 1930-2010). Langović (2020) pointed to an intensified process of bank erosion in the downstream part of the Južna Morava River, with maximum values of lateral channel migration of over 500 m in the period 1924-2019.

In order to emphasize the importance of hydrological factors on changes in the intensity of lateral erosion and soil loss along river banks, a regression analysis was performed using two variables. Mean annual discharge represent the most general hydrological parameter and the initial phase in the research of the hydrological causes of river bank dynamics. In Fig. 4, connections between these two variables for the representative meanders of three major river can be seen. Data on average annual loss were made for several time sections: 1929-2020, 1929-1971, 1971-2010, 2010-2012, 2012-2016 and 2016-2020. Although a small number of observations and data are placed in analysis, the obtain results will show some regularities. The largest agreement between the values of mean annual discharges and land loss was observed on the Velika Morava River (M4) with a coefficient of determination of 0.97 (the changes in the river discharge values exponentially follow changes in the annual land loss values). High values of stacking were obtained also on the example of the Zapadna Morava River – M3 ($R2$ = 0.86), while the lowest were obtained on the example of the M4 of the Južna Morava River ($R2$ = 0.7).

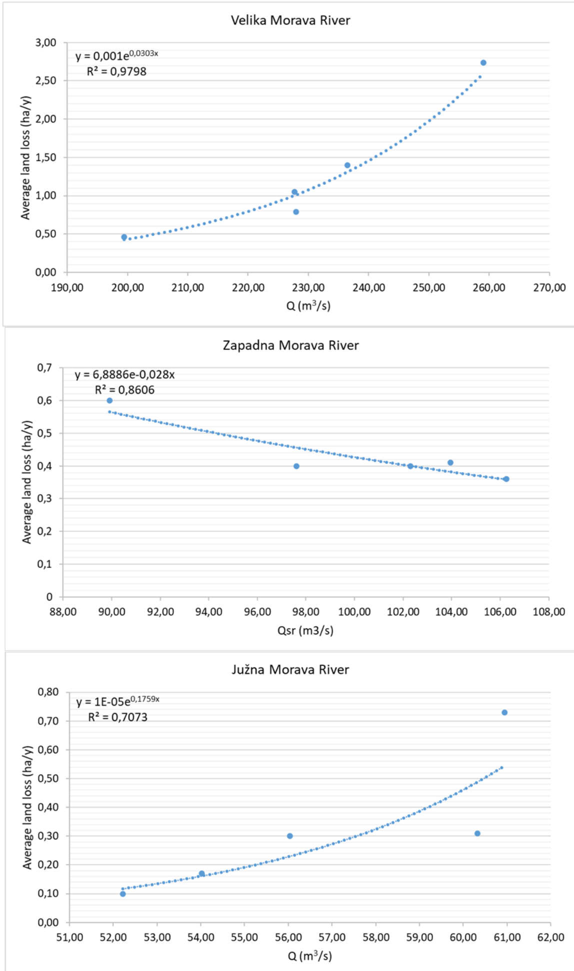

Fig. 4. Estimations of average annual land loss (ha/y) using the mean annual river discharge (m^3/s) for representative meanders (Velika Morava River – M 4; Zapadna Morava River – M 3; Južna Morava River - M 4

The direct dependence of riverbank erosion from the river discharge variations was expected, but there are differences depending on the registered trend of the discharges during the study period. Various studies (Kovačević-Majkić & Urošev, 2014; Langović, 2017; Bloch et al., 2019) have confirmed the existence of a decreasing trend of the mean annual discharge values of the rivers in Serbia, but a growing trend in the occurrence of extreme hydrological conditions under the influence of climate change. Therefore, the pressure on the river banks became more pronounced. Period 2012-2016 was especially pronounced because of the May 2014 flood events in the river basins of Velika Morava, Zapadna Morava, and Kolubara, and due to the 2015 winter flood events in the Južna Morava River Basin. In the period of four years average annual land loss had value of 0,7 ha/y (M4 – Južna Morava River) and 2,4 ha/y (M4 – Velika Morava River). This confirms the fact that one or two major floods in the larger period of time can have one-hundred percent effect on the land loss along the affected riverbanks. However, for a more comprehensive study of hydrological effects, it is necessary to determine the dependence with the frequency of occurrence of extreme hydrological conditions in the studied area.

Conclusion

The studies of the process of riverbank erosion and soil loss present an actual and contemporary research topic. Spatial and temporal analysis of these processes can obtain valuable results which can indicate on future tendencies of their dynamic. In the area of the Pannonian Basin and its southern rim, on the territory of Serbia, lateral channel migration is the most significant geomorphological and fluvial process, and therefore represent an excellent base for research of this type. The results of this research shown that selected riverbanks (Velika Morava, Južna Morava, Zapadna Morava, Mlava, Pek, Timok, and Kolubara) are particularly exposed to the intensive process of riverbank erosion and land loss, with special emphasis on specific sectors. In addition, results of study revealed that total land loss on five representative meanders amounted around 383.4 on the Velika Morava River, 154.5 ha on the Južna Morava River, 119.3 ha on the Zapadna Morava River, 25.3 ha on the Kolubara River, 24.8 ha on the Timok River, 14.7 ha on the Pek River, and 6.2 ha on the Mlava River. The highest rate of total land loss was registered at the M4 of the Velika Morava River (102 ha for the period 1923-2020). On the same meander, as well as on the certain meanders on the Mlava (M3, M4, M5), Južna Morava (M4), and Zapadna Morava (M3) rivers, is noted intensive dynamic of soil loss due to riverbank erosion in the last decade (2010-2020). This indicates that meanders are still active and that their evolution isn't sufficiently affected by anthropogenic and regulation influences. Such claims have been confirmed by bringing average annual land loss and mean annual discharge values into a regression ratio. High values of coefficient of determination justifies effects of hydrological influence on the riverbank erosion process.

Obtain values of the river bank erosion and soil degradation can be a reasonable guide to future activity. A better understanding of river channel migration in Serbia will be of a great importance for practical issues such as predicting channel migration rates for river engineering and planning purposes, soil and water management, land use changes, environment protection, etc. However, for future research it is necessary to explain more detail the causes of the registered process of bank erosion, through correlation with extreme meteorological and hydrological conditions, as well as to calculate the economic and financial losses caused by this process.

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ПРОЦЕНА ГУБИТКА ЗЕМЉИШТА УЗРОКОВАНОГ ЕРОЗИЈОМ РЕЧНИХ ОБАЛА У СРБИЈИ

Резиме: Латерална миграција речних токова и ерозија обала представљају важне геоморфолошке процесе који узрокују различите социо-економске, еколошке, хидролошке последице. Сваке године поменути процеси директно или индиректно утичу на живот милиона људи, уништавајући природне и антропогене ресурсе, пољопривредно земљиште, путеве, домаћинства итд. Плодно пољопривредно земљиште формирано на конкавној обали реке бива еродирано, док се са друге стране формира ново на речним спрудовима, које је најчешће обрасло зељастом или жбунастом вегетацијом и које нема значаја за развој пољопривреде. Ерозија обала представља важан процес дуж река које теку Панонском низијом и њеним јужним ободом. Ипак, на територији Србије истраживања процеса ерозије обала и њених последица нема широку истраживачку прошлост, већ је могуће издвојити неколико савремених студија које изучавају поменуту проблематику на примерима одређених река у Србији (Колубара, Дрина, Јужна Морава). Циљ овог рада је да се изврши процена губитка земљишта узрокованог процесом ерозије обала различитих река у Србији коришћењем доступних података и ГИС технологије. Детерминацијом просторне и временске варијабилности речних обала у различитим временским оквирима у зависности од доступних података, створена је основа за квантификовање укупног и просечног губитка земљишта проучаваних река. За потребе израде рада узети су најважнији унутрашњи речни токови: Велика Морава, Јужна Морава, Западна Морава, Тимок, Млава, Пек и Колубара.

Резултати истраживања показују да процењена вредност губитка земљишта износи око 2.561 ha (25,6 km^2). Укупни губитак земљишта пропорционалан је морфометријским и хидролошким карактеристикама речних токова. Дефинисани временски оквир за три највеће реке је око 100 година у току којих су забележене следеће вредности укупног губитка: Велика Морава – 950,3 ha, Јужна Морава 611,1 ha, Западна Морава – 547,2 ha. Због неједнаких трајања временских периода, значајнији показатељ је просечан губитак земљишта (ha/год.). Резултати су показали да је просечно годишње највише земљишта изгубљено дуж обала Велике Мораве (9,79 ha), затим Јужне и Западне Мораве (6 ha/год), док су за остале истраживане токове вредности ниже (од око 3 ha/год дуж реке Тимок, до 1,22 ha/год дуж реке Млаве). У циљу детаљније обраде истраживане проблематике издвојено је по пет меандара за сваку реку за које је утврђен годишњи и просечан губитак

земљишта. Резултати су показали да је укупни губитак на свих пет меандара износио око 383,4 ha на Великој Морави, 154,5 ha на Јужној Морави, 119,3 ha на Западној Морави, 25,3 ha на Колубари, 24,8 ha на Тимоку, 14,7 ha на Пеку и 6,2 ha на реци Млави. Највећа стопа укупног губитка земљишта регистрована је на Меандру 4 на Великој Морави (102 ha у периоду 1923-2020.). На истом меандру, као и на одређеним меандрима река Млаве (М3, М4, М5), Јужне Мораве (М4) и Западне Мораве (М3) забележена је интензивна динамика померања обала и губитка земљишта у последњој деценији (2010-2020.). Ова чињеница упућује на закључак да су одређени меандри још увек активни и да њихова еволуција није у довољној мери измењена под утицајем речних регулација и антропогене делатности. Овакве тврдње потврђене су и довођењем у корелациони однос вредности просечног губитка земљишта око одређеног меандра са једне и просечног годишњег протицаја реке у датом периоду са друге стране. Високе вредности коефицијента детерминације (0,97 – М4 на Великој Морави) оправдавају чињеницу да су хидролошки фактори најзначајније детерминанте интензитета процеса ерозије обала.

Добијени подаци могу послужити за наредна проучавање проблематике ерозије обала са различитих аспекта. У будућим истраживањима неопходно је акценат ставити на детаљније објашњење фактора који утичу на интензитет процеса ерозије обала, кроз корелацију са екстремним вредностима метеоролошких и хидролошких показатеља, али и на квантификовање економских и финансијских губитака изазваних овим процесом. Боље разумевање овог процеса на територији Србије може бити од значаја за решавање практичних проблема из области управљања водним и земљишним ресурсима, променама у коришћењу земљишта, заштити животне средине итд.