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LAND USE CHANGES CAUSED BY BANK EROSION ALONG THE LOWER PART OF THE BOSNA RIVER FROM 2001 TO 2013

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Abstract: The river channel dynamics are result of the complex interaction between natural and human impact. In the presented study, we assessed spatial and temporal dynamics of Bosna river channel migration during 2001-2013 period using orthophoto images and GIS. We have identified that the total area of bank erosion during given period equaled 2.8695 km^2, of which 1.2178 km^2 were on the left bank and 1.6516 km^2 on the right bank. The total area of bank accretion from 2001 to 2013 equaled 2.6841 km^2, of which 1.2864 km^2 was on the left bank and 1.3977 km^2 on the right bank. The Bosna riverbed average movement in the period 2001-2013 was established in the amount of 60.7 m. During this period, the average lateral channel migration was 5.05 m per year. Lateral migration of the Bosna River has caused serious problems: disappearance of arable land, forests, pastures and meadows, economic loss due to the reduction of agricultural. Using statistical analysis of a land use structure changes along the lower part of Bosna River, we obtained the results which show significant lost in arable land. According to results, 42.3 ha of arable land, 171.9 ha forests and 31.8 ha pastures and meadows were lost during 2001-2013 period. The data presented here are significant for practical issues such as predicting channel migration rates for engineering and planning purposes, soil and water management.

Key words: Bank erosion; Channel migration; GIS; Remote sensing; Bosna River, Republic of Srpska.

Introduction

River bank erosion, accretion and lateral channel migration are the most important geomorphological processes, which attract a great deal of attention from scientist over the last century. Understanding the mechanisms and rates of these processes has fundamental significance, as well as results of these researches which are applicable in the field of water and soil resources management, hydro-technical works, and in different aspects of the environmental protection (Hooke, 1979, 1980; Thorne, 1982; Lawler, 1993; Duan, 2005).

The processes of bank erosion, accretion, and lateral channel migration were not investigated in previous geomorphological researches in the Bosnia and Herzegovina, therefore, there are no articles in which results of bank erosion intensity and consequences of changes in river course were presented. In the region, the consequences of changes in river course and bank erosion intensity have been well-documented in the literature

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(Radoane et al., 2010; Blanka and Kiss 2011; Zaharia et al., 2011; Floriou, 2011; Roksandic et al., 2011; Dragicevic et al., 2012, 2013).

Considering all the problems that burdened the lower course of the Bosna River we started analysing these processes using available data and GIS. The availability and usage of orthophoto images from 2001, 2006, 2008, 2013 in combination with GIS opened up the possibility to research bank erosion, accretion, lateral channel migration, and land use changes caused by these processes (Thorne, 1982; Hooke and Redmond, 1989, Lawler et al., 1999; Richard et al., 2005; Tiegs and Pohl, 2005; Hooke, 2003, 2007; Kiss et al., 2008; Nicoll and Hickin, 2010; Henshaw et al., 2012).

The objectives of this study were to assess the rate of bank erosion and accretion, as well as rate of lateral channel migration of Bosna River using remote sensing and GIS. For the purposes of this study, comparative analyses have been made based on orthophoto images from 2001, 2006, 2008 and 2013. By comparing the data from these periods, we determined the land use changes along the lower part of the Bosna River. The data presented here represent a base in understanding the dynamics of bank erosion, accretion and lateral channel migration of Bosna River, and they influences on land use changes along the lower part of the Bosna River.

Study area

The research covered the southern part of the Pannonian Basin in the Bosnia and Herzegovina (Fig.1). The study area is located along the lower part Bosna River, with total channel length of 27.64 km. The Bosna River drains the central parts of the Dinaric Karst Massif and the central part of Bosnia and Herzegovina. The drainage basin area is of 10662 km^2, course length of 275 km, mean annual discharge at the confluence with the Sava River is 180.5 m^3s^{-1}, specific discharge 15.6 $ls^{-1}km^{-2}$, and the average fall is 1.48 m/km (Tošić et al., 2012; Dragicevic et al., 2013).

The tectonic characteristics of this area, more precisely, the Posavski Fault, had influenced the orientation of the hydrological network in the Bosna River basin. The decrease in the stream velocity in the lower part of the Bosna River is caused by the tectonic movements of sinking in the northern part of the basin. This process resulted sediment accumulation in the riverbeds, bank erosion, formation of meanders, and changes in the river course. Thus, the study area is characterised by intense lateral dynamics of the river channels.

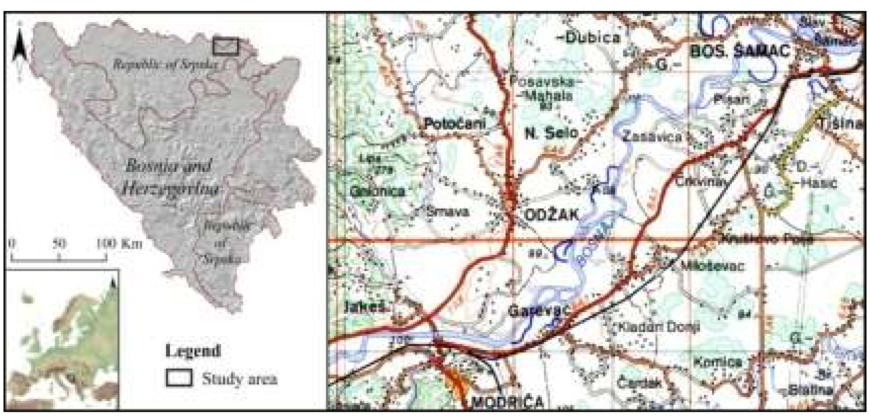

Fig. 1. Location of the study area - lower part of the Bosna River

Characteristic features of the lower part of the Bosna River come to the fore on the section from the Modrica Bridge to the confluence with the recipient - the Sava River, with a total length of about 28 kilometers. Almost in the entire sector, the concave curve banks are damaged vertically notched by mainstream high waters and subject to constant erosion. It is a general phenomenon that in the bands, the concave banks are being destroyed, while the sediment load is deposited on the convex banks.

Landscape studies are using aerial photographs, orthophoto images, satellite images and different scale paper maps to determine the river course changes. There is a large amount of literature indicating the usefulness of identifying planform changes in channel geometry using orthophoto in a geographic information system (GIS) environment (Downward, 1995; Downward et al., 1994; Gurnell, 1997; Gurnell et al., 1994; Petts, 1989; Winterbottom and Gilvear, 2000; Weng, 2002; Wellmeyer et al., 2005; Grove et al., 2013). One of the main characteristics of remote sensing is its capability of generating a large amount of information, frequently and spatially and thus studying river morphology. A review of techniques used to measure river bank retreat rates is provided by Lawler (1993).

Methodology

Comparing the data from different periods, we defined the evolution of the river channel position over different time series. In this study, we developed a time series of georeferenced data using an orthophoto images from 2001, 2006, 2008 and 2013. Aerial photogrammetry surveying of the lower part of the Bosna River was implemented by Z/I DMC camera with 120 mm focus and image dimension of 1324x7680 pixels. Scale of this survey was 1:33333 and as a result the spatial image resolution was 40 m. Reconnaissance of known trigonometric marks and GPS detection of new orientation marks along the whole recorded area of the lower part of the Bosna River made aero-triangulation and block alignment plausible. When aero-triangulation was finished the photogrammetric image processing, digital terrain model development, orthorectification and cartographic processing took place. Orthorectification of aerial images and conversion from central to orthogonal projection (Gauss-Krüger projection (VI zone) - World Geodetic System 1984) was implemented based on previously developed digital terrain model and stereopairs of aerial photographs.

The sheets of digital orthophoto plan in scale 1:5000 and resolution 50 cm were developed using orthorectification process. Orthophoto plans were created in TIFF+tfw format for simplified use in ArcGIS software, while aerial photographs were processed in PHOTOMOD software package.

In the ArcGIS software, we created a continuous polygon to represent the river channel in each year using the image data. We determined the changes in the locations of both riverbanks during three periods: 2001 to 2006, 2006 to 2008, and 2008 to 2013. The results revealed the places where erosion and accretion occurred during each period. We calculated erosion and accretion separately for each side of the river. We digitized the shorelines at the start of each period, copied the left shorelines of 2001 and 2013 into a single layer, and processed them using the GIS software to create polygons that represented the difference between the two positions. If a polygon was positioned to the left of the 2001 shoreline, it represented an erosion polygon; if a polygon was positioned to the right of the 2001 shoreline, it represented an accretion polygon.

We used the same process to assess erosion and accretion of the right bank, but with the following change: polygons to the left and right of the 2001 shoreline represented accretion and erosion, respectively. Summing the areas of these polygons provided the total eroded and accreted areas from 2001 to 2013. After determining these areas, we added the 2006, 2008 and 2013 shorelines sequentially to subdivide each of the polygons into smaller polygons that represented the shorelines on each of these dates. We used the ArcGIS software to calculate the areas of overlap between the shoreline in each year and the boundaries of the polygon that contained that portion of the shoreline. We then used the same approach that we used for the period from 2001 to 2013 to calculate the erosion and accretion between consecutive years (Downward et al., 1994; Yao et al., 2011).

Comparing the data from different periods, we determined the rate of lateral channel migration over different periods. The position of the channel centreline was marked in each data source 2001, 2006, 2008 and 2013. Channel outlines were digitized using the water boundary to denote the edge of the channel because it is clearly defined in the orthophoto images. Furthermore, the two digitized channel boundary lines are used in ArcGIS to generate a channel centreline which were digitized, and the channel migration rate was calculated (Hooke, 1979, 1980; Hudson and Kesel, 2000; Winterbottom and Gilevar, 2000; Mount and Louis, 2005; Hughes et al., 2006).

The estimation of land use changes along the Bosna River were based on the orthophoto images comparison from 2001, 2006, 2008 and 2013 years. We used the ArcGIS software to analyze changes which occurred from 2001 to 2013.

Results and discussions

In our analysis, we identified that the total area of bank erosion from 2001 to 2013 equaled 2.8695 km^2, of which 1.2178 km^2 were on the left bank and 1.6516 km^2 on the right bank (Fig.2). The total area of bank accretion from 2001 to 2013 equaled 2.6841 km^2, of which 1.2864 km^2 were on the left bank and 1.3977 km^2 on the right bank (Table 1).

Table 2 shows the distribution of the area of bank erosion along the Bosna River reaches from 2001 to 2013. Our analysis identified 176 erosion plots on the left bank and 166 erosion plots on the right bank. On the left and right bank no accretion plot is larger than 0.5 km^2. In contrast, 176 plots on left bank were smaller than 0.5 km^2, and these totaled 1.2177 km^2. On right bank, 166 plots were smaller than 0.5 km^2, and these totaled 1.6516 km^2.

Table 3 shows the distribution of the area of bank accretion along the Bosna River reaches from 2001 to 2013. Our analysis identified 178 accretion plots on the left bank and 170 accretion plots on the right bank. On the left bank, no accretion plot larger than 0.5 km^2, while 1 accretion plots on right bank are larger than 0.5 km^2, with total area of 0.6130 km^2. In contrast, 178 accretion plots on left bank were smaller than 0.5 km^2, and these totaled 1.2864 km^2. On right bank, 169 accretion plots were smaller than 0.5 km^2, and these totaled 0.7847 km^2.

In the research sector (Fig. 3), the Bosna River length was 27.584 km in 2001 (sinuosity was 1.606), 27.073 km in 2006 (sinuosity was 1.576), 24.642 in 2008 (sinuosity was 1.435) and 23.949 km in 2013 (sinuosity was 1.394). Analysis of the orthophoto images of the research area showed that the Bosna riverbed average movement in the period 2001-2013 was established in the amount of 60.7 m. Apart from this period, the maximum values of the period 2001-2006, 282.0 m, 2006-2008, 252.0 m, 2008-2013, 204.4 m, and the period from 2001 to 2013, 275.9 m (Table 4). During this period, the average lateral channel migration was 5.05 m per year.

Land use structure along the lower part of Bosna River is characterized by main category: arable land (which people used for farming, mostly wheat and corn-crop rotation practice), forests (alluvial forests of willows and poplars), infields, sand and gravel extraction, pastures and meadows.

Table 1. Area of riverbank erosion and accretion of the Bosna River from 2001 to 2013.

Time span	Area of erosion (km^2)			Area of accretion (km^2)		
	Left bank	Right bank	Total	Left bank	Right bank	Total
2001 – 2006	0.4838	0.6991	1.1829	0.2233	0.0884	0.3117
2006 – 2008	0.3765	0.2188	0.5954	0.5451	1.1866	1.7317
2008 – 2013	0.3575	0.7337	1.0912	0.5180	0.1227	0.6407
Total (2001 – 2013)	1.2178	1.6516	2.8695	1.2864	1.3977	2.6841

Table 2. Distribution of the bank erosion area along the study reaches from 2001 to 2013.

Time span	Area of erosion (km^2)											
	Left river bank						Right river bank					
	0.001-0.01	0.01-0.05	0.05-0.1	0.1-0.5	0.5-1	Total	0.001-0.01	0.01-0.05	0.05-0.1	0.1-0.5	0.5-1	Total
2001 – 2006												
Number of plots	66	9	1	1	0	77	58	9	3	2	0	72
Total area (km^2)	0.0269	0.2406	0.0738	0.1425	0.0000	0.4838	0.0208	0.2835	0.1694	0.2254	0.0000	0.6991
Proportion of total (%)	5.5655	49.7282	15.2461	29.4601	0.0000	100	2.9742	40.5535	24.2296	32.2428	0.0000	100
2006 – 2008												
Number of plots	36	4	0	1	0	41	43	5	1	0	0	49
Total area (km^2)	0.0241	0.0660	0.0000	0.2863	0.0000	0.3765	0.0286	0.0951	0.0951	0.0000	0.0000	0.2188
Proportion of total (%)	6.4125	17.5406	0.0000	76.0469	0.0000	100	13.0811	43.4690	43.4499	0.0000	0.0000	100
2008 – 2013												
Number of plots	49	8	1	0	0	58	35	6	1	3	0	45
Total area (km^2)	0.0623	0.2300	0.0652	0.0000	0.0000	0.3575	0.0418	0.1084	0.0629	0.5206	0.0000	0.7337
Proportion of total (%)	17.4276	64.3426	18.2298	0.0000	0.0000	100	5.6950	14.7801	8.5777	70.9472	0.0000	100

By statistical analysis of a land use structure changes along the lower part of Bosna River, we obtained the results which show significant lost in arable land (Table 5). According to data, 42.3 ha of arable land were lost within 12 years. Furthermore, a significant loss is noticeable within the area under forests, pastures and meadows; within 12 years 171.9 ha forests and 31.8 ha pastures and meadows were lost. In addition to landscape degradation, lateral migration of the Bosna River has caused serious problems for the disappearance of arable land, but also economic loss due to the reduction of agricultural production. Since the lateral erosion has more intensity, the river banks on concave side of the Bosna River often collapse and farmers who have arable land parcels on the river bank lost parts of the parcels which were carried away by the river flow.

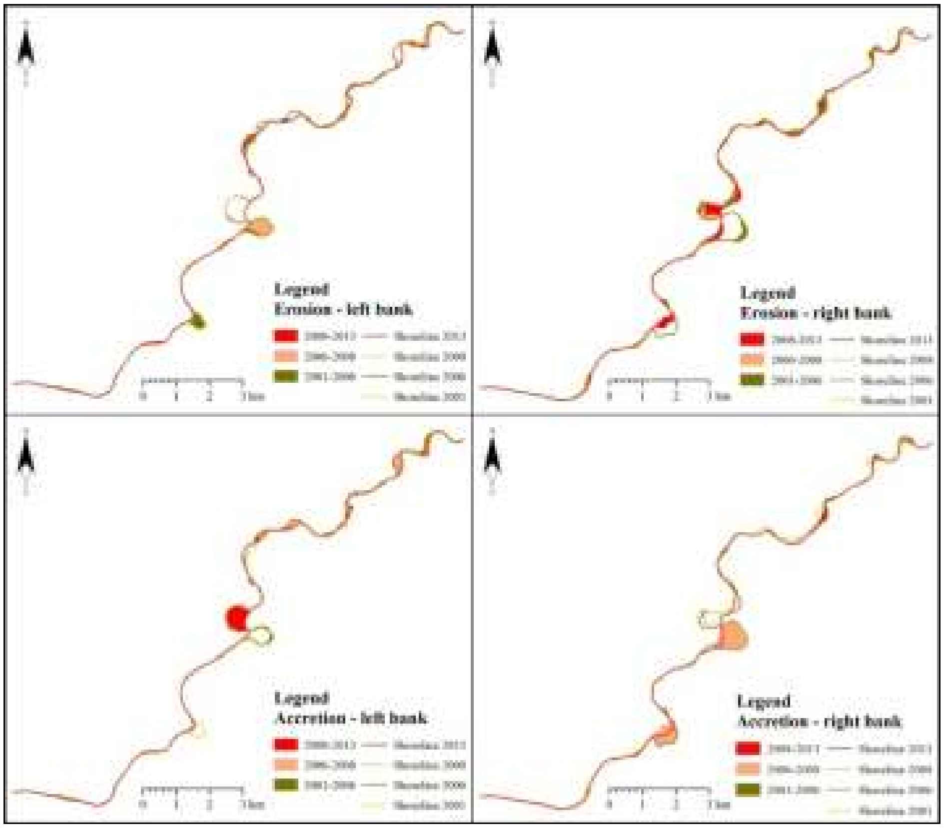

Fig. 2. Bank erosion and accretion during three periods from 2001 to 2013.

Comparing collected data for given period, one can conclude that bank erosion was the most intensive in the period 2001-2006 when the loss of arable land and area under forests, pastures and meadows was on the highest rate.

Making the constant pressure on state institutions through various appeals, indicating that current situation is unsustainable and stand by position of constant fear, this paper is one of many attempts to help the endangered population. In this context, the monitoring of the bank erosion, accretion and lateral channel migration of Bosna River is a logical solution and our contribution to fight for the basic human right to live without fear from natural hazards.

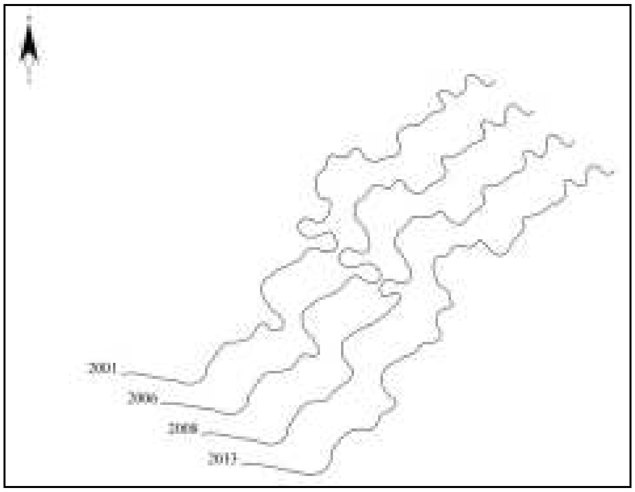

Fig. 3. Successive channel planform changes from 2001 to 2013 along the reaches of Bosna River.

Table 3. Distribution of the bank accretion area along the study reaches from 2001 to 2013.

Time span	Area of accretion (km^2)											
	Left river bank						Right river bank					
	0.001-0.01	0.01-0.05	0.05-0.1	0.1-0.5	0.5-1	Total	0.001-0.01	0.01-0.05	0.05-0.1	0.1-0.5	0.5-1	Total
2001 – 2006												
Number of plots	75	4	1	0	0	80	70	3	0	0	0	73
Total area (km^2)	0.0534	0.1101	0.0599	0.0000	0.0000	0.2233	0.0392	0.0492	0.0000	0.0000	0.0000	0.0884
Proportion of total (%)	23.8898	49.2987	26.8115	0.0000	0.0000	100	44.3282	55.6718	0.0000	0.0000	0.0000	100
2006 – 2008												
Number of plots	40	5	2	2	0	49	50	6	0	1	1	58
Total area (km^2)	0.0326	0.1547	0.1341	0.2237	0.0000	0.5451	0.0574	0.1454	0.0000	0.3708	0.6130	1.1866
Proportion of total (%)	5.9733	28.3858	24.5950	41.0459	0.0000	100	4.8352	12.2556	0.0000	31.2524	51.6568	100
2008 – 2013												
Number of plots	46	2	0	1	0	49	38	0	1	0	0	39
Total area (km^2)	0.0456	0.0252	0.0000	0.4472	0.0000	0.5180	0.0436	0.0000	0.0791	0.0000	0.0000	0.1227
Proportion of total (%)	8.7965	4.8701	0.0000	86.3334	0.0000	100	35.5435	0.0000	64.4565	0.0000	0.0000	100

Table 4. Lateral shift of the centreline of Bosna River - total in meter (m).

Shift in regard to 2001 year	**2006.**	**2008.**	**2013.**
Max shift [m]	282.0	266.2	275.9
Average shift [m]	39.9	42.9	60.7
Standard deviation [m]	46.2	50.2	59.4
Coefficient of variation [%]	115.7	117.2	98.0
Shift in regard to 2006 year		2008.	2013.
Max shift [m]		252.0	247.5
Average shift [m]		22.8	42.2
Standard deviation [m]		31.8	46.0
Coefficient of variation [%]		139.7	109.1
Shift in regard to 2008 year			2013.
Max shift [m]			204.4
Average shift [m]			37.9
Standard deviation [m]			43.6
Coefficient of variation [%]			115.0

Table 5. Land use category along the lower part of Bosna River - lost in hectare (ha).

In regard to 2001 year	**Land use**	**2006.**	**2008.**	**2013.**
	Arable land	29.0	30.6	42.3
	Forests	90.2	118.8	171.9
	Infields	0.0	0.0	0.1
	Sand and gravel extraction	4.6	4.8	5.2
	Pastures and meadows	14.7	23.7	31.8
In regard to 2006 year	**Land use**		**2008.**	**2013.**
	Arable land		2.7	11.4
	Forests		67.0	128.6
	Infields		0.0	0.1
	Sand and gravel extraction		10.0	10.5
	Pastures and meadows		1.2	7.2
In regard to 2008 year	**Land use**			**2013.**
	Arable land			9.3
	Forests			106.1
	Infields			0.1
	Sand and gravel extraction			41.9
	Pastures and meadows			6.8

Conclusion

Bank erosion, accretion and lateral channel migration, soil loss, sediment load deposition, floods, soil and water pollution are the major environmental problems in the Bosna River basin. This study has analyzed the spatio-temporal dynamics of river channel migration and that gives us a future synoptic view of the river course and changes in land use structure along the lower part of Bosna River. The results and database created during this study, combined with surveyed hydrographical data and digital elevation model of flood plain can be used for hydraulic and sedimentation modeling of this river reach and future flood and river bank erosion risk map can be generated based on this research. Thus, this study can become very much helpful for future mitigation and hazard preparedness programs for the government institution of water management to take.

For further research, it is necessary to link fluvial processes with socio-economic factors in order to predict the future development of the fluvial landscape.

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