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# Land Use Changes and Environmental Problems Caused by Bank Erosion: A Case Study of the Kolubara River Basin in Serbia

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Additional information is available at the end of the chapter

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## 1. Introduction

Geomorphological analysis of the dominant erosion processes and their intensity quantification were done in the previous researches of the Kolubara River basin [1-3]. The results showed that, the level of the landscape degradation and modification of geomorphologic processes by human activities has been increased in the past decades [4], and it was initiated by very fast demographic, socio-economic and technological changes in Serbia, likewise in the region [5-7], and in the world [8-11].

According to level and type of degradation, the Kolubara River basin belongs to the most endangered areas in Serbia. Due to the lignite exploitation in the Kolubara River basin, human impact led to morphological change of the entire area, as well as to the changes of the intensity of different geomorphologic processes: changes in river course [12,13], the intensity of bank erosion [14,15], sediment deposition [16] and environmental problems [17,18].

Unlike the other rivers with similar hydrological characteristics, the river network in the lower part of the Kolubara River basin were changed rapidly during the XX century because of direct human impact. Anthropogenic influences on the hydrological network in the study area were very intensive since 1959, when the huge river regulation works were done in the lower part of the Kolubara River. Spatial planning of the area, which included diverting of the Kolubara's river bed, had an aim to prepare the site for the lignite exploitation within the Kolubara mining basin. The Kolubara River divides the mining basin in two parts: eastern and western part. The productive area of the basin (geologic contours of lignite

deposits) is 520 km<sup>2</sup>. Kolubara mining basin is situated about 40 km south-southeast of Belgrade and represents the largest lignite deposits in the central part of Serbia; the annual production is 30 million tons of lignite, and it is the opencast mine. The mine expansion caused the need for technical solutions of diverting and removing river beds in this area. According to "General project of diverting the Kolubara River and its tributaries for the purpose of lignite exploitation", the Kolubara's riverbed was diverted into the Pestan's riverbed (its right tributary). This caused many problems which were not predicted by the General project.

In this way, anthropogenic factor modified existing natural conditions: the process of fluvial erosion was changed; bank erosion became stronger and resulted in soil loss, larger amounts of sediment load deposition, cutting off the meanders and fossilization of certain parts of the riverbed, floods, land use changes, landscape degradation, sediment load pollution, etc.

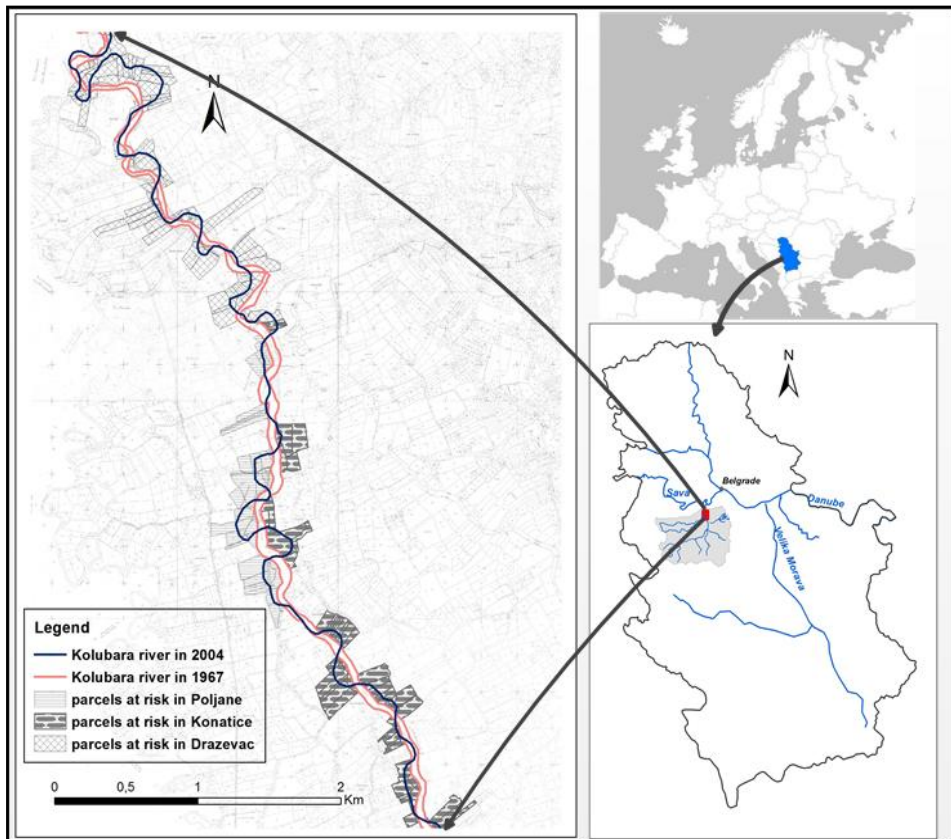
## 2. Research area

Regarding to natural conditions, the Kolubara River basin is similar to the other river basins in the area. Tectonic movements had an influence on a morphological evolution of the river network in the past. During the Paleogene and the Early Neogene a small bay of the Pannonian Sea named the Kolubara's bay existed in the area of the Kolubara River basin. After the sea recession, the fluvial erosion started in this bay and it formed today's hydrological network of the Kolubara River. Tectonic characteristics of this area, more precisely Kolubarsko-pestanski fault and Posavski fault had influenced the orientation of the hydrological network in the Kolubara River basin. But today the Kolubara's hydrological network is influenced by fluvial erosion and anthropogenic factors.

The Kolubara River Basin encompasses the western part of Serbia and covers 4.12% of Serbia's surface area. The highest point of the drainage basin is at 1,346 m, and the lowest has altitude of 73 m. The Kolubara River is the last large right tributary of the Sava River, and according to the flow length (86.4 km) and the basin area (3,641 km<sup>2</sup>) it is classified as a middle-sized river on the territory of Serbia [3].

The lower part of the Kolubara River basin is called the Donjokolubarski basin (area of 1,810 km<sup>2</sup>) and is situated in the municipality of Obrenovac. The Donjokolubarski basin encompasses the catchment area of the Kolubara's confluences (the Pestan River, the Turija River with the Beljanica River, the Tamnava River with the Ub River and the Kladnica River) and the lower part of the Kolubara's valley. The average altitude of the Donjokolubarski basin is 168 m, the highest point is at 695 m, and the lowest has an altitude of 73 m.

According to the nearest meteorological station in Obrenovac, this area is characterized by continental climate, the average temperature was 11°C, and the mean annual precipitation from year 1925 to 2000 was 722 mm [12]. The average annual runoff of the Kolubara River (at Drazevac gauging station) for the period 1961-2005 was 21.8 m<sup>3</sup>/s.



**Figure 1.** Position of the Kolubara River basin in Serbia (right) and study area (left)

### 3. Methodology

In this research we used different methods that can be divided into the field and lab work methods. The GIS methods were used for the modeling of terrain evolution and landscape changes, which represents the base for bank erosion intensity quantification.

Analysis of topographical maps, aerial photo and orthophoto images were used in the previous researches aiming to determine the evolution of the riverbed [6,15,19-23]. The results showed that the application of GIS has an advantage in quantification of river migration processes.

For the purposes of this study, comparative analyses have been made on the base of Cadastral maps scale 1:2500 from 1967 and orthophoto images from 2004; reconstruction of the hydrological system has been done for the periods from 1967 to 2004. By comparing the data from two periods, we determined the evolution of the Kolubara River course in 37 years. River bank lines were digitized and the extent of bank erosion was calculated under

Geomedia professional. The same software was used for the estimation of the Kolubara River lateral migration rate. This rate was estimated using the calculated area between river positions in 1967 and in 2004 (area of river migration), which was divided by the total length of the river course in 1967. The loss of land ( $S$ ) is expressed as the ratio between area of endangered land parcels (ha) in 1967 ( $P_{1967}$ ) and area of endangered land parcels (ha) in 2004 ( $P_{2004}$ ) [15]:

$$S = \frac{P_{1967} - P_{2004}}{P_{1967}} * 100$$

River erosion and frequent floods make great material damages to people, villages and economy. The owners of the arable land parcels on the Kolubara River banks loose the parts of the parcels that river carries away. The reduction of parcels on the Kolubara River banks, land loss and land use changes were estimated comparing the cadastral maps from 1967 and orthophoto images from 2004.

Land use structure in the area of villages: Drazevac, Konatice and Poljane are characterized by: arable land (which people used for farming mostly wheat and corn-crop rotation practice), forests (alluvial forests of willows and poplars) and few pastures. The river dynamic is intensive in the Kolubara's alluvial zone, which influenced sandbank formation, mostly on the concave side of the river. By statistical analysis of a land use structure [24] in the three villages with degraded land parcels on the river banks, we obtained the results which show significant reduction in arable land. And by analyses of the questionnaire carried out among the owners of degraded land parcels in the villages Drazevac, Konatice and Poljane, it can be concluded that it was significant decrease in the agricultural production. The risks from the floods and further soil loss influenced the land owners' decision making about farming the degraded land parcels.

The change of fluvial erosion intensity was analyzed regarding to changes in water balance and sediment load transport on two hydrological profiles. The results of water balance that D. Dukic [25] has made in his research for the period of 1925-1960 and the results obtained in this study were analyzed and compared. This comparative analysis appoints to the amount of water which Donjokolubarski basin disposed before regulatory changes of Kolubara in 1959/60 and after them. River flow regimes of different periods were compared because that could be a factor which has a significant influence on the observed process. All these efforts should confirm or eliminate the influence of natural factors on the river banks degradation in the Donjokolubarska valley.

Having data of extreme discharges, in order to estimate the impact of future floods on bank erosion, we have made a probability curve of maximum discharges of the Kolubara River and its tributaries.

Because of intense anthropogenic impacts in the Donjokolubarska valley, we have sampled the suspended sediments from the Kolubara's riverbed and later analyzed the pollution of the accumulated load. Since the processes of bank erosion and sediment accumulation occur close to the villages and that endangered land parcels are used for food production, such approach points to ecological aspect of researched problem.

The sediment samples were taken on two locations in the Kolubara's riverbed. For heavy metals and carbon analysis the soil was milled to a fine powder. Heavy metals were determined by AAS method.

## 4. The intensity of bank erosion

### 4.1. Natural conditions changes as a factor of bank erosion in the study area

On the research sector (Fig. 1) the Kolubara River length in 1967 was 8.2 km and 10.6 km in 2004. This fact appoints to the river course evolution through the landscape. In the period between 1967 and 1981 the Kolubara River has migrated 50 m, actually 27 m into left and 23 m into right, and the average migration of the Kolubara River was 3.6 m per year. By further comparison of aerial photo image from 1981 and orthophoto image from 2004 it can be observed that the Kolubara's riverbed was stabilized and during 23 years migrated only 26 m. So, the Kolubara River average migration in this period was 1.1 m per year which is three times less comparing to the previous period of observation (1967-1981) [13].

The rate of the Kolubara river lateral migration along the research sector is 47 m in average for the period of 37 years, which means 1.27 m per year. At the most endangered part (in the area of Drazevac village) the most intensive migration rate of the riverbed was 224 m in 37 years, with the average of 6.05 m per a year [15].

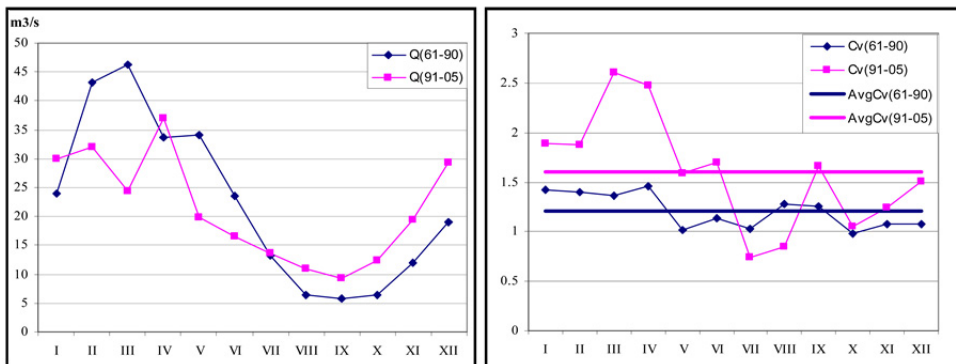
The changes of fluvial erosion intensity may result from changes in climatic-hydrological characteristics of the river basin (which are manifested in discharge regime changes) and various human impacts. Therefore, the natural factors of the Donjokolubarski basin were analyzed to determine whether they have influenced the stronger bank erosion.

The results showed that average mean annual discharge of the Kolubara River measured in Drazevac was 22.3 m<sup>3</sup>/s in the observation period 1961-1990, and 21.3 m<sup>3</sup>/s in the observation period 1991-2005. Amplitude of average high and low flows in the period 1961-1990 was 77.94 m<sup>3</sup>/s, and in the period 1991-2005 it was 64.66 m<sup>3</sup>/s [13].

To study water balance of the Donjokolubarski basin we used the following periods: 1925-1960, 1961-1990 and 1991-2005. With this approach it was possible to determine the changes that may be occurred after diverting the Kolubara River into the Pestan's riverbed in 1959. Briefly, precipitation analysis showed that the second period was a bit wetter than the first, actually about 60 mm in the Pestan River basin and 80 mm in the Turija River basin and the Tamnava River basin. Meanwhile, higher air temperatures and higher evaporation caused almost the same specific discharges of these rivers. The last period was in mean values similar to the second, apart from intensified variation of extreme values of all climatic elements. The discharges were influenced by more frequent alternation of wet and dry periods, which could be seen on figure 2.

Monthly coefficients of variation of the period 1991-2005 are higher in all river sub basins except in July and August. These differences are significant, the variation of discharges in eight months are higher than the highest coefficients of variation of the period 1961-1990, which is 1.5. The more important is the fact that the period of appearances of unstable

discharges is March-April (over 2.5), which is related to snow melting. That is the period of maximum discharges and any sudden disturbance of soil moisture resulting in serious disorder of river bank stability. Some of the natural factors have been changed in the last two decades, for example, March used to be, in Serbia, the month with the most stable discharges (and the highest). The differences in March discharges during the observed periods are over 20 m<sup>3</sup>/s (almost twice reduced), and it was followed by extreme discharge variations. These are the significant changes since the area of the Kolubara River basin is bigger than 3500 km<sup>2</sup> and maximum discharges are higher than 500 m<sup>3</sup>/s. Although the mean values are not of crucial importance, they indicate some disturbances which should be kept in mind; particularly because the last period of observation is twice shorter than the previous one and all analyses in the world indicate that extreme values of natural phenomena are more pronounced and more frequent.



**Figure 2.** Mean monthly discharges (Q) and coefficients of variation (Cv) of the Kolubara River measured in Drazevac gauging station for the both periods of observation

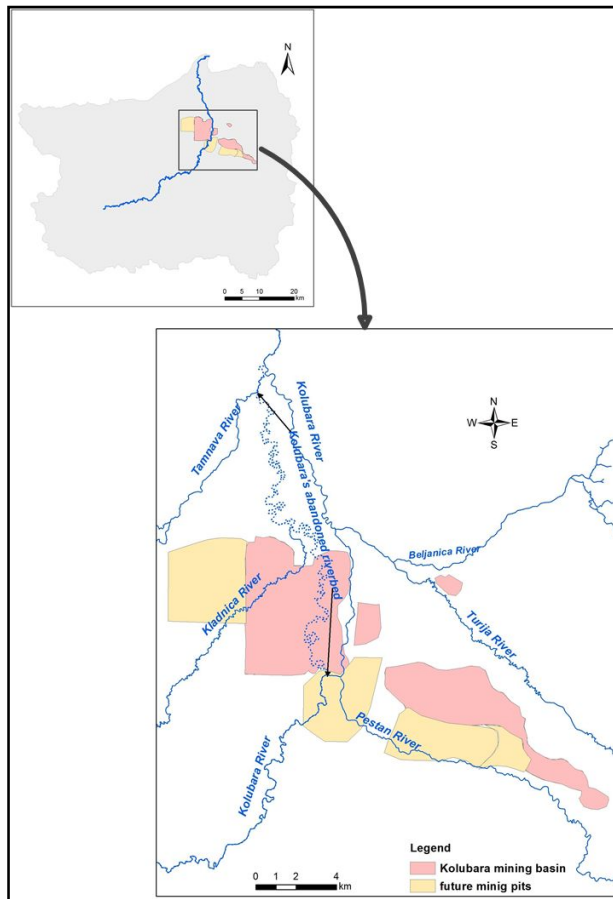
Preliminary results of the Donjokolubarski basin annual flow variation show discrepancy in spring and summer monthly flow among two studied periods (Figure 2 - right). Further research should examine correlation of monthly flow and bank erosion intensity.

#### 4.2. Anthropogenic influences as a factor of bank erosion in the study area

The erosion control works in the river channel can cause changes in river morphology, since they influence the changes in river regimes, river bank characteristics and amount of sediment transport [26]. The consequences of these interventions are numerous, and often lead to riverbed widening and undermining concave sides of the river banks. The processes of river bank collapsing and erosion are complex since they are results of several factors, including sediment transport, ground lithology, stratigraphy, slope, flow geometry and anthropogenic activities [27].

Opencast lignite exploitation in Kolubara mining basin started in 1952 when the mining field "A" was open (it was exploited till 1966). Mining field "B" was opened in 1952, mining

field "D" in 1961, "Tamnava-East Mining Field" in 1979, "Tamnava-West Mining Field" in 1994 and mining field "Veliki Crljeni" in 2008 [28].



**Figure 3.** Plan of the mining fields in Kolubara mining basin [28]

Beogradsko-posavska water community "Beograd" has made a project „Regulation of the Kolubara River and its right tributaries from Čelije to Poljane (km 23+200 – km 55+506)“ in 1957. Regulation works on the Kolubara River and its tributaries had begun in 1959/60. The diverting of the Kolubara River was done to clear the area for lignite exploitation, actually for opening new mining fields.

From that moment the Kolubara River flows through the Pestan's riverbed (its right tributary), and previous Kolubara's riverbed is abandoned with the periodic flow. The length of the Kolubara River was shortened by 20 km because of diverting its riverbed, while the length of the Pestan River was also shortened because its confluence was moved to the South. By diverting the Kolubara's riverbed into the Pestan's riverbed, which

morphologically was not predisposed for kinetic energy of stronger flow, bank erosion became a dominating geomorphological process in the area and initiated processes of digging the riverbanks, transportation and deposition of eroded material. It is obvious that river system changes in lower part of the Kolubara River are demonstrated in domination of fluvial (lateral) erosion on one hand, and in cutting the meanders and fossilization of certain parts of the riverbed, on the other hand.

## **5. The consequences of bank erosion**

### **5.1. Forming of meanders**

Map of the Kolubara's basin first trend of relief energy [2] shows that almost whole area of the Donjokolubarska valley is under tectonic movements of slowly sinking. For this reason the sediments are accumulated in the riverbed, river velocity decreases which cause the riverbed meandering and stronger bank erosion. This natural process became more intensive since the Kolubara River was diverted into the riverbed of Pestan. In the Donjokolubarski basin there are numerous sectors with abandoned riverbeds and cut off meanders.

Forming of meanders and cutting the "necks" are recent geomorphologic-hydrological process, which is dominated in the study area. According to results of the recent researches [13], there are 89 abandoned parts of the riverbeds and cut off meanders in the area of the Donjokolubarski basin. The Kolubara and its tributaries tend to move to the east because of the Kolubarsko-pestanski fault, which indicate more abandoned riverbeds and cut off meanders on the left side of the Kolubara valley (64), compared to the right side (25).

In the study area there are 40 cut off meanders with total length of 20.30 km while the number of abandoned parts of the riverbeds is 49 with total length of 76.03 km. Hence, the total length of all abandoned riverbeds and cut off meanders in the Donjokolubarski basin is 96.33 km, and their total surface is 3.35 km<sup>2</sup>. The longest cut off meander is 1.7 km long and the shortest is 185.7 m long. The longest abandoned riverbed is 6.49 km long.

The length of the Kolubara's riverbed is influenced by stronger bank erosion and formation of meanders, which is clearly perceived in the field. According to orthophoto image from 2004 and satellite image (Google Earth) the Kolubara River length (in the Donjokolubarska valley) is 66.52 km, while according to topographical map from 1970 it was 67.5 km, and according to topographical map from 1925 it was 87.6 km.

After cut off meander, the riverbed itself morphologically adjusts to the new state [29]. Morphological changes of the rivers are reflected in digging the concave river banks and sediment accumulation on the convex river banks.

### **5.2. Land use changes**

As we earlier indicated, river erosion and frequent floods can make great material damages to people, villages and economy. Since the lateral erosion has more intensity, the river banks



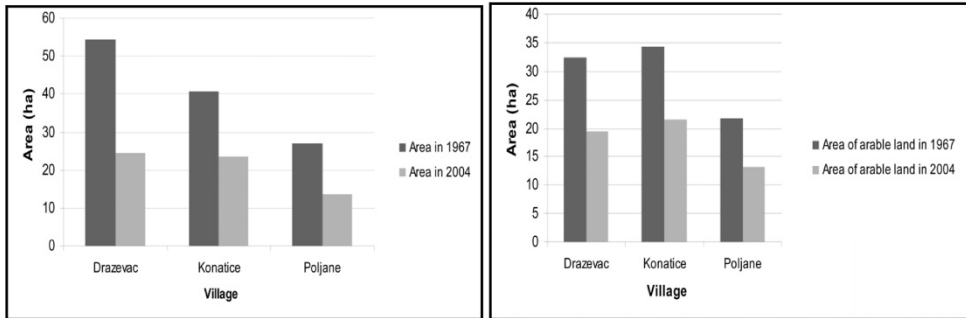
on concave side of the Kolubara River often collapse and farmers who have arable land parcels on the river bank (in the area of three villages the Kolubara flows through) loose the parts of the parcels which were carried away by the river. Based on Cadastral maps from 1967 and orthophoto images from 2004 we have estimated the area of diminished land parcels and their land loss.

Farmers who have land parcels in three villages (Drazevac, Konatice and Poljane) on the Kolubara river bank cannot farm them in whole, because the river has changed its course and took some parts of the land parcels away. The cadastral maps of the researched area scale 1:2500 from 1967 and orthophoto images from 2004 were compared. Using the results of this comparative analysis, the evolution of the hydrological system in the period from 1967 to 2004 was presented. The previous research showed that 60.37 ha was lost and degraded by the river bank erosion, which means that the land loss is 50.57 % of the land parcels from 1967 [15].

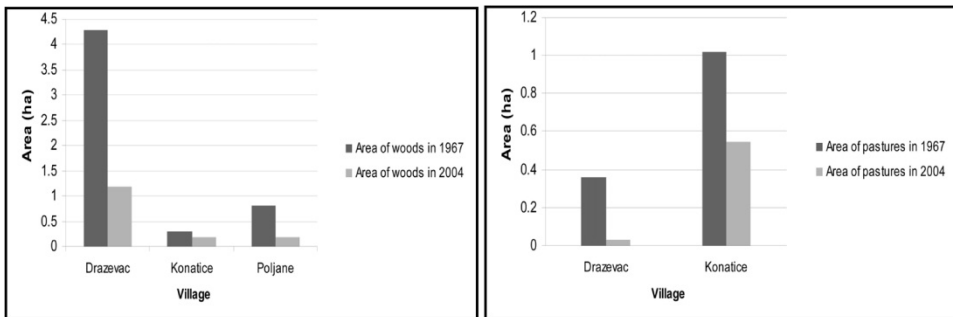
Land use	Total	Arable land	Woods	Pastures	Meadows	Sand banks	Other (roads...)
<i>Drazevac</i>							
number of endangered parcels	95	39	16	1	5	34	-
area in 1967 (ha)	57.76	34.96	5.56	0.25	2.93	14.07	-
area in 2004 (ha)	28.23	21.76	2.48	0.02	1.30	2.67	-
loss of land (ha)	29.53	13.20	3.08	0.23	1.63	11.40	-
<i>Konatice</i>							
number of endangered parcels	86	56	2	2	-	25	1
area in 1967 (ha)	50.44	42.73	0.49	1.02	-	6.12	0.09
area in 2004 (ha)	32.13	29.57	0.34	0.55	-	1.60	0.06
loss of land (ha)	18.31	13.16	0.15	0.47	-	4.52	0.03
<i>Poljane</i>							
number of endangered parcels	66	41	3	-	-	21	1
area in 1967 (ha)	40.09	33.91	0.82	-	-	5.11	0.25
area in 2004 (ha)	26.26	25.15	0.19	-	-	0.89	0.03
loss of land (ha)	13.83	8.76	0.63	-	-	4.22	0.22

**Table 1.** Land use structure in Drazevac, Konatice and Poljane.

On the basis of the recent and more accurate data from Obrenovac Municipality Cadastre we have determined land use structure of degraded land parcels on the Kolubara River banks. According to these data, total area of all 247 endangered land parcels was 148.3 ha in 1967, and 86.62 ha in 2004. Therefore, 61.68 ha of soil were lost within 37 years [13].



**Figure 4.** Land use changes in total area (left) and area of arable land (right) in Drazevac, Konatice and Poljane between 1967 and 2004



**Figure 5.** Land use changes in area of woods (left) and area of pastures (right) in Drazevac, Konatice and Poljane between 1967 and 2004

From 247 endangered land parcels, 136 are arable land with the area of 111.6 ha in 1967, and 76.48 ha in 2004, which means that within 37 years 35.12 ha of arable land was lost for farming, and it is 31.5 % of the initial area (in 1967). The woods comprise 21 of all endangered land parcels with area of 6.87 ha in 1967, and 3.01 ha in 2004, which means that it has been lost 3.86 ha of woods. There are only the three endangered land parcels with pastures, and their area was 1.27 ha in 1967, and 0.57 ha in 2004. All five endangered land parcels with meadows are in the area of Drazevac village.

Analyzing the area of endangered parts in the three villages, one can conclude that erosion was the most intensive in the period 1967-1981, when 50.9 ha of soil was lost within 14 years. The riverbed was stabilized later and the erosion decreased. This appoints to the fact that diverting the Kolubara River into the Pestan's riverbed caused more intensive bank erosion since in time erosion was diminished which brought to the riverbed stabilization.

Three villages on the Kolubara River banks (Drazevac, Konatice and Poljane) were characterized by agricultural production and agricultural population. Analyzing the land use structure of endangered parcels one can conclude that arable land parcels are the most endangered and degraded by intensified lateral erosion of Kolubara.

In Serbia there is 4.25 million ha of arable land, and each year 500000 ha (which means 11.74 %) of arable land remain uncultivated [30]. In the above mentioned three villages 33.47 % of arable land (on the Kolubara River banks) remain uncultivated, which is three times more than the average in Republic of Serbia. During the field work, the interviewed owners of endangered arable land parcels pointed that they do not farm their land on the river banks because of flood risks. The Kolubara River floods almost every year and crop is ruined. Therefore, besides the loss of arable land, frequent floods are huge problem in this area.

The economic consequences of bank erosion in the area of the Donjokolubarski basin could be analyzed through losses that the owners of endangered arable land parcels had (because the arable land parcels were reduced). The area of arable land (on the river banks) was diminished by 35.12 ha within 37 years. In the research area the average annual yield is 3-4 t per hectare, so the annual losses of crops (mostly wheat and corn) in recent years are between 100 and 140 t per year.

### 5.3. Sediment load discharge

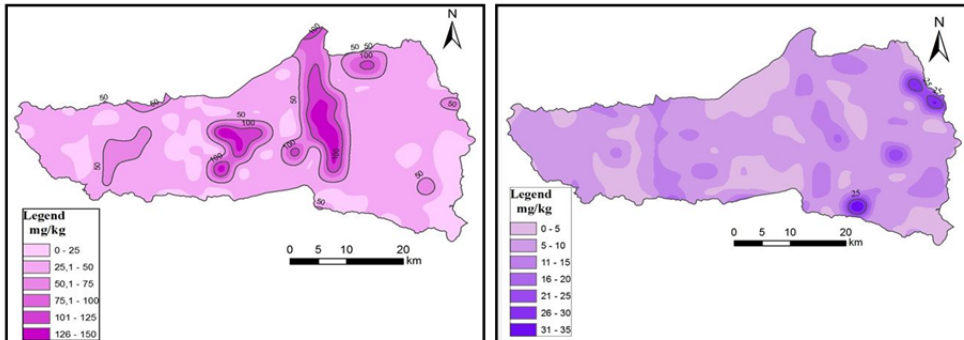
Changes of land use structure and changes in sediment regimes are the direct consequences of the bank erosion [22]. The calculation of one-day sediment load discharge at the monitored hydrological profile includes the values of mean daily flow ( $Q - m^3/s$ ) and the relevant concentration of the suspended load ( $C - mg/l$ ). The assessment of sediment deposition rate is based on the results of RHMSS [31] measurements and the results of own daily measurements of suspended load concentration during the period (1985-2004). The results show that 193253.8 tons of material was accumulated between two hydrological profiles. And the riverbed itself was raised for 36 cm, which is nine times enlarged comparing to previous research when it was raised for 4.2 cm (with a shorter time series) [2]. The extraction of the river deposited sediments from the Kolubara's riverbed was stopped. Although the river deposits were hand extracted with low intensity, it certainly had great positive effects from the aspect of maintaining the surface of riverbed profile. Simple solutions, like the river deposit extraction, do not need huge investments for the implementation and they can be carried out without limitation of the natural conditions.

REIK Kolubara has a negative ecological impact on the Donjokolubarska valley. There are lots of waste waters after the ore production. Waste waters from the mine "REIK Kolubara" are discharged without any treatment into the Kolubara River. Therefore, the Kolubara River contains waste waters from the mine and after each flood the soil on the river banks is contaminated by substances from the waste waters. The results of soil analysis in the Kolubara river basin show increased concentration of nickel, arsenic and lead in the area of the Donjokolubarski basin [18].

The eroded material from the river banks is accumulated downstream. The accumulated sediments can contain considerable concentrations of heavy metals and that is threat for the aquatic habitats and for the people [8, 32-34].

Ecological aspects of mechanical water pollution by suspended sediment, chemical water pollution by organic and mineral fertilizers used in plant production in the catchment,

nutrients found in the soil as well as chemical pollution of water and sediment by pesticides and heavy metals are very important ecological problem in the study area. On two locations we have sampled the accumulated material from the Kolubara's riverbed to examine the transport of contamination and accumulation of contaminated sediments due to bank erosion processes.



**Figure 6.** Distribution of Ni (left) and As (right) in the soil of the Donjokolubarski basin [18].



**Figure 7.** Sampling of deposited sediments on location 1 (left) and 2 (right)

The deposited sediments have sandy-clay texture. Chemical characteristics of deposited sediments from Kolubara's riverbed are: mildly alkaline reaction, high bases saturation degree and low humus content. The average heavy metal concentration in sediments decreased in the order: Ni > Cr > Zn > Pb > Cu > Cd.

In Serbia there is no law defining limitation of heavy metals in suspended sediments. Some European countries have such laws [34], but the differences between countries are significant. In most of the cases the critical values are obtained using the equilibrium method and maximum acceptable concentration (MAC) for the surface waters with regard to direct and indirect effects on living organisms in the water-sediments systems. According to these data, the range for different elements is as follows: 15 - 100 mg.kg<sup>-1</sup> for Pb; 0.6 - 2.4

mg.kg<sup>-1</sup> for Cd; 36 - 120 mg.kg<sup>-1</sup> for Cu; 123 - 1050 mg.kg<sup>-1</sup> for Zn; 10 - 180 mg.kg<sup>-1</sup> for Ni and 37 - 120 mg.kg<sup>-1</sup> for Cr. These ranges are bigger than estimated ecotoxic criteria [35], which are: 5 - 50 mg.kg<sup>-1</sup> for Pb, Ni i Cu; 0.1 - 1.0 mg.kg<sup>-1</sup> for Cd; 50 - 500 mg.kg<sup>-1</sup> for Zn; 10 - 100 mg.kg<sup>-1</sup> for Cr.

Sample	Zn	Cu	Pb	Cd	Cr	Ni
	mg.kg <sup>-1</sup>					
Location 1	39.3	15.9	23.0	0.0	94.0	198.3
Location 2	41.0	20.2	27.9	0.1	103.0	210.9

**Table 2.** Heavy metal contents in the deposited sediment load.

Respecting the above mentioned criteria, mean measured concentration of Pb, Zn and Cr are within the limits (after de Vries and Bakker [35]), while concentration of Cu and Cd are below the limits and concentration of Ni are above the limits. According to OSPAR limitation values [36], average concentrations of Pb, Cu and Cd are below the limits, average concentrations of Cr and Zn are within the limits, while average concentrations of Ni are above the limits.

#### 5.4. Floods

The Kolubara River is a good example which represents the existence of all conditions for frequent and large scale floods. As an indirect consequence of the anthropogenic influence on the hydrological system in the lower part of the Kolubara valley, once a year (sometimes twice a year) the Kolubara River overflows, and the area of lower part of the Kolubara River basin is endangered by floods. Catastrophic floods of the Kolubara River and its tributaries spread over the area of lower part of the Kolubara River basin during the spring of 1937, and they lasted two months approximately (from March to May). In this area large scale floods also happened in 1965, 1975, 1981, 1996, 1998, 1999, 2001, 2004, 2006, 2008 and 2010.

The highest discharge of the Kolubara River in the period of 1959-2000 was 646 m<sup>3</sup>/s and it was registered on Drazevac hydrological station. According to probability curve of high discharges the discharge of 646 m<sup>3</sup>/s may occur once in a 46 years. The lowest value of annual maximum discharge would be about 25 m<sup>3</sup>/s, the highest discharge in a hundred years would be 740 m<sup>3</sup>/s, and the highest discharge in a thousand years would be 960 m<sup>3</sup>/s. During the first decade of XXI century almost every two years the flood wave was bigger than the biggest one which occurs once in a fifty years. Huge flood waves were occurred in 2001, 2004, 2006, 2008 and 2010. The last flood in December 2010 had already reached the maximum value which occurs once in a hundred years (according to probability calculation (until and including) year of 2000)). Since the floods are directly and indirectly related to bank erosion these data should be included in bank erosion analysis because their analogy is proved, although there is no quantification of their correlation. Therefore, researches should be focused on causes of floods, and on reduction of bank erosion uncertainties. Many factors that influence the Kolubara River floods are already known. Firstly, there is a difference in

flows in the upper and lower part of the Kolubara River basin. The drainage conditions in the upper part are more favorable. The area of hydrological profile Slovac is less than 1/3 of the whole basin, but it drains a half of all waters in the Kolubara River basin. Downstream hydrological profile Beli Brod encompasses a half of the basin, and its discharge is 3/4 of Kolubara's discharge. In the Donjokolubarski basin the drainage conditions are different, and the most significant factor is slope (the slope of the river flow and the slope of the river basin). The distance between Beli Brod and the Kolubara's confluence with the Sava River is 50 km and the altitude difference is 20 m. The present slope of 40 cm/km (0.4 ‰) is declining every year due to intensive sediment accumulation in the riverbed. Relating these processes with the shape of the river basin and rapid concentration of water downstream of the Beli Brod, it does not surprise that Kolubara River "ramp" over its alluvial plain. Moreover, in the last decade there is simultaneity of frequent rains of high intensity with extended duration and sudden snowmelt, and that is the reason for increased concern. Considering that rivers in the sub basins are mostly torrential, this concern is even more enhanced. Additionally, in this area rivers were diverted to bring the economic benefits. Because of all these reasons, the life in the coastal zone of the Kolubara River basin is gloomy but real with lot of uncertainties.

In order to prevent the frequent floods there are a several plans to deal with the actual situation in the area. Construction of several small accumulations on the Kolubara's tributaries is at its first phase, but there is no indication for solving the existing water problems. There is an idea to channelize the Kolubara's riverbed for sailing (i.e. for the transportation of lignite from the Kolubara mine), but it is still in the early phase of planning, although the initiative appeared long time ago. The height difference between the Kolubara's River confluence with Sava River and the location of lignite exploitation in the Kolubara mine basin is 23 m [12]. This height difference and the wideness of the Kolubara's riverbed would facilitate its riverbed training works, enabling cheaper lignite transportation from the Kolubara mine basin. Training works the Kolubara's riverbed and its preparation for lignite transportation could easily be carried out, so the invested means would be economically justified. Thus, the meandering flow would be straightened, and the strong bank erosion in the riverbed would be regulated which means that some factors of flooding would be eliminated.

## 6. Conclusion

Bank erosion, soil loss, sediment load deposition, changes in the river course, floods, landslides, soil and water pollution are the major environmental problems in the Kolubara River basin which could be aggravated by the land-use changes. The solutions for all mentioned environmental problems demand a complex analysis of the area characteristics and development of the strategy for solving the existing water problems in this area, but in the same time they have to provide necessary conditions for the further lignite exploitation. Some villages are located in the lower part of the Kolubara River basin, in the area which is planned for the expansion of the Kolubara mining basin, so it is an important factor for the future sustainable landscape planning.

Hydrological network of the Donjokolubarski basin is constantly changing due to natural factors and anthropogenic impacts. The damage which is done cannot be compensated, but even worse is the fact that no one feels responsible and that the population in this area is still left to the mercy of torrential river. Numerous calls for helping endangered people and goods were sent to the different addresses, but no one tried to help. Apparently, the problem goes beyond the “values” of a few villages and the state interest (lignite exploitation) has absolute priority, like in the case of neighboring Dubrava and unique sources of Obrenovac Municipality [34]. This situation lasted till the catastrophic floods in June 2010, when the shocking images of flood damage terrified the publicity, and problem could not be ignored anymore. As an attempt to repair the flood consequences, during 2010 two dikes were constructed with the length of 200 m in total. The first location was repaired for bridge protection, and the second one for household protection. The total cost of construction works was 100 000 euros. Since, the total length of all degraded river banks of first category is about 5 km; the economic profitability of this repairing method is questioned. It made sense in the initial phase of degradation, but now it goes beyond the reality of existing situation. It seems that, after the construction of two dikes, somebody tries to justify the negligence, because it is obvious that these two dykes are insufficient to solve the problem. In cases like this one, even not doing anything for protection of degraded areas represents a serious violation of principles of sustainable management of natural resources, actually that is an offence. The responsible for effects of the changes in the Kolubara River basin is still unknown, is it nature or man?

Making the constant pressure on state institutions through various appeals, indicating to unsustainability of current situation 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 Kolubara River in the Donjokolubarski basin is a logical solution and our contribution, with particular results and recommendations, to fight for the basic human right to live without fear from hazards.

What kind of message can be sent to people living in this area and dealing with above mentioned problems? As they say, finding that the state does not protect them from the problems that come upon them, they give up farming the parcels of endangered area (along the river). The even more irrational, is the fact that they still pay taxes on the parcels, which does not exist anymore or they are significantly reduced, because the taxes calculation is made according to Cadaster from 1967! The estimation of all unnecessary loss of land, land values, personal losses of individuals and damage done to whole community is in the course. At the time when the personal status is far beyond collective responsibility due to difficult economic situation, this scientific approach is the only way to inspire the responsible ones in finding the solution.

This research could be the warning for the future anthropogenic activities on the river system since the new changes on the hydrological network were planned in this area. The four new mining fields should be opened, and if it happens, the hydrological network will be changed again and new problems will appear in the river basin.

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