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ANALYSIS OF THE KOLUBARA DRAINAGE BASIN AND IMPACTS OF THE RIVER ON THE TOWN OF VALJEVO AND ITS SURROUNDINGS

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ABSTRACT
After heavy rains and floods in 2014 that hit western Serbia, the river Kolubara burst its banks, inflicting heavy damages to the town of Valjevo and its environment. This region has the specific climatic factors characterized by a rapid melting of snow and periods of heavy rainfall in spring. As a result, the erosion and damages occur in the steep terrains devoid of forests or other vegetation, as well as the extensive floods in the alluvial plains of the Kolubara river. This paper will analyze a part of the Kolubara river drainage basin upstream of the town of Valjevo. We will show the individual analyses and calculation of water level, flow rate, amount of precipitation, etc. The worse consequences of heavy rainfall include floods, erosion in the river basin and river bed, as well as their impacts on forests, agricultural and building land. The data analysis will provide a clear picture of the assessment of future flood risks and erosion, suitable and unsuitable terrains, remediation systems, as well as flood protection systems. In this respect, it is also necessary to clearly define the planning guidelines and integrated development of the sectors and services at all levels of government.

Keywords: the river Kolubara, floods, erosion, forests, protection, planning

1 INTRODUCTION

The drainage basin of the river Kolubara is situated in the northwestern part of Serbia, fringed by middle and low mountain ranges of Valjevo and Sumadija, and the gently hilly terrain with which it opens up towards the Pannonian basin. It covers the territory of approximately 3.600km^2, shaped as an irregular rectangle, 80km in width in the west-east direction (from Vlasici to Kosmaj), and 60km in length in the north-south direction. The river Kolubara and its tributaries spring in the hilly-mountain area, in their middle reaches run through the gently hilly area, while the rest of the drainage basin predominantly lies in the plains. Mean altitude of the river Kolubara drainage basin is around 206m above sea level. The Kolubara is the central river in the basin. It forms near the town of Valjevo from the river Obnica, which springs at the foot of the Kulina hill, 924m above sea level, and the river Jablanica, springing at the foot of the Povlen range, 1,000m above sea level. Both the Obnica and the Jablanica are 28km long and run through the terrain with large oscilations in altitudes – the average gradient of the Obnica is 26.5‰ and the Jablanica 29.3‰. Near the town of Valjevo, the river Kolubara joins the river Gradac, and the downstream tributaries are plenty, such as the Lepenica, the Ribnica, the Toplica, the Ljig, the Lukavica, the Vranicina, the Pestan, the Turija (with the Beljanica), and the Tamnava (with the Ub and the Gracica).

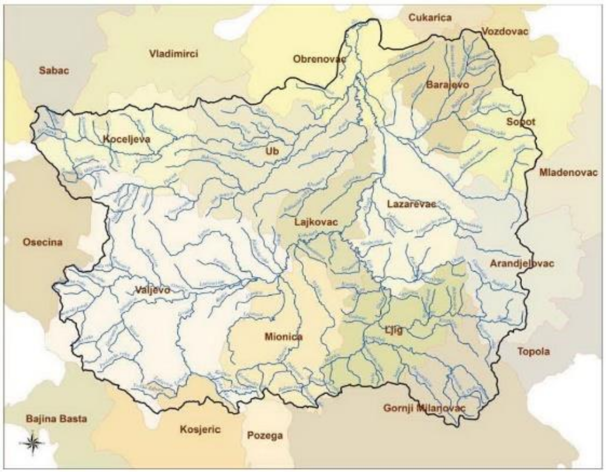
The town of Valjevo covers the area of 905 km^2. The town is surrounded by the following municipalities: Ub and Koceljeva in the north, Osecina and Ljubovija in the west, Kosjeric i Pozega in the south, and Mionica and Lajkovac in the east. In the administrative sense, it belongs to the Kolubara administrative district. According to the Law on regional development (*The Official Gazette of the Republic of Serbia*, no. 51/09 and 30/10), the town of Valjevo belongs to the regions of Sumadija and Western Serbia. Traffic and geographical position of the town are determined by its relation to other territorial units in Serbia and the region, as well as by its natural characteristics, which, along the river valleys in the east-west and north-south directions, enabled good traffic communication of the town with the city of Belgrade, the Republika Srpska, the Autonomous Province of Vojvodina and southwestern Serbia. According to the 2011 census, Valjevo had 90,312 inhabitants. The population growth in 1948–2011 (index: 128.2) was somewhat higher than the average population growth in Central Serbia (index: 126.5). At the same time, there was a decrease of the population in the Kolubara administrative district (index: 90.6, growth rate: 1.5‰). Population growth between censuses was always low; between the last two censuses (2002–2011) the population decreased by 6,449 citizens.

2 THE RIVER KOLUBARA DRAINAGE BASIN AND ITS IMPACT ON THE TOWN OF VALJEVO AND ITS SURROUNDINGS

The territory of the town of Valjevo consists of valleys, kettle depressions and gorges mostly belonging to the Kolubara drainage basin, and to a smaller extent to the Drina and Moravica basins. The

Kolubara drainage basin encompasses parts of the basins of rivers Kolubara, Gradac and Ub, and complete basins of the rivers Jablanica and Obnica. The Drina drainage basin encompasses a part of the basin of the river Zavojstica, while the Moravica drainage basin includes the stream basins (the Taor) in the south-western slopes of the Valjevo Mountains (Spatial Plan of the Town of Valjevo, 2013).

Figure 1. The Kolubara drainage basin



Source: *http://www.sepa.gov.rs/download/prezentacije/2013/3Osnovne_karakteristike_sliva_Kolubare.pdf*

Table 1. Magnitude of drainage basins in the town of Valjevo

Basin/river	Area	
	km^2	%
The Kolubara basin	873.55	96.5
The Kolubara	240.75	26.6
The Jablanica	166.54	18.4
The Obnica	211.59	23.38
The Gradac	158.18	17.47
The Ub	96.49	10.66
The Moravica basin	8.21	0.09
The Drina basin (Zavojstica)	23.51	2.6
Total	**905**	**100.00**

Source: Spatial Plan of the Town of Valjevo, 2013

Rapid meltdown of snow in the mountains and heavy spring precipitation cause heavy floods in the alluvial planes of the river Kolubara and its large tributaries. The heaviest floods affect large areas of arable, building and other types of land in the valleys of the Kolubara basin. The average drainage density of the river network in the Kolubara basin is low, totaling around 400m/km². The size of the river network largely depends on lithological composition of the terrain, relief and precipitation, which in the Kolubara basin are not particularly beneficial for the creation of watercourses. The large number of watercourses are active torrential flows and it is estimated that there are 700 of them in the area. The upper parts of the Tamnava, the Ub and the Ljig basins are especially prone to intensive erosion (https://sh.wikipedia.org/wiki/Kolubara_%28reka%29).

The term “flood” denotes, generally speaking, the incidence of the water leaving the river bed due to heavy precipitation, rapid snow cover meltdown, abrupt overflow from accumulations, seismological phenomena and similar. In broader sense, however, the term “flood” covers temporary partial or total flooding of a certain area of dry land due to: the spill or the overflow of rivers, streams, canals, lakes; heavy atmospheric precipitation and rapid snow cover meltdown; storm surges; tsunamis; river or sea waves; mud streams; breakage of facilities for harnessing water (dams and floodgates); the increase of the groundwater level; the return of communal wastewater into the sewer, and similar. River overflows are caused by heavy rains that fall for days or even weeks and saturate the ground. Tributaries bring large amounts of water into the river bed, which soon becomes too small for all the water. Embankments on both banks of the river secure its continuous flow towards the sea. However, if the additional water exceeds the capacity of the river bed or if the protection against floods does not function, it results in the long-lasting excessive floods.

Water regime in the Kolubara basin is quite unfavourable, affected by hydrometeorological, topographical, geological and hydraulic conditions in the basin. Unfavourable temporal and spatial distribution of precipitation and excessive gradients of tributaries, together with unfavourable layout of hydrographic network of watercourses, regularly cause rapid and concentrated runoff in relatively short section of the central part of the Kolubara valley.

The climate of Valjevo and its surrounding is humid continental, with specific characteristics that can be classified as sub-humid and microthermal. The average annual temperature in 2001–2010 was 11.2°C. The warmest month of the year is July, with the average temperature of 21.1°C, while January sits on the opposite end of the scale, with the average annual temperature of 0.8°C. The average level of precipitation, recorded in Valjevo meteorological station in 2001–2010, was 781mm (Видојевић, 2016). The wettest month is June, with 110.2mm of rainfall, while the driest month is February, with 44.3mm of rainfall. Snow falls in Valjevo on average 30.9 days a year, and on the highest altitudes of Mount Povlen over 60 days. In the large part of the Kolubara and the Tamnava basins snow cover stays on average 40 days a year. In the altitudes above 700m, the snow is present on over 90 days, and on Mount Povlen over 120 days (http://www.serbianmeteo.com/forum/index.php?topic=1438.0).

Naturally unfavourable characteristics of large watercourses in the Kolubara basin are aggravated by anthropogenic influence. The outflow of water is intensified by deforestation and destruction of other natural vegetation, as well as by enlargement of urbanized areas with increased runoff coefficient and runoff speed as compared to their natural condition. Forests are one of the most important resource of the environment and their role is manifold. Forests are natural habitats for numerous plant and animal species, they produce oxygen, prevent erosion, take part in purification of water and soil, provide building and fire material, they are a place suitable for recreational use, tourism and science. According to the Article 5 of the Serbian Forest Law (The Official gazette of the Republic of Serbia, no. 30/2010 and 93/2012), a forest is an area of land larger than 5 ares overgrown with forest trees, as well as a forest nursery within forest complex, a seed plantation a protective tree belt larger than 5 ares. Forests are one of the main factors in prevention of erosion and protection against torrential floods. The soil is protected from erosion in several stages. In the first stage the land is protected against the raindrop impact, and/or a breakdown of the soil aggregate and disturbance of its porosity and infiltration capacity. Another protective role of forests is that the roots of trees bind the soil together and interweave with other roots, forming a more solid mass. Tree-tops intercept and absorb large amount of precipitation, which gradually percolate and partly evaporate from the surface. Plant litter on forest floors withholds, physically and chemically filtrates and then gradually releases water that infiltrates the soil. Such ground-water runoff prevents erosion. All the factors mentioned above urge us to nourish and protect the existing forests and plant new ones.

The areas exposed to floods in the past are now protected by means of defensive embankments along the river banks. Watercourses have been bridged by numerous bridges, which have additionally raised the level of water. Frequent flood flow comes as a consequence of, among other things, poor conditions of water beds, which are clogged with detritus and often waste matter. Single or combined effects of unfavourable natural and anthropogenic factors in most watercourses in the Kolubara basin have caused serious deterioration of flood flow regimes, namely the increase of extreme discharge, the increase of water level, the shortening of flood flow waves duration and the increase of their volume. In the time of global climatic changes, which for now cannot be quantified for the Kolubara basin, further deterioration of flood flow regime is expected (Study of Improving the Protection from High Waters in the Kolubara Basin, 2015).

In the extreme meteorological conditions and excess flooding in 2014, the whole sub-basin of the Kolubara river was exposed to substantial rainfall. Increased runoff from the mountain slopes led to the creation of flood waves in riverbeds of left and right tributaries, which almost simultaneously poured into the river Kolubara. In sections protected against floods, in built-up areas and in lower parts of the courses, water gushed out of river beds, destroying embankments on its way. Soon there was no embankment in the Kolubara drainage basin that was not breached or damaged.

According to the Water management basics of Serbia from 1977, geological composition of land in the large part of the Kolubara drainage basin was prone to erosion: 4.9% of the territory was exposed to markedly severe (class I) erosion, 11.5% of the territory to the strong (class II) erosion, 63.5% to the medium or weak (classes III and IV) erosion, while the remaining 20.1% was exposed to slight erosion. Some additional studies on the state of erosion and mountain torrents for certain parts of the basin were performed after that (Water management basics of Serbia).

Erosion destroys the structure of the land, creating, carrying or washing away the sediment. Such degraded soil cannot be used. However, there are some other ways in which erosion can destroy the soil: compactness or devastation of the soil structure and its increased porosity due to the usage of heavy mechanization or excessive pasturage are also types of erosion (Bezbradica 2013).

Erosion can be perceived through the following phases: the denudation phase or the wearing away of the Earth's surface by different factors; the ablation phase or the removal of material from the surface; and the accumulation phase or the deposition of the eroded material. The term corrosion denotes the solution and removal of sediments from river banks, while the term suffosion denotes the erosion caused by ground water. As for the causing factor, erosion can be divided into the following types:

- **water erosion** – caused by the activity of water (it can be divided into regional or pluvial, caused by the activity of rain; fluvial, caused by the activity of river water; glacial, caused by the activity of glaciers; and ground erosion or suffosion, caused by the activity of ground water);
- **aeolian erosion** – caused by the activity of wind (it can be divided into weak surface aeolian erosion, medium surface aeolian erosion, strong surface aeolian erosion and deep or linear aeolian erosion), and

- **abrasive erosion** – caused by the activity of the sea and other types of waves (Kostadinov 1996).

Around 70% of the town's territory is exposed to erosion, mostly to the erosion of the classes III, IV and V, i.e. medium or weak processes (84.2%), while the upper courses of the rivers Jablanica, Susica and Gradac are exposed to the excessive, class I erosion. Because of the steep inclination of the tributaries' drainage basins, flood flows run down in short periods of time, and in the Kolubara's central valley their torrential waters cause destruction, floods and bring sediment to the agricultural land, create obstacles in river beds which force river to meander heavily and cause great damage to the settlements, industry, roads, etc. Erosion leaves behind great material and non-material damage, which in some cases is irreparable. In the initial phases of the erosion process, the surface, the most fertile, organic layer of the land is removed, leading to negative pedologic conditions and the loss of vegetation, which is the main safeguard of the soil. When the vegetation disappears, the erosion processes grow stronger and bring on more and more infertile sediment, which covers the fertile land and the remaining plants, contributing to the creation of torrential streams and floods, covering accumulations, etc. After the waves of the river Kolubara flood flows run through the town of Valjevo, numerous damages, smaller of greater in extent, could be seen in the regulated river bed and banks, which diminished the protective function of the river regulation. During the works in the regulated bed of the river Kolubara during the construction of the magistral water pipeline "Rovni", the main stabilization objects on the left bank along the river course were damaged or destroyed. That greatly affected the regulation of the river bed through the town of Valjevo during the floods in 2014.

Figure 2. Damage caused to the left bank of the river Kolubara's regulated bed *Source: Malesevic Dj., Valjevo*

Potential damage on the larger scale encompasses everything that can be jeopardized by the flood: population, animals, housing, infrastructure, movable property, open spaces (yards, parks and gardens), in addition to the industry and crops. The criteria for determining potential damage to the population is the number of people exposed to the risk of flooding. Damages done can be analyzed on the international, regional and local level, depending on the size of the basin and the characteristics of the flood waves. More extensive and serious floods in the town of Valjevo and its surrounding were avoided thanks to the "Stubo-Rovni" damn with the accumulation, which is still under construction and which partly absorbed the flood wave. Regional water management system "Rovni" is one of the most important water management systems in the western Serbia. The most significant facility in the system is the eponymous damn and the accompanying accumulation. The "Rovni" damn is situated on the river Jablanica, some 15 km upstream from the town of Valjevo, between village Stubo on the right bank and village Rovni on the left bank. When finished, the damn will form an accumulation up to normal backwater elevation level.

3 THE ANALYSES OF A PART OF THE RIVER KOLUBARA BASIN

Drainage basin of a river is an area with specific, mutually interdependent physical geographical processes and phenomena. The parameters of a drainage basin reveal a set of characteristics in terms of hydrology, vegetation, climate, morphometry, etc. All those characteristics are crucial for optimal planning and management of the area and all the activities in it. Basic morphometric parameters of the drainage basin in question up to the river mouth profile of the Jablanica and the Obnica, are the following:

- **magnitude of the basin area** (in square kilometres), as an auxiliary parameter to a number of other parameters, totals 340km^2;

- **basin perimeter length** (in kilometres), which is the length as measured along the entire drainage basin boundary or drainage divide, totals around 70km;
- **compactness ratio**, which is the ratio of the basin perimeter to that of the equivalent circle. If its value is below 1.0, the shape of a basin is close to a circle and the concentration of flood flow is the quickest. Its value for the Kolubara basin is 1.20, and the basin is in the shape of a fan.

Basic hypsometric parameters are:

- **mean altitude of the river basin** (in metres), according to which all basins are classified as low-lying, hilly, hilly-mountainous and mountainous, totals 550 metres above sea;
- **maximum relief elevation at the river source** (in meters) totals 1,200m;
- **minimum relief elevation** (in meters), which always corresponds with the elevation of the river mouth, totals 200m;
- **relative slope of the course** (in percentage or per mille), an important parameter of the river basin, used in many formulas determining characteristics of flood flows in ungauged rivers, totals 4 ‰;
- **average slope of terrain** (in percentage or per mille), which determines the runoff speed, sediment discharge, erosion, torrential floods and floods, totals 16.66 %.

Basic hydrographic parameters of the drainage basin are:

- **length of the river** (in kilometres), as the main hydrological datum for the identification of the river network, for both the Jablanica and the Obnica totals around 30km each;
- **total length of the river network in the drainage basin** (in kilometres), which denotes hydrographic development of the basin – the larger the basin, the more developed the basin and the quicker the water runs off into the river network, for the Kolubara river totals around 80km;
- **density of the river network** (in kilometers per square kilometer), which is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin. The density is lowest in low-lying and in karst basins, and the highest in mountain areas. If the value of the density is between 1.0 and 2.0, the density is considered high. In this case it equals 0.30 km/km^2.

One of the basic vegetation parameters of the drainage basin is:

- **forest coverage coefficient** (the bigger the coefficient, the larger the area of the basin covered in trees, the more favourable the runoff and the smaller the chances for the erosion to take place), which totals 0.3.

One of the basic geomorphological and geological parameters of the drainage basin is:

- **discharge capacity coefficient** – it is one of the most important elements in analysing the regime of surface and ground-water runoff and it is directly linked to pedological and geological composition; the coefficient runs from 0.4 for the terrains with high infiltration capacity to 1.0 for the terrains with no infiltration capacity. For the part of the Kolubara basin discharge capacity coefficient is 0.7 (Оцокољић, Милијашевић).

Table 2. Discharge for the part of the basin at the mouth of the Obnica and the Jablanica

River / marks /periods	Q_{max} – m³/s				
	1,000–0.1%	100–1%	50–2 %	10–10 %	2–50 %
The Kolubara, Valjevo	500	100	266	173	73

Source: Malesević, 2016

Table 3. Discharge for the part of the basin at the mouth of the Obnica and the Jablanica

River	Qmin – m³/s
The Kolubara (Valjevo)	0.91

Source: Malešević, 2016

4 IMPROVEMENT AND PROTECTION OF THE RIVER KOLUBARA BASIN

Frequent floods and substantial damages caused by the floods in the river Kolubara basin, especially the magnitude of the flood wave in 2014, urge for urgent improvement of protection against floods and the creation of conditions for better flood risk management in line with the spatial and economic development of that area. Flood protection issues in the river Kolubara basin are closely connected to different geomorphological characteristics and phenomena. Watercourses in the upper parts of the basin are prone to torrential floods, characterized by short duration, high velocity of streams and massive transport of sediment. In the lower parts of the basin, on the other hand, flood flow waves are considerably slower. The protection against floods in the low-land parts of the river Kolubara basin is a topical issue for several decades. The severity of the issue was especially stressed after the latest floods in 2014, when population, industry, infrastructure and natural resources along the river Kolubara and its tributaries suffered grave damages and consequences.

Projects concerned with the flood protection should enable, with the certain level of acceptable risk, the security of the housing and other economic and social systems and facilities, land and other property from the damaging activity of water. Flood protection and watercourse management should in the first place be realized by means of combined investment active and passive measures, as well as non-investment protection measures as a part of integral water management system. The investment measures can basically be divided into passive (linear systems, embankments, regulations) and active measures (accumulations, retentions and channel systems). Non-investment measures, which play highly important role in flood protection, comprise of the complex of measures, out of which safety measures, limiting the development of certain facilities in the areas exposed to floods, are of high importance because those measures prevent damage from potential floods. Protection against erosion include implementation of biological anti-erosion measures (afforestation, raising grass strips, terracing, contour ploughing, etc.) and technical anti-erosion works (construction of different facilities in order to reduce the terrain inclination and the velocity of water, to stop the sediment transport, etc.)

A special measure against floods are administrative bans and limitation of rights of land owners to freely use their land. Improvement of the flood protection in the Kolubara basin should be based on the concept of integral protection, comprising the following: anti-erosion management of the whole drainage basin, accumulating water in the upper parts of the basin, forming retention areas, and development and reconstruction of flood protection structures and facilities. Development of flood protection systems must be in line with the laws on water management, environment protection, spatial development of towns/municipalities, and on planning in the electric power industry and other supporting infrastructural systems. Flood protection facilities in the basin of the river Kolubara and its tributaries are erected with the view to providing security to the area in case of excessive flood flows with a return periods of 50, 100, even 1,000 years in certain cases.

In the last few decades a number of construction projects aimed at managing torrential streams and erosion protection have been undertaken. Land registries of torrential streams in this area have not been updated for years now, so there is no precise and systematic data on these works. For decades, the works have been undertaken partially and many facilities are out of order by now, so they in no way affect the situation regarding torrential floods. In a large number of spatial plans flood protection is predominantly treated as a general concept with guidelines. Planned facilities and works aimed at flood protection are neither precisely defined spatially nor graphically presented. The exceptions are planned facilities and works for the flood protection of mine pits in the Special purpose plan for the Kolubara lignite basin. In the analyzed spatial plans the planned flood protection facilities and works are not directly connected with the facilities in infrastructure systems, but will have indirect effects, which for the purpose of this analysis cannot be linked to any infrastructure facility. In the spatial plans for special purpose areas of the highway Belgrade – South Adriatic Sea and the railway Valjevo – Loznica, there is no mentioning of any planned flood protection facilities or works, since the solutions to that issue are usually laid out in technical documentation. Flood risk management is a permanent process of decision-making on whether and how floodable areas should be used, with a certain, tolerable level of risk. On each examined potentially or actually floodable area there is an array of different conditions that should be considered in order to reach a decision on combining strategies and supporting measures for the reduction of ever-present risk of floods (Study of Improving the Protection from High Waters in the Kolubara Basin, 2015).

An adequate choice allows for consideration of a larger number of different combinations of measures, the effects of which are assessed by one of the known methods (such as multicriteria analysis, for example). While at it, the activities in the floodable area must be considered in the context of their impact on the whole river basin, since each part of the basin depends on other parts, so that a decision on the regulation of one part of the basin can have an undesirable effects on other parts (for example, urbanisation in the upper parts of the basin accelerates runoff and creates torrential floods, while the erection of embankments on one part of the river basin can worsen the situation along the watercourse). In addition, the surveyed floodable area must be viewed as a part of certain territorial (town, village) and administrative whole (municipality, county, etc.). Possible administrative strategies and measures are considered not just for so far unprotected

floodable zones, but for those with already developed protective facilities as well (Study of Improving the Protection from High Waters in the Kolubara Basin, 2015).
In the river Kolubara basin it is important to establish an integral approach to the flood risk management. This means to define a strategy for the whole river basin, with an adequate combination of investment (construction or structural) and non-investment works and measures, based on the estimation of costs, assessment of technical feasibility, impact on the environmental and social acceptability of these measures and works (Study of Improving the Protection from High Waters in the Kolubara Basin, 2015).

5 CONCLUSION

In the river Kolubara basin it is important to establish interdisciplinary cooperation on both national and local level in the sectors of water management, environment protection, spatial and urban planning. That would secure a required level of harmonization of planning high waters and flood protective measures and usage of space (land usage, development of infrastructure, urban and rural settlements, etc.) It is necessary to establish a set of administrative, regulatory and institutional measures for preventive minimization of direct, indirect and potential damage from floods, such as safety and operational measures, regulatory and institutional measures, solidarity measures for reducing the negative effects of floods or informing the public. In addition, by adopting the corresponding laws, strategies and plans, it is possible to establish balance between growing demands for further urbanization and economic exploitation of river banks and the need that certain spaces be reserved for regulation of runoff and containment of water within basins, which is an important measure for the improvement of preventive protection and risk reduction.

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