THE SAVA PLAIN: DEFINITION, DENOMINATION, DELINEATION AND SUBDIVISON (GF 2019 THEMATIC ISSUE)

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Abstract: The Sava River based its fluvial architecture compromised its upper- and lower courses. The Sava River upper course starts at Radovljica and continues downstream till Krško while from Krško till Belgrade is the Sava lower course. The Sava upper course is positioned in the mountain valley and characterized with headwaters. The Sava lower course positioned in the lowland area.

The Sava Plain encompass the lowermost, almost flat surface of plain segments of the Sava valley and lower plain segments of its tributaries. The Sava Plain surface geology composed of Holocene fluvial, as well as Pleistocene alluvial and eolian sediments. According to the Holocene fluvial architecture of the Sava river three significant parts can be defined as the Krško-Samobor Plain, the Upper- and the Lower Sava Plain. The Upper Sava valley represents the Krško-Samobor Basin from Krško downstream till the Podsused Gate. The Upper Sava Plain covers the Sava plain in between Podsused Gate downstream to the Slavonski- and Bosanski Brod or the Brod Gate. The Lower Sava Plain ascends from Brod Gate downstream till the mouth of the Sava to the Danube in Belgrade.

The Krško-Podsused Plain and the Upper Sava Plain channel planform type characterized with the gentle meandering river architecture its area composed of Holocene fluvial sediments, while the Lower Sava Plain with meandering river architecture of Pleistocene fluvial and eolian sediments and Holocene fluvial sediments.

Keywords: Sava River; Upper Sava Plain; Lower Sava Plain; Sava valley; geomorphological subdivision.

Introduction

The Sava River originates from two headwaters Sava Bohinjka and Sava Dolinka which joint at Radovljica (Upper Carniola, Slovenia). It mounts to the Danube is in Belgrade (Serbia). The Sava River 990 km length, including the 45 km long course of Sava Dolinka and catchment area of 97,713 km^2. The Sava River catchment encompasses 12% of the Danube basin, draining into the Black Sea.

The Sava River represents in terms of water volume the greatest tributary of the Danube and the second-largest tributary of the Danube (after the Tisza) by its length and in terms of catchment area.

Main geographical studies were focused on the Sava Basin / catchment area (Fig.1.) regarding its hydrological and climatic features, while the Sava valley was

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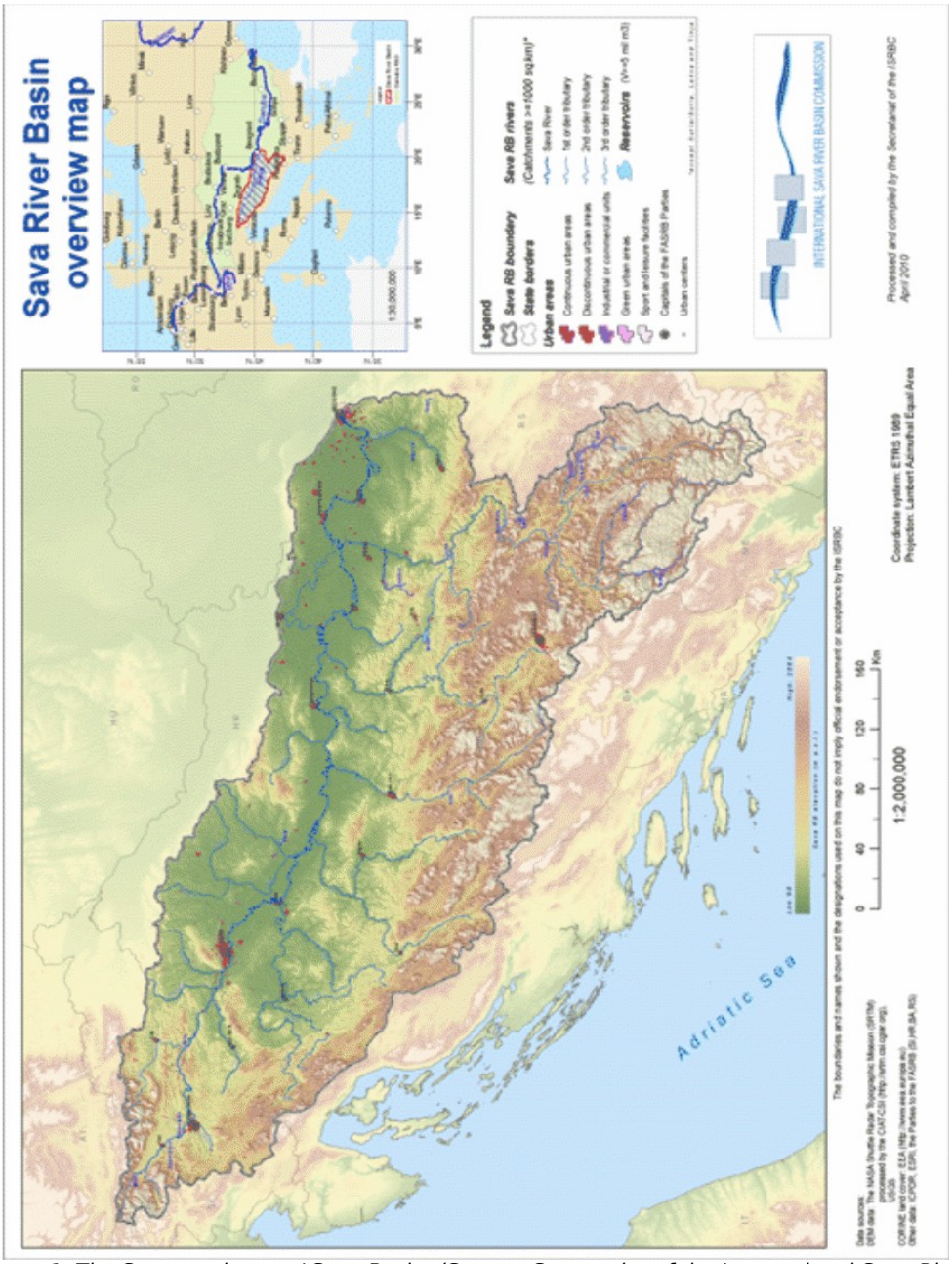


Figure 1. The Sava catchment / Sava Basin. (Source: Secretariat of the International Sava River Basin Commission)

not in the focus of investigations (e.g. Cvijić, 1924, 1926; Dukić, 1959) except on hydrogeologic, flood and hazards analysis (e.g. Bačani et al., 1999). According to its relief and surface geology only the segments of the Sava valley were analyzed regarding its geology, hydrology or geomorphology (e.g. Nikolić, 1985; Gaudenyi et al, 2015; Brkić, 2017)

The aim of this paper is to define, delineate, denominate and to propose the subdivision of the Sava river plain according to the main landform categories.

Geographical Setting of the Sava valley

The the area of investigation of this study is the Sava valley. The upper Sava valley is from the north limited with the Karavanka Mts on the South with the Julian Alps. The lower Sava valley bordered on the north with Kalnik, Medvednica, Moslavička Gora, Psunj, Babja Gora, Dilj Gora, Fruška Gora Mts. in the south bordered with Žumberačka Gora, Samobroska Gora, Vukomeričke Gorice, Zrinska Gora, Kozara, Prosara, Motajnica, Vučjak, Trebava, Majevica, Cer (*cf.* Bertić & Križovan, 1987). The Sava valley is a part of four countries (Slovenia; Croatia; Bosnia and Hercegovina; Serbia). The Sava valley relief get its final form in the Holocene due to the neotectonics, fluvial processes (sedimentation and accumulation), eolian processes, slope process and anthopogenic impacts.

The lower Sava valley area in paleogeographic context

The results and developments of the geological investigations seems do not follows with further reconstructions of the past environments and the paleogeography. After a very successful petrographic and mineralogical analysis of Quaternary sediments in Easten Slavonia (e.g. Mutić, 1989, 1990, 1993) and investigations of the Pleistocene glaciations of Julijan Alps, Kamnik-Savinja Alps and Karavanke Mountains and its forelands (e.g. Bavec & Verbič, 2011 and references therein) it became evident that some statements regarding the paleogeography of the Sava River should be rewritten.

The late Cretaceous to Eocene collision of the crustal blocks followed by the Miocene uplift and extension of the Pannonain craton. The tectonic extension, accompanied by volcanism, was coeval with the uplift the surrounding Alpine orogenic belts, which largely separated the epicontinental Paratethyan domain from the Mediterranean oceanic Tethyan domain (Rögl, 1999; Rundić et al, 2016). The early to middle Miocene pre- and syn-rift deposits in the Pannonain Basin show a transition from conitntal alluvial-lacustrine to fully marine environments (Ter Borgh et al, 2013). The peak of extension was reached in the Badenian-Sarmatian rifting phase (ca. 15-11 Ma) at the eastern part of the Carpathian Basin to the Fruška Gora Mts. (Fodor et al., 1999). The long-lived Lake Pannon formed at the middle/late Moicene boundary (ca. 11.6 Ma) as a consequence of the tectonic uplift of the Carpathians that separated the basin from marine influences (Rundić et al, 2013 and refernces therein). It took more than 7 Ma for the large Pannonian Basin to be filled with lacustrin and fluvio-deltaic sediments derived by the erosion of the surrounding orognenic belts (cf. Magyar et al, 1999, Radivojević et al, 2014). At the beginning of the Pliocene the semi-brackish Lake Pannon evolved in the smaller lake denominated Paludina Lake due to the high sediment influx and neotectonics. The significant differences beside its size that the Lake Pannon was semi-brackish while the much smaller Paludina Lake was freshwater (Rundić et al, 2013).

The Paludina Lake existed till the beginning of the Quaternary when it transformed to the Pleistocene river system. The forming of the Pleistocene river system (and vanishing the lake system) in the area of the Carpathian Basin was the

beginning of the Quaternary on the stratigraphic scale. The evidence was record in the changes in the *Viviparidae* malacological assemblages (e.g. Gaudenyi et al, 2015). The Pleistocene Paleosava River represents quite different fluvial system which originate in Bosnia. The Bosnian rivers gave the main water volume, while the enstanite and kaemmerite record show their provenance from central Bosnia (Pamić, 1970, Grafenauer, 1975, Mutić, 1993) confirms the existence of Plesitocene river systems from central Bosnia to the Sava valley. These ultramafic rocks and chromite deposits which found in the Pleistocene Paleosava river sediments in Slavonia their origin confirmed as the area of Konjuh and Duboštica. In the same time the Julian Alps and Karavanke Mts. belonged to the glacial and periglacial realm and rivers such as the Sava River cannot formed in the mentioned environmental conditions (Bavec & Verbič, 2011).

The Sava River system was developed in the Holocene with stable climatic and neotectonic conditions recognized by their headwaters (Sava Bohinjka and Sava Dolinka) which were formed in the area of Slovenia.

Table 1. Evolution of the lower Sava valley area during the last 12 million years (after Ćalić et al., 2012; modified).

Paleogeograpic unit	Stratigraphic frame	Numeric age time frame
Lake Pannon	middle Miocene – early Pliocene	~11.6 - ~4.5 Ma
Paludina Lake	early Pliocene - end Pliocene	~4.5 - ~2.6 Ma
Paleosava	Pleistocene	~2.6 - ~0.1 Ma
Sava	Holocene	~0.1 Ma

Material and Methods

The to anayzed the area of the Sava valley 21 DEM-s of 30m resolution were used from the Earth Explorer DEM collection of the United States Geological Survey (https://earthexplorer.usgs.gov) which were merged using QGIS software. The pixel resolution used in our case was 100 x 100 m.

The surface geology of Quaternary sediments were analyzed by the basic geologic maps of former Yugoslavia at scale 1 : 100,000 (e.g. Buser, 1977; Buzaljko & Marinković, 1986; Cajhen et al., 1970; Galović et al., 1989; Jovanović & Magaš, 1986; Šikić et al., 1971; Šparica & Buzaljko, 1984; Šparica et al., 1980, 1987) and other geologic maps of lower resolution (Čičić, 2002; Croatian Geological Survey, 2009). The main aim was to disseminate the Pleistocene and Holocene sediments which constitutes the Sava River plain. It served as a control mechanism in case of application of the surface roughness.

The study beside the geologic surveying data for the study, on the DEM the roughness tool from QGIS Software used for the delineation of the Sava Plain.

“Tools to analyze and visualize DEMs outputs the single-band raster with values computed from the elevation. Roughness is the degree of irregularity of the surface. It is calculated by the largest inter-cell difference of a central pixel and it surrounding cell. The determination of the roughness plays role in the analysis of terrain elevation data., it is useful for calculation of river morphology and physical geography in general, is derived from the GDAL DEM utility” (QGIS 2.8 User Guide). The DEM resolution 100 x 100 m was chosen. With the tool “Roughness” of QGIS software we separate the surface roughness in five classes. The plain terrain of the Sava valley was defined with roughness coefficients of 0-5. Later the generalization and the manual delineation was drown. The division of the plain in the Sava Valley was based on boundaries between the Sava Plain segments was on tectonic boundaries according to the position of the Gates.

Results

Definition and Denomination

If we look back Finch et al., (1957) one of the seminal work of the North American physical geography published after WWII the major classes of the terrain based upon similarities and differences with respect of main characteristics: relatively amount of gently sloping land, local relief, and generalized profile. Plains were defined as surfaces having a gently sloping land coupled with local relief. Within the broad limits allowed by this definition, however plains exhibit a surprising degree of variety. Some approach as near to perfect flatness as it is possible for a land surface to become, while others are so rolling or dissected as barely to avoid being classed as hills. Some are marshy or seasonally waterlogged, while others are arid sand, gravel or soil. Some are rock-floored; others are surfaced with permanent snow or ice. Some are lie near the sea level while others are thousands meters higher. The only statement that apply to all are that most most of their slopes are gentle and that the differences in elevation within limited areas are small.
The Sava Plain limited to the mainly meandering alluvial and fluvial surfaces, connected planform lower segments of its tributaries and loess plateaus along the alluvial plain of the lower course of the Sava River, from Krško downstream till Belgrade. So the alluvial plain of the Sava River cannot be the synonymous to the Sava Plain which is encompass wider area long the Sava River.

Figure 2. Classification of structures and faults of the Sava valley (cropped from Prelogović et al., 1998).

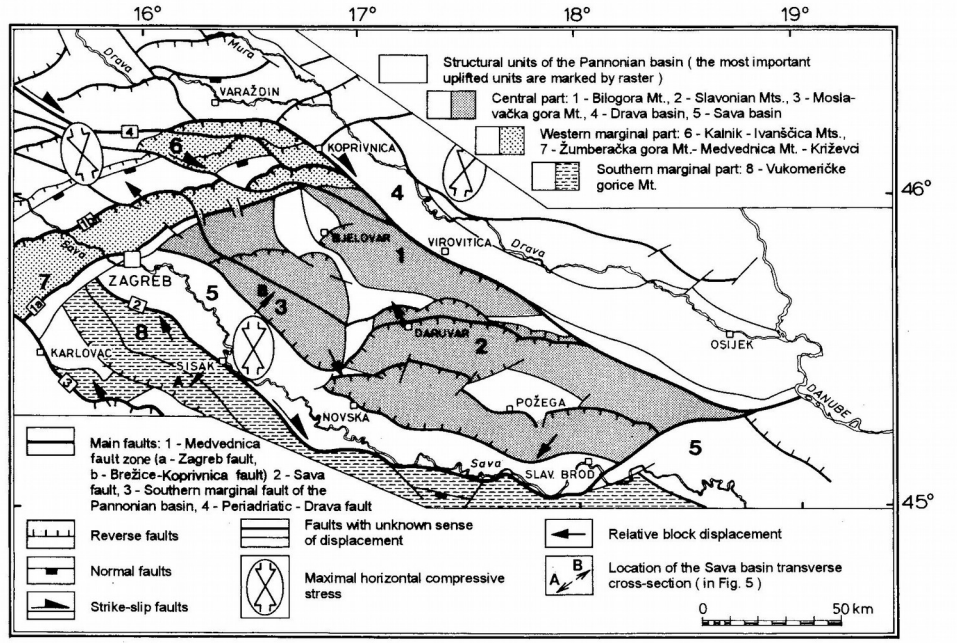
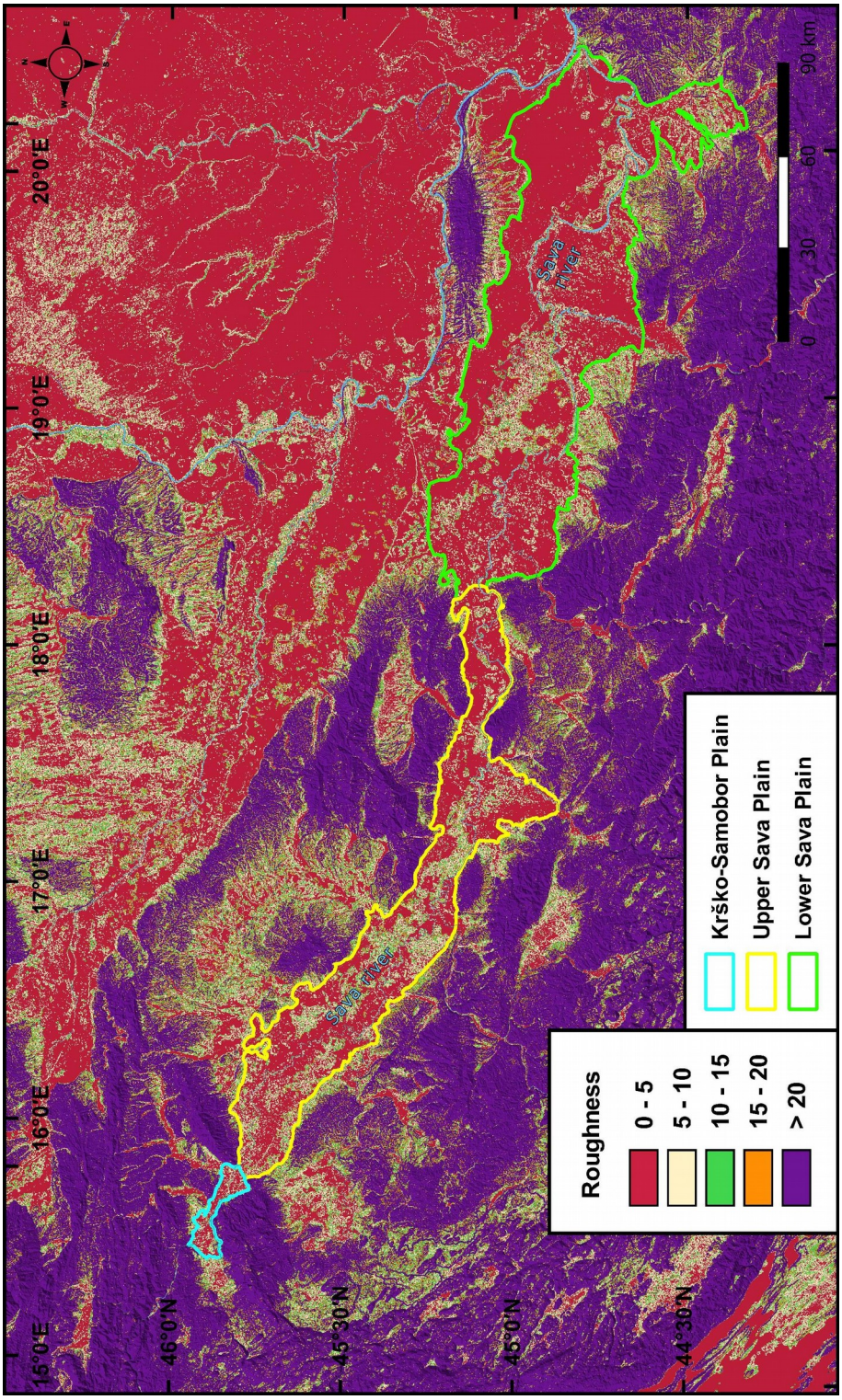


Figure 3. Subdivision of the Sava Plain based on the DEM of surface roughness cofficients.



Delineation and Subdivision

The Sava Plain area shown based on the surface roughness on Fig. 3. It was evident that two fluvial bottlenecks identified. These bottlenecks are the Podsused Gate (in Serbian: *Podsusedska probojnica*) and the Bosanski- and Slavonski Brod transect or the Brod Gate (in Serbian: *Brodska probojnica*). Both Gates also identified in the fault system of the Sava region (e.g. Vukašinović, 1973a, 1973b, 1975; Prelogović et al., 1998) (Fig. 2). The Podsused Gate is genetically connected to the Zagreb fault at Žumberačka Gora – Medvednica Mt. - Križevci contact with the Sava Basin, while the Brod Gate on the Sava faults at the contact of Sava Basin and the Slavonian Mts (cf. Prelogović et al., 1998) (Fig. 2). These geodynamic phenomena serve for the subdivision Plains align the lower Sava course. Three plain segments identified the Krško-Samobor Plain, the Upper Sava Plain and the Lower Sava Plain.

The Krško- and Samobor Basins already defined and denominated by Nikolić (1985). The **Krško-Samobor Plain** encompass the lower plain segment of the Sava River from krško till Podsused as well as its tributaries: the Krka-, Sutla- and Krapina Rivers (Fig. 3). The meandering character of the river is not visible nowadays clearly on the relief due to river regulation works e.g. in 1775 (Pick, 1910) and later changes (e.g. Dukić, 1957). Its surface geology shown only fluvial sediments (*sensu* Šikić et al., 1972; Cajhen et al., 1970; Buser, 1977).
The **Upper Sava Plain** encompass the plain segment of the Sava River valley along from Podused Gate and Brod Gate. Beside the Sava fluvial relief including the lower plain relief of the Kupa-, Una- and Vrbas Rivers. It is surficial geology composed exclusively of fluvial sediments (Fig. 3).
The **Lower Sava Plain** encompass the plain segment of the Sava River and the lower plain segment of its tributaries Bosna, Drina, Bosut, Kolubara. As well as the whole Mačva Plain and south part of the Srem Loess Plateau. Beside fluvial sediments it encompass the eolian sediments (loess) (Fig. 3).

Discussion

The QGIS tool “Roughness” was first time tested for the Western Balkan countries. The DEM resolution 100 x 100 m shows similar results as used in the paper of Ćalić et al. (2012) which based on the subsequent calculations and analyses were by using the raster-based GIS software Idrisi Andes®. In that case the SRTM was resampled from 90 x 90 m grid cells to 200 x 200 m grid cells. The 5 x 5 cells were gathered into a moving window for calculation of average elevation within a window. In our case when have to make a further generalization. The surface roughness coefficients in the also shown the surface roughness coefficient lower than 5 indicated the plain relief (same cofficients as in Ćalić et al, 2012). However nearly same results got with more simplified method by using QGIS “Roughness” tool. The control checking were don applying the results in the the Basic Geologic Map of Yugoslavia at scale 1:100,000, where the Neogene and Quaternary slope sediments must excluded.

The denomination of Sava Plain is not restricted to the area exclusively to Sava floodplain and terraces. The Sava name used in the context of the area of the Sava River valley with some segments of its tributaries. Due that the prevailing and most visible was the Sava River in each maps and models we choose the name Sava Plain.
The Krško-Samobor Pain formally should be the Upper Sava Plain. However, due its previously used contesxts of the Krško- and Samobor microbasins (Nikolić, 1985). We trying to keep this geographical toponimes in the denomination. We exclude the

Krško-Samobor Plain from the Upper Sava Plain because not formally the Sava area of Sisak and Zagreb often in the unformal context mentioned upper Sava region (Serbian/Croatian: Gornja Posavina). The two segments of the Sava Plain are separated with the Podsused Gate and cannot form the same segment of the Sava Plain. There are also significant differences in the area which encompass the segments of the Sava Plain. The Krško-Samobor Plain is narrower and smaller, while the Upper- and Lower Sava Plain area wider and greater segments of the Sava Plain.

Conclusions

The Sava River Catchment or the Sava Basin represents the catchment area which exceeds 97,713 km^2 (Fig. 1.)

The Sava valley defined the valley from the confluence of Sava Dolinka and Sava Bohinjka at Radovljica till the mouth of the Sava River mouth to the Danube at Belgrade. The upper Sava valley defied eariler, it ascents till the Podsused Gate, while from Podsused Gate downsream is the lower Sava valley.

The Sava River upper course starts at Radovljica and continues downstream till Krško, from Krško till Belgrade is the Sava lower course.

Along the Sava lower course we can define the Sava Plain. The complex Sava Plain have 3 segments. These are: the Krško-Samobor Plain, the Upper Sava Plain and the Lower Sava Plain. The mentioned segments are divided by the Podsused- and the Brod Gate (Fig. 2).

The Krško-Samobor Plain formed in the Krško- and Samobor microbasins (defined after Nikolić, 1985) and represents the lower plain relief of the Sava river alluvial plain and the plain segments of its tributaries (Krka, Sutla, Krapina). The surface geology of Krško-Samobor Plain shown only fluvial sediments.

The Upper Sava Plain formed on fluvial sediments of the Sava River and its tributaries from Bosnia, Zagorje and Slavonia.

The Lower Sava Plain formed the on Fluvial sediments of the Sava River its tributaries in Srem, Bosnia and Šumadija as well as eolian sedimens of the south parts of the Srem Loess Plateau.

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