European Journal of Environment and Earth Sciences
Vol 5 | Issue 5 | September 2024
ISSN 2684-446X

RESEARCH ARTICLE

Hydrogeological Regions of Kolubarska Posavina (Central Serbia)

Đorđije Božović[1], Tivadar Gaudenyi[2,*], and Draženko Nenadić[3]

ABSTRACT

The groundwater catchments of the Kolubarska Posavina are of significant importance because if some contamination affects the groundwater system, it is necessary to find a quality groundwater source for the water supply of Obrenovac Municipality. Reconstruction of sedimentary evolution plays a significant role in the investigation of groundwater catchment. In this study, the variation in sedimentary characteristics and sedimentary evolution/paleogeography were studied for Quaternary catchment identification in Kolubarska Posavina. The groundwater catchment of the Kolubarska Posavina can distinguished into two main parts. The western part of Kolubarska Posavina is identified as the Sava groundwater catchment, where the Sava alluvial plain and the (paleo) meanders of the Sava are located. The east part belongs to the Kolubara groundwater catchment, characterized by the remnants of the (macro) alluvial fan of Kolubara and the Kolubara floodplain. The Kolubara catchment is located eastwards from the older meander of the Sava River.

Keywords: Belgrade Groundwater Source, Groundwater Provinces, Kolubarska Posavina, Serbia.

Submitted: August 13, 2024

Published: September 28, 2024

10.24018/ejgeo.2024.5.5.483

[1] *Belgrade Waterworks and Sewerage, Serbia.*
[2] *Geographical Institute Jovan Cvijić of the Serbian Academy of Sciences and Arts, Serbia.*
[3] *Faculty of Mining and Geology, University of Belgrade, Serbia.*

* ***Corresponding Author:***
e-mail: t.gaudenyi@gi.sanu.ac.rs

1. Introduction

The Kolubara River, a right-hand tributary of the Sava River, is situated in western Serbia within the Šumadija region of Central Serbia (Fig. 1). Its catchment area covers around 4.12% of the country's total territory. The highest point in the watershed is Povlen Mountain, which rises to 1346 m above sea level, while the lowest point is at the river's confluence with the Sava River, which is at 76 m above sea level [1], [2].

With a flow length of 86.4 km and a basin area of 3641 km^2, the Kolubara River is considered a medium-sized river basin in Serbia (Fig. 1). The catchment area is notable for its high population density, housing approximately 317,000 residents, which equates to about 87 people per km^2. This underscores the river's significance for the local population and its impact on the regional environment and economy [1], [2].

Kolubarska Posavina, denominated by Jovanović [3], encompasses the lowland area along the right bank of the Sava River, including the mouth of the Kolubara River. The area of Kolubarska Posavina encompassed the former meanders of the Sava River and the former "delta" of Kolubara River. Basically area bordered from the west by villages Debrc and Provo, from the south the village of Grabovac, eastwards will the village of Barič, while its north boundary is the Sava River.

The previous research on the Kolubara River basin has involved geomorphological analyses to evaluate the main erosion processes and measure their intensity [4]–[6]. These analyses have shown a rise in landscape degradation and changes in geomorphological processes caused by human activities over the past few decades [7]. This trend has been influenced by rapid demographic, socio-economic, and technological developments in Serbia, the region, and worldwide [8]–[14].

The Kolubara River basin, in terms of both the extent and nature of degradation, is among the most at-risk areas in Serbia. The exploitation of lignite within the basin has had a profound impact, leading to significant morphological changes and affecting various geomorphological processes. These impacts include alterations in the river's course [15], [16], increased bank erosion [17], [18], sediment deposition [19], and other environmental problems [20], [21].

Climate change is leading to more frequent extreme weather events, which in turn raises the risk of river flooding and triggers a range of environmental disturbances, such as potential contamination of agricultural soils. In

Fig. 1. The Kolubara River catchment in Serbia [2].

Serbia, the devastating floods of 2014 impacted six river basins, including the Kolubara River Basin. This basin, a significant sub-catchment of the extensive Sava River Basin, is marked by its vast agricultural areas, diverse geological substrates, and various types of industrial pollution [22].

There is no doubt that the most important town in the area of Kolubarska Posavina is Obrenovac. The water supply for the settlements Kolubarska Posavina is based on local groundwater sources. Obrenovac Municipality belongs to the City of Belgrade and its Belgrade Groundwater Source. Groundwater provinces are delineated based on the distribution and characteristics of Quaternary sediments within a region. They represent areas where the geological and hydrological conditions of the Quaternary sediments significantly influence groundwater resources. In case of some hazards, if some contamination affects the groundwater system, it is necessary to find a quality groundwater source for the water supply of Obrenovac Municipality.

The Kolubara- and the Sava Hydrogeological Regions are dynamic and multifaceted areas with significant implications for regional water resources and environmental health. Understanding its geological and hydrogeological characteristics is essential for effective management and sustainable development. By addressing challenges related to water quality, resource management, and contamination control, stakeholders can work towards a balanced approach that supports both human needs and ecological sustainability.

2. Materials and Methods

Surveying the Quaternary sediments of Kolubarska Posavina involves a systematic methodology to understand the geological history and current dynamics of rivers.

2.1. Literature Review and Background Research

Begin by reviewing existing geological maps, reports, and studies of the region to understand the broader geological context and previous findings related to the river system, e.g., [23]–[25].

2.2. Field Surveying

Conduct initial field visits to observe the river's morphology, floodplain, alluvial fan and oxbow lake sediment characteristics, and surrounding geological features. Identify potential sampling sites based on accessibility, diversity of sediment types, and geological interest. The methodology was followed by Jones *et al*. [26].

2.3. Sediment Sampling

Select representative sampling locations along the points of interest, i.e., river channel and floodplain. A sampling at open exposure and hand drilling on sites of potential interest. Collect sediment samples using various methods, including hand coring. Ensure samples cover a range of depths and locations to capture variability in sediment composition and age. The methodology was followed by Jones *et al*. [26].

2.4. Stratigraphic Interpretation and Chronological Reconstruction

Published geological maps at a scale of 100,000 we used [23], [27]–[30]. In our case, going further in detail was not the aim and was relevant for this study.

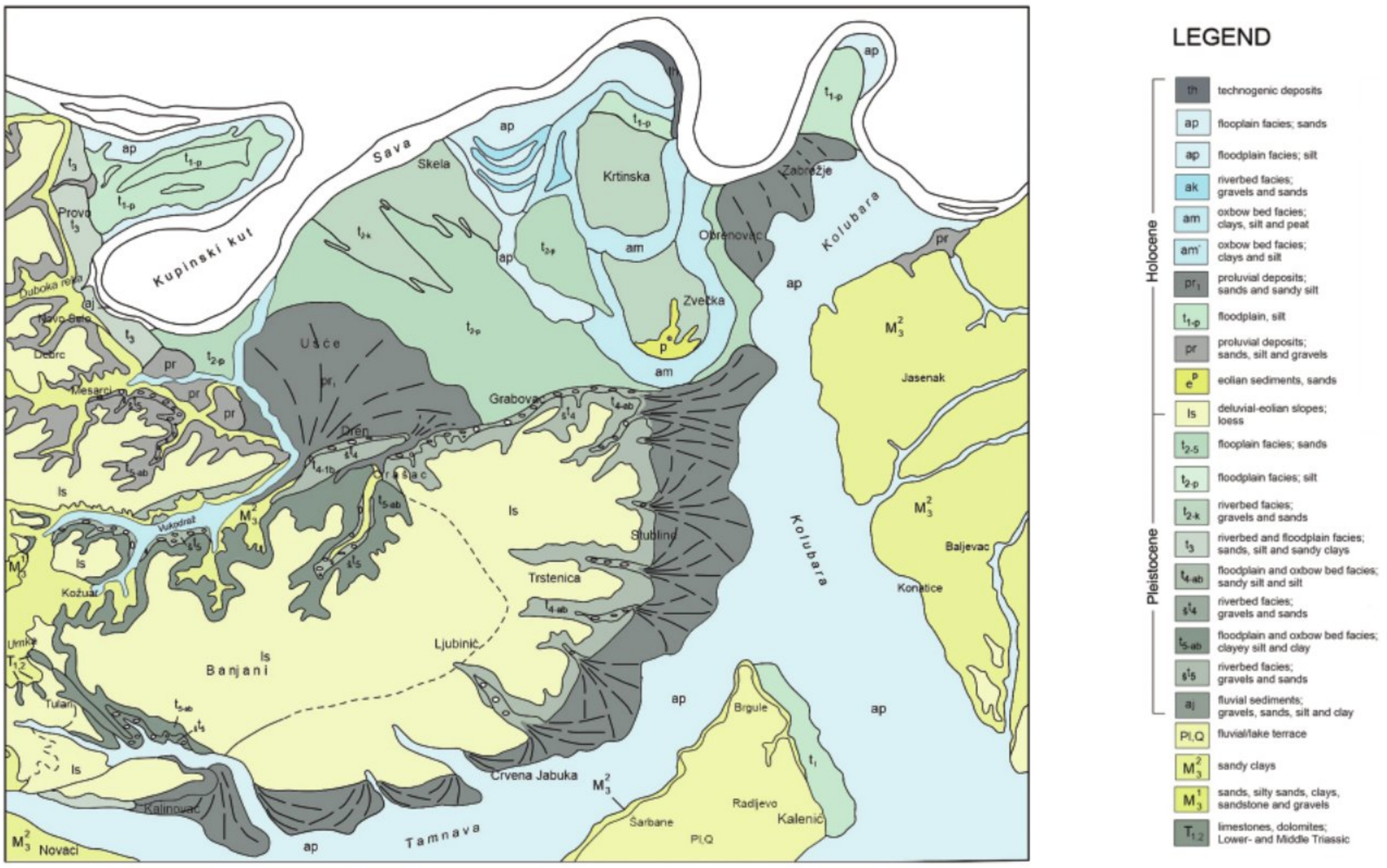

Fig. 2. Geological map of Kolubarska Posavina based on this study. Modified from Stejić's map [23].

By following this structured methodology, Quaternary geological surveying of river sediments aims to reconstruct the complex interplay of geological processes and environmental factors shaping riverine landscapes throughout history.

3. Results

Based on sedimentary domains of Quaternary clastics and paleogeography, two sedimentary domains have been identified that define the hydrogeological regions of the Kolubarska Posavina. In the Kolubarska Posavina, the hydrological region of the Sava and the Kolubara has been identified (Fig. 2).

3.1. Sediments of the Kolubara

The sediments of the Kolubara River reflect a variety of geological processes and depositional environments. Understanding these sediments is crucial for assessing the region's hydrogeological and environmental conditions. A detailed overview of the types of sediments found in the Kolubara River Basin.

3.1.1 Alluvial Sediments

Alluvial sediments are primarily found in the river valleys and floodplains of the Kolubara River. These sediments are deposited by the river and its tributaries and include:

- Angular gravels: Deposited by torential floods, by high-energy rivers;
- Sand: Coarse, granular material deposited by high-energy river flows, commonly found in the riverbed and along the channel;
- Silt: Fine particles deposited in areas of lower water velocity, such as floodplains and backwaters. Silt contributes to the formation of fertile soils in the river's floodplain;
- Clay: Very fine particles that settle in the quietest parts of the river system. Clay sediments are often found in the floodplain and delta regions, forming soft, water-retentive soils.

3.1.2 Floodplain Deposits

Floodplain deposits are formed during periods of high river flow when the river overflows its banks. These deposits include:

- Silts and clays: These fine sediments are deposited over the floodplain during flooding events. They contribute to the formation of rich agricultural soils but can also be prone to waterlogging and erosion;
- Organic matter: In flooded areas with significant vegetation, organic matter from decomposing plants accumulates with the sediments, contributing to soil fertility.

3.1.3 Colluvial Sediments

Colluvial sediments are formed through the process of soil creep and slope wash, where materials are transported down slopes and deposited at the base. These sediments include:

- Gravel and coarse sand: These materials are often found in the lower parts of slopes and in areas where erosion and sedimentation processes dominate;

- Clay, and silt: Fine sediments can also be transported by slope wash and deposited in valley bottoms or other low-energy environments.

3.1.4 Deltaic Sediments

Deltaic sediments are deposited in areas where the Kolubara River meets larger bodies of water or where it slows significantly. These sediments often include:

- Fine sands and silts: deposited in deltaic environments where the river's velocity decreases, leading to the settlement of finer particles;
- Organic-rich mud: accumulated in quieter parts of the delta, contributing to nutrient-rich sediments that support Erosion processes contribute to the river's sediment load, wetland vegetation.

3.1.5 Anthropogenic Sediments

Anthropogenic sediments (of human activities) have influenced the sediment composition in the Kolubara River Basin. Key anthropogenic contributions include:

- Mining waste: Coal mining operations in the region have introduced various sediments, including coal dust and mine tailings, into the river system. These materials can impact water quality and sediment composition;
- Agricultural runoff: Runoff from agricultural lands can carry fertilizers, pesticides, and soil particles into the river, affecting sediment composition and quality.

3.2. The Sava Hydrogeological Region

The sediments of the Sava River, which flows through southeastern Europe, have diverse characteristics shaped by the river's geological, hydrological, and climatic conditions. Here is a detailed overview of the types of sediments typically found in the Sava River.

3.2.1. Alluvial Sediments

Alluvial sediments are sediments deposited by the river's flow, particularly in its floodplains and channels:

- Sand: Coarse, granular material that settles in areas with higher flow energy. Sand is commonly found in the riverbed and in sediment deposits along the channel. It is typically transported during high-flow events and can form sandbars and riverbanks.
- Silt: Fine particles that settle in lowerenergy environments such as floodplains, backwaters, and slackwater areas. Silt contributes to the formation of fertile soils in the river's floodplain.
- Clay: Very fine particles that settle in the calmest parts of the river system. Clay deposits are often found in the floodplain and delta regions, where they contribute to soft, water-retentive soils.

3.2.2. Floodplain Deposits

Floodplain deposits are laid down during flood events when the river overflows its banks:

- Silts and clays: These fine sediments are deposited over the floodplain during periods of high flow. They enhance soil fertility, making the floodplain suitable for agriculture, but can also be prone to waterlogging and erosion;
- Organic matter: Accumulated plant material and decomposed organic matter found in floodplain deposits contribute to nutrient-rich soils, supporting diverse vegetation.

3.2.3. Anthropogenic Sediments

Anthropogenic sediments have significantly influenced the sediment composition in the Sava River Basin:

- Industrial and urban waste: Sediments can be affected by industrial discharges and urban runoff, which may introduce pollutants and alter sediment characteristics;
- Agricultural runoff: Runoff from agricultural lands introduces sediments mixed with fertilizers, pesticides, and soil particles into the river, impacting sediment composition and water quality.

3.2.4. Erosional Sediments

Erosional sediments result from the erosion of riverbanks and upstream areas:

- Eroded soil and rock fragments (Erosion processes contribute to the river's sediment load, including fragments of soil and rock from upstream areas and riverbanks. These materials are transported downstream and can influence sediment composition and river morphology).

3.2.5. Key Differences

Key differences in sedimentary environments in the Kolubarska Posavina: The sediments of the Sava River and the Kolubara River differ primarily due to their size, geological settings, and human impacts. The Sava River, being larger and more hydrologically complex, transports and deposits a broader range of sediment types, sand, and smaller-sized sediments. In contrast, the Kolubara River's sediments are more localized, with significant impacts from angular small-sized pebbles and sediments from coal mining. These differences reflect the distinct sedimentary record.

The paleogeography of the area distinguishes the two main hydrogeological regions in Posavska Kolubara (Fig. 2).

The Sava River sedimentary domain, which represents the Sava hydrogeological domain, is extended in the western parts of the Posavska Kolubara from the line Novo Selo-Debrc eastwards till the line of the settlement of Zvečka, in the South from the village Grabovac northwards till the Sava River. The smaller part is identified northwards from the settlement Zabrežje northwards till the Sava River. That is the area considered the Sava River hydrogeological region.

The Kolubara River sedimentary domain is identified in the eastern parts of the Kolubarska Posavina roughly eastwards from the line of settlement Zvečka eastwards

till line Jasenak-Stubline, From the south from settlement Jasenak northwards till the line Zabrežje-Sava River.

4. Discussion

The main aims of the study were well-defined in the geological maps. It was quite easy to distinguish the two sedimentary provinces which define the hydrogeological regions. The challenge was to find a solution with some other proxy to confirm the results shown in the geological maps. The sedimentary analysis with grain size cards enables a quick and reliable method to find the way to characterise these sedimentary domains. The key factor was the small gravel, which is connected exclusively to the Kolubara River sedimentary domain. According to the river architecture of Kolubarska Posavina, coarser material is deposited by the torrential floods of the Kolubara River. The Sava River sediments in the Kolubarska Posavina have clearly connected with the lowland meandering low-energy river sediments with grain size particles of sand or smaller.

5. Conclusions

The groundwater catchment of Kolubarska Posavina can be divided into two main regions. They belong to the Sava River catchment, but in case of some hazards, the Kolubara River catchment is necessary to distinguish. This paper is associated with the Sava River catchment, which is upstream from the mouth of Kolubara River to the Sava River. The western part, known as the Sava groundwater catchment, includes the Sava alluvial plain and the (paleo) meanders of the Sava River. In contrast, the eastern part falls under the Kolubara groundwater catchment, which is characterized by the remnants of the (macro) alluvial fan of the Kolubara and the Kolubara floodplain. This Kolubara catchment is situated east of the older meander of the Sava River.

Funding

The research of D. Nenadić was supported through the Project NEEMO of the Fund for Science of the Republic of Serbia, number 7746827. The investigations were part of the Ph.D. project of Dj. Božović, "Hydrodynamic analysis of radial collector well ageing at Belgrade well field."

Conflict of Interest

The authors declare that they do not have any conflict of interest.

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