

Human Impacts on Water Resources in the Lower Danube River Basin in Serbia



Dejana Jakovljević, Ana Milanović Pešić , and Dragana Miljanović

Abstract Due to favourable living conditions, the Lower Danube River Basin in Serbia has constantly been populated since prehistory, which has caused different impacts on the environment. This chapter aims to address human impacts on water resources in this area. These impacts involve the use of aquatic resources for water supply, hydropower, navigation, fishing, tourism and recreation. The multiple purposes of the Đerdap Hydropower and Navigation System (also known as Iron Gate) are also presented. Human activities cause changes in the hydrochemistry and living conditions for aquatic organisms in the Danube River and its tributaries. Water quality and pollution was assessed using the water quality indices, including the Serbian Water Quality Index (SWQI), Canadian Water Quality Index (CWQI), Agri-food Water Quality Index (AFWQI), and the Water Pollution Index (WPI). Measurements are performed on three hydrological stations: Tekija, Brza Palanka and Radujevac. Results show that water quality depends on parameters used in different indices. However, general conclusion is that the lowest water quality is recorded at Radujevac, which is the farthest downstream. Anthropogenic pollution sources include Copper Mine in Majdanpek, industrial zone in Mosna, the production of phosphoric and mineral fertilizers in Elixir Prahovo, untreated wastewater and landfills, emissions from road traffic and navigation, pesticides and other chemicals from agriculture. Besides significant multifunctional role of the Đerdap Hydropower and Navigation System, the construction of Đerdap reservoir had negative impact on migratory fish species. The chapter also addressed issues on protection and restoration of water resources. In this context, protective measures and international projects jointly implemented by Serbia and Romania are presented and the role of the Đerdap National Park for the conservation of water resources was emphasized.

D. Jakovljević · A. Milanović Pešić (✉) · D. Miljanović
Geographical Institute “Jovan Cvijić” of the Serbian Academy of Sciences
and Arts, Belgrade, Republic of Serbia
e-mail: a.milanovic@gi.sanu.ac.rs

D. Jakovljević
e-mail: d.jakovljevic@gi.sanu.ac.rs

D. Miljanović
e-mail: d.miljanovic@gi.sanu.ac.rs

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1 Introduction

Water resources and aquatic ecosystems are affected by population increase, economic development and urbanization. All these stressors affect the integrity of aquatic ecosystems and sustainable use of water resources. Land use changes, such as increasing urbanization and deforestation, decrease groundwater recharge and increase flood hazards. Agricultural practices, such as irrigation, strongly impact the availability of freshwater for humans and ecosystems [1]. Agricultural land use degrades water resources by increased diffuse inputs of sediments, pesticides and nutrients [2]. Effluents from wastewater treatment plants, untreated sewage and industry severely affect water quality [3]. Increased urban land use can change the amount and variety of pollutant runoff, increase water temperature, leading to the loss of riparian vegetation and degradation of aquatic habitats [2]. Rivers are among the most affected ecosystems [4]. Anthropogenic influences have considerable effects on large river systems, resulting in multiple and severe hydromorphological alterations changes in sediment and nutrient flux [5, 6]. Rivers are threatened by pollution, water abstraction, river damming and channelization [4]. River channelization measures alter the fluvial morphology in the most direct form. When a meandering river is transformed into a straight channel, the whole ecosystem in the main river arm and the alluvial reaches beside it is affected by the hydraulic effects of channelization. The construction of dams is a local severe intervention with remote upstream and downstream impacts on the river system. Dams capture sediment moving down the river, causing severe downstream consequences, such as the erosion of fine sediment and degradation of habitats for aquatic species [7, 8]. Transforming rivers to reservoirs has far-reaching impacts, including production of organic matter, biodiversity, and changes in function and services provided by aquatic ecosystems [9]. Dammed reservoirs serve as a sink for contaminants [10]. The hydrological alteration, including river regulation, impoundments, and channelization, causing floodplains to be disconnection from the main river, may also significantly impact nutrient cycling [11]. Rivers are also used for water supply, fisheries [12] and hydropower [1]. Hydropower generation causes a major pressure on river ecosystems. Through damming, water abstractions, hydropeaking, hydropower plants affect aquatic habitats by altering discharge regimes and fragmenting river channels [1, 13]. Hydropeaking (discontinuous release of turbinized water due to the peaks of energy demand) causes artificial discharge fluctuations downstream of reservoirs with a harmful impact on aquatic ecology, e.g. the relocation of organisms to a potentially less suitable habitats, as well as physiological, mechanical, or predatory stress [14]. Human activities can negatively impact fish habitats; the same applies to commercial or recreational fisheries, which can use stocks in an unsustainable

way [15]. Please check and confirm the author names and initials are correct. Also, kindly confirm the details in the metadata are correct. We confirmed.

Significant pressures on the Danube River include organic pollution and pollution with nutrients, and hazardous substances, as well as hydromorphological alterations, and other issues, such as changes of quality and quantity of sediments, and appearance of alien invasive species. Organic and nutrient pollution is generated from urban wastewater, industry and agricultural sources. Hydromorphological alteration involves interruptions of river continuity and morphological alterations, wetland or floodplain disconnection and hydrological alterations [16]. The alterations of Danube's morphology involve engineering approaches to create a single straightened channel accompanied with changing the depth or width of the river. In order to improve inland navigation, flood protection and hydropower generation, the Danube River has been narrowed, channelized, disconnected from floodplains and morphologically degraded [5]. The impact of these works has been boosted by the effects of land use changes, such as agricultural intensification and forestry development. Engineering works also cause river bed erosion and lateral erosion (e.g. downstream of Đerdap I and II) [6]. The construction of hydropower impoundments changes river systems by disrupting the connection between the river and backwater, changing the shoreline, and stabilizing previously dynamic water levels [17]. Impoundments are marked by deposition and excessive sedimentation and remobilization of fine sediments during severe floods [6]. This ecological situation is reflected in the alteration of riverine habitats, leading to the decline of the biodiversity of species and affect certain faunal associations, especially fish assemblages [17], such as sturgeon [5].

The main issue addressed in the chapter is the human impact on water resources in Lower Danube River Basin. The chapter aims to present water resource uses including water supply, hydropower use, navigation, tourism and recreation and fishing, as well as water quality, pollution and protection of water resources. In order to assess water quality (general and for different purposes), various indices were used and compared, which provide the added value of this study.

2 Study Area

Out of the total length of the Danube River (2,857 km), 588 km (20.58%) are located in Serbia. Its basin area covers 801,463 km², of which 81,506 km² (10.17%) belong to Serbia [18]. The Danube River enters Serbia near the settlement of Batina (km 1,433, at a height of 81 m above sea level), and exits at the mouth of the Timok River (km 845.5, at a height of 28 m above sea level). It is the border river with Croatia (138 km, km) and Romania (230 km) [19]. In terms of natural features, the watercourse of the Danube River in Serbia can be divided into the Pannonian, Đerdap and Western Pontic sectors. The lengths of these sectors are determined based on the Navigation Chart of the Danube River in the Republic of Serbia (km 1433.1–km 845.5) [20]. In the Pannonian sector, which stretches from the Hungarian–Serbian border (km 1,433) to the settlement of Golubac (km 1,042), reaching the length of about 391 km, the

Danube River is a plain water course. The Đerdap sector encompasses the course of the Danube River through the Đerdap Gorge (also known as Iron Gate) from Golubac (km 1,042), to the settlement of Sip (km, 939) and it is 103 km long [20]. In this part, the Danube River used to be a mountain river. Now, the river velocities are significantly reduced. Downstream from Sip (km 939) to the confluence of the Timok River into the Danube River (km 845), on the Serbian–Bulgarian border, there is a 94 km long Western Pontic sector. In this part, the Danube River has the characteristics of a plain river. This chapter deals with the Lower Danube River in Serbia, which covers the Đerdap and Western Pontic sectors, and has a total length of 197 km (Fig. 1). In administrative terms, this area in Serbia covers 3,018 km² in the territories of four municipalities (Golubac, Majdanpek, Kladovo and Negotin) and has a population of 84,708 inhabitants [21].

According to the 1948 Danube Convention, the Đerdap sector of the Danube River is 117 km long: from the settlement of Vinci (upstream from Golubac) to the settlement of Kostol (downstream from Kladovo). However, based on geomorphological criteria, the Danube River enters the Đerdap Gorge near the Golubac fortress (km 1,042) and exits near the settlement of Sip (km, 939) [22]. In this 103 km long sector, the river flows through a composite valley, including four gorges (Golubac, Gospodin Vir, Kazan and the Sip) and three alternating valleys (Ljupkovska Valley, Donjomilanovačka Valley and Oršavska Valley). Before the construction of the Đerdap I Hydropower and Navigation System, the Danube River was a mountain river with large falls in this sector, 180–2,200 m wide, with a river flow speed of 18 km/h [23]. With vortex erosion between rocks, it cut giant pot holes, causing



Fig. 1 Map of study area

significant difficulties in navigation. In one of them, near the rock of Pjatra Lunga (Long Stone) in the gorge of Gospođin Vir, the greatest depth of the Danube River and the greatest river depth in Europe (82 m) was measured. After the construction of the Đerdap reservoir, the water velocity was reduced to 1.08 km/h, and many rocks in the riverbed were submerged [23]. The largest bays of the Danube River in the Đerdap sector are located along the Romanian coast, at the mouth of the river Cerna near Orșova (4.5 km long and up to 2.1 km wide) and on the Serbian coast at the mouth of the Porečka River (4.25 km long, up to 0.62 km wide) [22]. They were formed after the construction of the Đerdap reservoir in places where water submerged the lower parts of river valleys.

The Đerdap reservoir, formed by partitioning the Danube River in the Đerdap Gorge is the largest lake in Serbia. It was constructed at km, 943 in 1964–1972. The dam has two side parts and a central space with 14 overflow fields, which drain excess water from the reservoir. It is 61 m wide and 1,278 m long [24]. Hydropower Plant Đerdap I (HPP Đerdap I) is located on it. The formation of the reservoir improved conditions for upstream and downstream navigation because the waters submerged underwater rocks. When the water level on the Danube River changes, its shoreline shifts, and all morphometric indicators change. At high water levels, Đerdap reservoir covers an area of 253 km² (163 km² on the Serbian side and 90 km² on the Romanian side) [25] and the maximum volume of the reservoir reaches 2.8×10^9 m³ of water [26]. The width is different in its parts: it is the smallest in the gorge Mali Kazan (about 180 m) and the largest in the Donjomilanovačka Valley (about 2,200 m). There are also different data regarding the maximum depth, ranging from 82 to 92 m. The maximum water transparency is 3–4 m. The largest island in the lake is Moldova, located 10–35 m above the lake surface opposite Golubac and it belongs to Romania [22]. The submergence of the coastal zone caused changes in the territorial distribution of settlements. The reservoir completely or partially submerged the settlements of Donji Milanovac, Mosna, Malo Golubinje, Veliko Golubinje, Tekija, Sip, Dobra, Brnjica, Golubac and Usje. The population and more valuable buildings from these settlements were relocated. Cultural and historical monuments (Lepenski Vir, Trajan's Way, the fortress on the island of Ada Kale) were submerged, while Trajan's Plaque was raised above the level of the lake [22].

Downstream from the Đerdap Gorge at km 862.8 of the Danube River it was built a second dam and reservoir in 1977–1985. The second dam was built 80 km downstream from the first one for additional power production and more flexibility of the joint operation of the two power plants [27].

The major tributaries of the Lower Danube River in Serbia include: Brnjica River (25.6 km), Porečka River (19.1 km), Boljetinska River (16 km) and Dobranjska River (12.8 km) [22] in Đerdap sector, and Timok River (202 km), Jesenička River (40 km), Zamna River (35 km), Slatinska River (23 km) [23] and Podvrška River (20.4 km) [22] in the Pontic sector.

Based on data from the nearest hydrological station where discharge is measured, Veliko Gradište (located upstream of the Đerdap sector), the average annual discharge of the Danube River in this sector is 5,460 m³/s. The highest waters occur in April (7,793 m³/s), and the lowest in October (3,637 m³/s) [22]. It is estimated that the mean

multiannual discharge of the Danube at the exit from Serbia is approximately 5,500 m³/s [28]. Based on the above-mentioned data, it can be concluded that the Danube River is abundant in water in April–May, and the poorest in water in September–October. The Danube’s tributaries in this area, and especially the Timok River, have the highest discharges in March and April, and the lowest in August and September.

In Serbia, the Đerdap Gorge, together with the Danube River and Đerdap reservoir, was granted the status of a national park in 1974. The Serbian part of the Đerdap National Park stretches along the right bank of the Danube River over the territory of three municipalities (Golubac, Majdanpek and Kladovo), covering an area of 637.68 km² [29] and it is the largest national park in Serbia. It is referred to as the “river national park” [30], keeping in mind that a significant part (7.8% of the total area of the NP) is the Danube River [22]. The Đerdap Gorge is the most striking natural phenomenon in the National Park. It is the longest incising composite gorge in Europe [22, 29, 31, 32].

The Đerdap National Park is internationally recognized as an Important Plant Area (IPA): 57 highly complex and diverse forest communities and 1080 plant species have been identified in the national park. The Park was also declared an internationally Important Bird Area (IBA), since about 255 species of birds are present, as well as a Prime Butterfly Area (PBA), thanks to the presence of 104 species of daily butterflies [22]. Finally, the Đerdap area was declared in 2020 the eleventh and largest area in Serbia that has been included in the list of Wetlands of International Importance (Ramsar sites). The Đerdap Ramsar area covers a total area of 665.25 km². It includes the Đerdap National Park and the Internationally Important Bird Area Mala Vrbica, which is outside the boundaries of the National Park. It has gained the status of an Internationally Important Area thanks to the presence of habitats of wetland birds [33–35]. The Đerdap National Park is also a member of the Danube River Network of Protected Areas [36].

The Đerdap Geopark is the first area in Serbia to be inscribed on the UNESCO Global Geoparks Network in 2020. It covers an area of 1,330 km² and includes the territory of the Đerdap National Park and Danube hinterland (parts of the Kučaj and Miroč mountain massifs) by 692 km². It includes four municipalities: Golubac, Majdanpek, Kladovo and Negotin [32].

3 Water Management Framework in Serbia

3.1 Legal Framework

Establishing a national water legislation framework compliant to the requirements of the European water legislation (known as the *Acquis*) is one of the priorities in the European Union accession process.

The water sector in Serbia is regulated by numerous laws, of which the main one is the Water Law [37]. Its implementation is supported by relevant bylaws related

to water (Regulations and Rulebooks), such as: the Regulation on emission limit values of pollutants in water and deadlines for their achievement [38]; Rulebook on parameters of the ecological and chemical status of surface waters, and parameters of the chemical and quantitative status of ground waters [39]; Regulation on limit values of pollutants in surface and ground waters and sediments and deadlines for their achievement [40]; Regulation on limit values of priority and priority hazardous substances that pollute the surface waters and deadlines for their achievement [41]; Rulebook on the method and conditions for measuring the quantity and testing the quality of wastewater and the content of the report on the performed measurements [42]; Decision on determining the boundaries of water areas [43]; Rulebook on defining the methodology for designing the vulnerability map and flood risk map [44], and etc. (more information about all bylaws is available on the internet portal of the Water Directorate [45]).

The transposition of the *Acquis* (European legislation) into national legislation is presented in the National Programme for the Adoption of the *Acquis*—Third Revision [46]. Apart from the mentioned document, the transposition of the EU environmental legislation (environmental *Acquis*) into national legislation and the required institutional framework to implement that legislation, as well as the estimated the total cost of environmental approximation, are presented in the National Environmental Approximation Strategy for the Republic of Serbia [NEAS] [47]. In the Water Sector Approximation Strategy [48], the framework for approximation of EU water legislation, regulations that are relevant for the Republic of Serbia, are defined in an accompanying document to the NEAS. The aforementioned National Programme for the Adoption of the *Acquis*—Third Revision [46] presents the current situation regarding the transposition and implementation of the EU environmental legislation (Section 3.27), including water management directives (Subsection 3.27.4). The directives that have not been fully transposed into the national legislation (Water Law and accompanying bylaws) have been singled out. As highlighted in the National Environmental Approximation Strategy for the Republic of Serbia [47], based on the experience from previous EU enlargement processes, the transitional period involves only Heavy Investment Directives, which require significant financial resources (about € 4.1 billion), such as the Urban Waste Water Treatment Directive and the Nitrates Directive.

According to [49] difficulties related to EU Urban Waste Water Treatment Directive implementation in Serbia are associated with poor sewage systems and unsatisfactory wastewater treatment (the lack or wastewater treatment or inadequate procedures), which is reflected in the quality of wastewater from households and industry. It is loaded with organic matter and nutrients, as well as with hazardous substances. As the authors conclude, untreated wastewaters are one of the most important threats to surface water in Serbia. Namely, in 2017, about 62.2% of urban waste-water was collected by public sewage systems, 13.9% of which was collected by public systems with treatment (1.3% of the population is connected to primary treatment, 9.2% to secondary treatment, and only 3.4% to the most advanced, tertiary treatment), and 48.3% to the systems without purification [50]. Given the level of sanitation of

urban settlements, it is evident that Serbia is lagging significantly behind European countries, as indicated by the data presented in [49].

In Serbia, 50 wastewater treatment plants were built in settlements with more than 2,000 inhabitants and 32 plants are active. Only a few wastewater treatment plants operate according to their design criteria [24]. According to the 2011 Census, settlements with up to 2,000 inhabitants account for 90.5% of the total number of settlements, with about 25% of the total population, while the population of settlements with more than 2,000 inhabitants (9.5% of the total number of settlements) accounts for about 75% of the total population [51]. The national settlements network is dominated by the capital city, owning 16.23% of the total population and 27.45% of the population of urban settlements [52]. These data reveal the spatial distribution of the population, i.e. an unbalanced population development and regional inequality [51–54].

Results of analysis of nitrate concentrations trends in Serbian watercourses for two decades (1998–2007 and 2008–2017) according to [55], show the importance of Serbia's obligations (related to reduce water pollution caused by nitrates from agricultural sources) in the implementation of the provisions of the Nitrates Directive in the EU accession process.

Environmental legislation, primarily in relation to water protection from pollution, is of particular importance for achieving the good status of water. The following laws are particularly important: Law on Environmental Protection [56], Law on Environmental Impact Assessment [57], Law on Strategic Environmental Impact Assessment [58] and Law on the Integrated Prevention and Control of Environmental Pollution [59]. The aforementioned National Programme for the Adoption of the *Acquis*—Third Revision [46] outlines further steps in the process of harmonizing with the EU's environmental legislation (Section 3.27), sections Horizontal legislation (Subsection 3.27.2) and Industrial pollution (Subsection 3.27.6), where the implementation of Directive 2010/75/EU of the European Parliament and the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) is of special importance in terms of water protection (to reduce pollution from industrial facilities). It has been partially transposed into the Law on Integrated Prevention and Control of Environmental Pollution [59] and bylaws.

Spatial development policy is closely related to environmental protection policy [60] and, accordingly, to water management policy. As already mentioned, the Law on Planning and construction [61], which determines the conditions and the land use mode towards preventing conflicts of the physical space, is also important for water protection, as well as for the protection of organisms living in aquatic ecosystems, and accommodation of water infrastructure in physical space. In addition, land use planning is an important instrument for reducing flood risk. In contrast, according to [62], an uncontrolled urban development in Serbia increases the vulnerability of urban areas to natural disasters.

There are other laws which regulate particular aspects of water policy (i.e. water quality protection and the protection of natural/hydrological heritage, water use, protection against the harmful effects of water, monitoring, etc.). These are the Law on Nature Conservation [63], Law on Protection and Sustainable Use of Fish Resources

[64], Law on Public Health [65], Law on Navigation and Ports on Inland Waterways [66], Energy Law [67], Law on Waste Management [68], Law on Meteorological and Hydrological Activities [69], Law on Communal Activities [70], Law on Local Government [71], Law on Disaster Risk Reduction and Emergency Situations Management [72], and another laws.

3.2 Institutional Framework

The institutional framework for the water sector, consisting of institutions and national, regional and local government bodies, and public water-related companies, ensures successful transposition and implementation of water-related EU directives, i.e. the implementation of adopted laws. The competence of relevant institutions is defined by the Water Law [37].

The Ministry of Agriculture, Forestry and Water Management, in accordance with the Law on Ministries [73], is responsible for the water sector, together with the Water Directorate (an administrative unit in the Ministry). The Serbian Environmental Protection Agency (SEPA), responsible for air and water quality monitoring, reporting on the status of the environment, and other activities in the domain of environmental protection according to the Law on Environmental Protection [56] and Law on Ministries [73], is part of the Ministry of Environmental Protection.

Reporting on water quality in Serbia is defined by national legislation. In accordance with the 2011 Law on Ministries [74], the implementation of the annual surface and groundwater quality monitoring programme has been transferred from the competence of the Republic Hydrometeorological Service (RHMS) of Serbia to the competence of the Serbian Environmental Protection Agency (SEPA) under the Ministry of Environment Mining and Spatial Planning. The Agency publishes water quality data. Annual water quality reports have been published since 1965 [75]. According to the authors, in 2012, the SEPA started the implementation of a surface and groundwater status monitoring programme in accordance with several bylaws harmonized with the Water Framework Directive. Quantitative monitoring including data collection about water levels, discharges and temperatures of surface waters, as well as water tables and temperatures of groundwater is performed by the RHMS of Serbia.

Two monitoring programmes (one for the Đerdap I reservoir in 1978, and the other for the Đerdap II reservoir, in 1985) were established to ensure the monitoring of the environmental impacts of the Đerdap Hydropower and Navigation System on the Danube River and effects of the protection measures (Mladenović and Radosavljević, 2013, cited in [13]).

In addition to the Ministry of Agriculture, Forestry and Water Management and the Ministry of Environmental Protection, other ministries are also involved in the activities in the water sector, in accordance with the Law on Ministries [73], e.g. the Ministry of Health, the Ministry of Construction, Transport and Infrastructure, and

the Ploput Waterways Directorate (responsible for the maintenance and development of inland waterways in the Republic of Serbia with international and interstate navigation regimes—the Danube, Sava and Tisa Rivers), the Ministry of Mining and Energy—Energy Agency, Ministry of Interior—Sector for Emergency Situations, etc.

At the local level, local self-government units, such as secretariats (for the territory of the City of Belgrade), or directorates, departments and other units in other local self-governments (cities and municipalities) are responsible for activities in the water sector [24].

Three public water management companies (WMC) are responsible for water management activities on the territory of Serbia: Srbijavode WMC, Vode Vojvodine WMC and Beogradvode WMC [24]. Public Water Management Company Srbijavode has three water management centres [76], of which Sava–Danube center (for the Sava and Danube water areas outside the territory of the Autonomous Province of Vojvodina), includes Low Danube Basin in Serbia. The Jaroslav Černi Institute for the Development of Water Resources is a leading research organization in Serbia in the water sector [77].

3.3 *Planning Framework*

The Water Law [37] stipulates the development of the Water Management Strategy for the territory of the Republic of Serbia, a planning document which indicates the long-term directions of water management in this country. As highlighted in the Water Management Strategy for the territory of the Republic of Serbia until 2034 [24], the adoption of this planning document ensures continuity in the long-term planning of the water sector. Until the adoption of the Strategy, issues related to water management were regulated by the document Water Management Plan of the territory of the Republic of Serbia [78]. The current Water Management Strategy defines the long-term directions of water regulation and water use, water protection from pollution and waterway regulation, as well as protection against the harmful effects of water, in accordance with the EU water legislation.

The Spatial Plan of the Republic of Serbia from 2021 to 2035 [79] as the basic document of spatial planning and development in this country, defines, inter alia: the concept of the long-term water infrastructure development so as to ensure the rational use, regulation and protection of waters; the concept of protection and improvement of environmental status based on the conservation of major compartments of the environment (e.g. air, water and soil); and the development concepts for other thematic fields that regulate some of the issues related to water, as well as development concepts for other sectors. According to [61], regional plans as well as plans of local government units (municipalities) also deal with water infrastructure development.

The National Strategy for Sustainable Use of Natural Resources and Goods [80] stands out as a strategic document relevant for the water sector. The goal of the Strategy is to improve the economic development through an efficient use of

natural resources, which involves less intensive use, while reducing the environmental impact. In the context of water protection refers, it implies an economic growth that does not put pressure on water resources (reduced water use) and does not cause water pollution.

The importance of strategic development direction's for individual segments in the water sector, from water use to water protection, is also highlighted in other national documents/sectoral strategies (for example: development strategies on industry, tourism, agriculture, waste management, water transport, etc.). Namely, the intertwining of public policies reflects the functional interdependencies within the natural system, as well as those between social systems (institutions) and the fields of public policies—sectoral integration [60]. Thus, for example, providing a sustainable solution to the issue of waste management through the construction of modern infrastructure would prevent the contamination of surface and groundwater from landfills as a serious form of pollution in Serbia. It is necessary to emphasize the role of education as one of the most important strategies to increase awareness of environmental problems [e.g. 81, 82], i.e. on water pollution, as well as the importance of education in protection against natural disasters, i.e. for natural disaster preparedness [e.g. 83, 84].

4 Human Use of Water Resources

The importance of the Danube River as a water resource for various uses has been recognized since ancient days. This is evidenced by numerous archaeological sites at various locations; several of them can be found in the Đerdap Gorge. The most famous is the archeological site Lepenski Vir (9500 BC), which shows that humans inhabited this area in an early age due to favorable living conditions [22]. In the past, the Danube River was mostly used for navigation and fishing. Danube River in the Đerdap Gorge was a natural spawning ground for sea fish in fresh waters: beluga sturgeon, trout, sturgeon, sterlet. The river species caught by fishermen include catfish, perch, carp, bream, barbel, chub etc. Caviar was obtained from the caught sea fish, which had a significant share in the fish catch, especially after World War I. With the construction of the HPPs Đerdap I and Đerdap II, fish migration routes were cut off, due to which river fish species now prevail in the fish catch in the Danube River.

Nowadays, the Danube River as a water resource is used for different purposes: water supply of settlements, hydropower production, industry, agriculture, tourism and recreation.

4.1 Water Supply

In Serbia, the water supply of the population ranges between acceptable and good [28] and this situation is also reflected in the municipalities of the Lower Danube Basin. In the municipal centres of the Lower Danube River, water supply is organized

from regional or local water supply systems. The inhabitants of rural areas receive drinking water from public water supply systems operated by municipalities, local water supply systems built and maintained by the communities, or from their own wells.

In the territory of the four municipalities in the Lower Danube River discussed in this chapter, groundwater from local sources (often accumulated in karst massifs) is prevalently used for water supply. Alluvial aquifers, the Danube River and reservoirs are also used. According to the data of the Statistical Office of the Republic of Serbia for the 2009–2019 period [85] the average amount of extracted water in the municipalities of the Lower Danube River in Serbia was $8.37 \times 10^6 \text{ m}^3/\text{year}$, out of which $4.27 \times 10^6 \text{ m}^3/\text{year}$ was delivered for drinking water supply, which is about 51% of the total extracted water. Based on data from 2019, it may be calculated that 25,674 households are connected to various water supply systems, accounting for about 81.46% of the total households. This is slightly lower than Serbia's average, showing that 86.71% of the total households are connected to drinking water supply systems. Based on the amount of delivered drinking water and the number of households connected to water supply systems in the analyzed period, the average specific water consumption in the Lower Danube River Basin in Serbia was calculated to be 170.1 l/inhabitant/day. This value is above Serbia's average, which was 148 l/inhabitant/day in the previous period [28]. However, the consumption is lower than the average consumption in European countries, which is 200–300 l/inhabitant/day [86]. For a more detailed analysis of water supply in individual municipalities, values were calculated based on the data provided by the Statistical Office of the Republic of Serbia for 2009–2019 [85]. The amount of water consumed as drinking water in the municipalities of the Lower Danube River in Serbia is shown in Fig. 2. A significant decrease in the supplied drinking water can be observed in the municipalities of Kladovo and Majdanpek after 2011. According to [85], the number of households connected to water supply systems in Kladovo

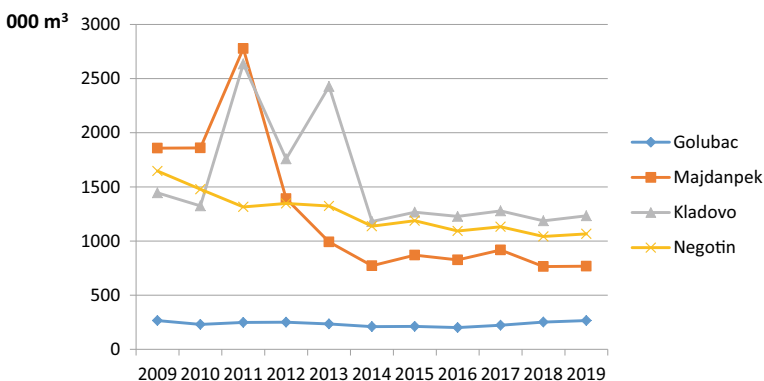


Fig. 2 Supplied drinking water by municipalities in the Lower Danube River Basin in Serbia (Source of data [85])

Municipality was around 10,500 in the period 2009–2011, while since 2012 there are about 7,100 households. The decrease in the number of households by about 3,400 contributed to lower consumption of drinking water. In Majdanpek Municipality, no trend was noticed in the change of number of households in the analyzed period. Therefore a clear reason for the decrease in drinking water consumption can not be stated. One of the reasons could be the decrease in the number of inhabitants in this municipality. However, the latest data in the number are from the 2011 Census, so now it is difficult to determine the exact number of inhabitants.

In the Golubac Municipality, the groundwater springs is used for water supply. There is a central water supply system for the municipal centre at Golubac and five suburban settlements along the Danube River. Other 18 settlements are supplied from rural water supply systems relying on local water intakes and springs [87]. According to the data provided by [85], it was calculated that the average amount of extracted water was $0.84 \times 10^6 \text{ m}^3/\text{year}$. Out of that amount, $0.23 \times 10^6 \text{ m}^3/\text{year}$ on average was delivered as drinking water (about 27.4%). Based on data for 2019, it is calculated that 70.7% of households in this municipality are connected to various water supply systems. The specific water consumption in this municipality was 107.03 l/inhabitant/day in the analyzed period.

The Majdanpek Municipality is supplied with water from reservoirs on the rivers Veliki Pek and Mali Pek, Danube River and local springs in the mountainous area. It is noteworthy that the second-largest settlement in this municipality, Donji Milanovac, is supplied from a drinking water treatment plant with a capacity of about 40 l/s. This plant uses the Danube water as raw water [88]. In 2009–2019 period, the average amount of extracted water in the Majdanpek Municipality was $2.9 \times 10^6 \text{ m}^3/\text{year}$, out of which $1.25 \times 10^6 \text{ m}^3/\text{year}$ was delivered as drinking water (about 43.1%). Based on data for 2019, it is calculated that 82.8% of households in this municipality are connected to water supply systems. Specific water consumption was 221.22 l/inhabitant/day in the 2009–2019 period.

In the Kladovo Municipality, 18 settlements have water supply systems, two of them have combined water supply, while three settlements do not have water supply systems [22, 89]. The supply with drinking water to the municipal center of Kladovo and two surrounding settlements is based on groundwater. The average amount of extracted water for 2009–2019 in the Kladovo Municipality was $2.51 \times 10^6 \text{ m}^3/\text{year}$, out of which $1.54 \times 10^6 \text{ m}^3/\text{year}$ was delivered as drinking water (about 61.3%) of the total extracted water. Based on data for 2019, it is calculated that 92% of households in this municipality are connected to water supply systems. Also, it has been calculated that in the Kladovo Municipality, the specific water consumption was 222.77 l/inhabitant/day in the analyzed period. A higher water consumption and the fact that the water supply system in Kladovo does not meet current needs are a consequence of the high loss in the network, which amounts to 40% [90].

The population of the Negotin Municipality is supplied with drinking water from local sources through groundwater exploitation, as well as from the Timok Regional Water Supply System, Bor–Zaječar Subsystem [91]. This subsystem for water supply consists of two reservoirs in Timok River Basin. In Negotin Municipality, 27 settlements are supplied with drinking water from different water supply systems, while

12 settlements do not have water supply systems as their construction is merely planned [92]. In the 2009–2019 period, the average amount of extracted water in the Negotin Municipality was 2.12×10^6 m³/year, out of which 1.25×10^6 m³/year was delivered for as drinking water (about 59%). According to the data for 2019, it is calculated that 76.9% of households in this municipality are connected to the water supply systems. The specific water consumption in the Negotin Municipality amounted to 120.3 l/inhabitant/day in 2009–2019 period. The main problem is the frequent lack of water during summer.

Generally, in Serbia, problems related to technological and economic development, as well as underdeveloped awareness on water protection reflect in impaired water quality in water supply systems [93]. Inadequate water quality is more present in small settlements, and this also applies to the municipalities of Lower Danube River. Another problem in Serbia are illegal wells, mostly in rural and suburban areas, built for individual household water supply [93]. This problem is observed in rural settlements of the Lower Danube River Basin as well.

4.2 *Hydropower Use*

In Serbia, the Danube River has a great hydropower potential, which is estimated at 10,000 GWh/year in total, while the specific potential amounts to 38.46 GWh/km per year [91]. Particularly favourable conditions for the hydropower potential use can be found in the Lower Danube River, in the area of the Đerdap Gorge. Thanks to its morphological characteristics and the flow greater than 5,000 m³/s, attention has so far been mostly focused on exploiting hydropower potential in this sector. The former Socialist Federal Republic (SFR) of Yugoslavia and the Socialist Republic (SR) of Romania jointly undertook to construct a dam and a reservoir in the Đerdap sector of the Danube River in the 1960s. The Đerdap Hydropower and Navigation System is the largest hydro-technical structure on the Danube River in Serbia and Europe. It consists of two flow hydropower plants HPP Đerdap I and HPP Đerdap II.

The HPP Đerdap I (Iron Gate I; Fig. 3) is the largest hydropower plant in Serbia and the largest hydro-engineering facility on the Danube River. It is located at km 943 km of the Danube River, 10 km upstream from Kladovo. In mid-1964, preparation works for its construction were undertaken and the first hydro generating units were put into operation in 1971. According to the Agreement on Construction and Exploitation between the SFR of Yugoslavia and the SR of Romania, the HPP Đerdap I was designed and built so that each side has one power plant, one ship lock and seven spillways [26]. The two power plants are connected so that power generators on the Serbian side can deliver electric power to the network on the Romanian side, and vice versa, if such a need arises. The total length of the structure is 1,278 m, whereas its height is 34.8 m [24]. The two-level ship lock is 310 m long and 34 m high [27]. Its depth at the threshold is 5.5 m; it has an under-keel clearance of 13.5 m and is suitable for river and sea ships with a carrying capacity of 5,000 t. On the Serbian side, there



Fig. 3 Hydropower Plant Đerdap I (Photo taken from the archaeological site of Diana. *Source* Geographical Institute “Jovan Cvijić” SASA)

are six hydropower generating units: two with a capacity of 171 MW and four revitalizing hydro units of 190 MW each [26]. The revitalization of the hydropower generating units and adaptation of the ship lock began in 2009, and was completed in 2021. The nominal active power of the power plant is now 1,102 MW and the total controlled flow amounts to 5,040 m³/s. The average electricity production is about 5,500 GWh/year [94].

The HPP Đerdap II (Iron Gate II) is located 80 km downstream from the HPP Đerdap I, at a distance of 862.8 km from the mouth of the Danube River, at the profile Kusjak–Ostrovl Mare. This is another power plant on the Danube River that was jointly constructed by the SFR of Yugoslavia and the SR of Romania. It was completed in 1985 as a multipurpose hydro-engineering facility, just like the HPP Đerdap I. HPP Đerdap II consists of the main power plant, two additional power plants, two ship locks, two overflow dams and two power distribution facilities. The dam is located on the main course of the Danube River and it is 1,009 m long and 330 m wide [27]. The hydropower generating units were put into operation between 1985 and 2001. On the Serbian side, there are ten hydropower generating units with a total installed capacity of 270 MW (10 × 27 MW). The installed flow rate amounts to 4,200 m³/s and the average electricity production is around 1,500 GWh/year [26]. The adaptation of the ship lock is also underway, and the overhaul of all 10 hydro units is planned to be completed over the next 10 years. This will increase the installed production capacity of the HPP Đerdap II by 50 MW. Before revitalization the average electricity production in the HPPs Đerdap I and II was

about 6,989 GWh. After the revitalization of hydropower generating units in the HPP Đerdap I, the annual electricity production amounted to 7,072 GWh (18% of electricity production in Serbia) [2694]. The remaining hydropower potential of the Danube River in Serbia can be used only in accordance with the criteria related to the multipurpose use of water and environmental protection, taking into account the international character of the river.

The formation of Đerdap reservoir has caused some geographical changes (in the microclimate, vegetation, reduction of water velocities, content of chemical compounds in the water, groundwater regime, river regime, ice regime, water quality etc.). After the formation of this reservoir, the hydrological regime of the Danube River in the slow zone (up to Veliko Gradište at high waters) has been significantly changed, while some river mouths and settlements were submerged [90, 95, 96]. In the slow zone, water velocities are reduced and depths are increased depending on the natural regime. As a result of these changes, the sediment transport power is significantly reduced, due to which sediments are deposited in the reservoir [97]. Deposited sediments reduce the useful volume of the reservoir, which affects flood protection, electricity production and water quality. After the construction of HPP Đerdap I, the ice regime on the Danube River changed. Under the natural regime, due to hydraulic and morphological conditions, the Đerdap sector was in danger of congestion (ice jam). Later, this critical part moved upstream, to the slow zone, between Veliko Gradište and Novi Sad.

4.3 Navigation

The Danube River, as the important European waterway E80 (also known as the Danube Corridor, Cprridor VII), about 196 km long, increases the accessibility of this area. The Danube Corridor is a link between West, Central and East Europe. It allows navigation of the largest river cruisers, and it is also recognized as one of the nine multimodal TransEuropean transport corridors (TEN-T) networks. The Danube River enables the spatial and functional integration of this area into a transnational context (Danube Strategy); however, this great potential for development is still insufficiently exploited in terms of navigation and tourism. After the construction of the Đerdap Hydropower and Navigation system, conditions for navigation have been improved by building appropriate ship locks. However, the intensity of the national river traffic is still low. In this sector, the Danube River belongs to the waterways of the highest category (class VII), i.e. it serves as a waterway for cargo ships reaching up to 285 m in length, ranging between 33 m and 34.2 m in width, having a deep draft from 2.5 m to 4.5 m [22]. River-sea ships with a carrying capacity of 5,000 t can sail, provided that the preconditions for navigation of these vessels are met downstream from HPP Đerdap II. At the dam of HPP Đerdap I, the minimum depth at the threshold is 5 m, which enables the simultaneous transfer of a convoy composed of tugs (pushers) and nine pushers with a total carrying capacity of 14,500–27,000 t, or two ships with a carrying capacity of 5,000 t [19]. These conditions are met by

Table 1 Cargo handling and passenger transport on the Danube River in Serbia

Year	Cargo handling (t)	Passenger transport	
		Number of port calls	Embarked/disembarked passengers
2015	5,006,191.80	903	114,932
2016	9,936,455.21	955	119,125
2017	11,071,071.84	996	131,780
2018	12,324,912.06	1,150	157,901
2019	14,168,142.05	1,542	208,797

Source of data [98]

building ship locks, due to which navigation is now determined by the ice regime. Information about cargo handling and passenger transport by river cruises on the Danube River, towards the Black Sea are shown in Table 1. Based on the data, it can be concluded that there was a constant significant increase in cargo handling and passenger transport over the five-year period. Compared to 2015, cargo handling was almost three times higher, the number of port calls increased by almost 70%, and the number of passengers was by about 80% greater.

The accompanying facilities at the Danube waterway in this area include harbours for tourism (Tekija, Donji Milanovac, Kladovo and Brza Palanka) and transportation purposes: Jelenske Stene, shipyard in Kladovo and Prahovo and moorings in Novi Mihajlovac (Fig. 4). Also, some unregulated parts of the riverside are used for boat anchorage.

Comparative analyses of large river navigation systems in Europe (Danube, Volga, Rhine and Elbe) have shown that the Danube River is potentially the most cost-effective traffic route and, at the same time, a traffic route with a great potential to increase traffic intensity [90]. In 2019, the Chamber of Commerce and Industry of Serbia, in cooperation with the Port Governance Agency, adopted a strategic document defining a network of marinas on international, interstate and national waterways in the Lower Danube Basin. The Port Governance Agency [98] prepared the studies on the port area of marinas in Kladovo and Golubac, which are the basis for the further development of these sites towards making marinas an unavoidable and equally significant segment of waterway passenger transport.

4.4 Tourism and Recreation

Tourism development in this area begins in the period when the HPP Đerdap I was built (1964–1970). At that time, ports were modernized and the infrastructure for workers' accommodation was built. A major influence on tourism development between Serbia and Romania was the construction of a road across the dam and the establishment of a border crossing [22]. Tourist values are numerous and could be classified into two main categories: natural assets and cultural heritage. Natural

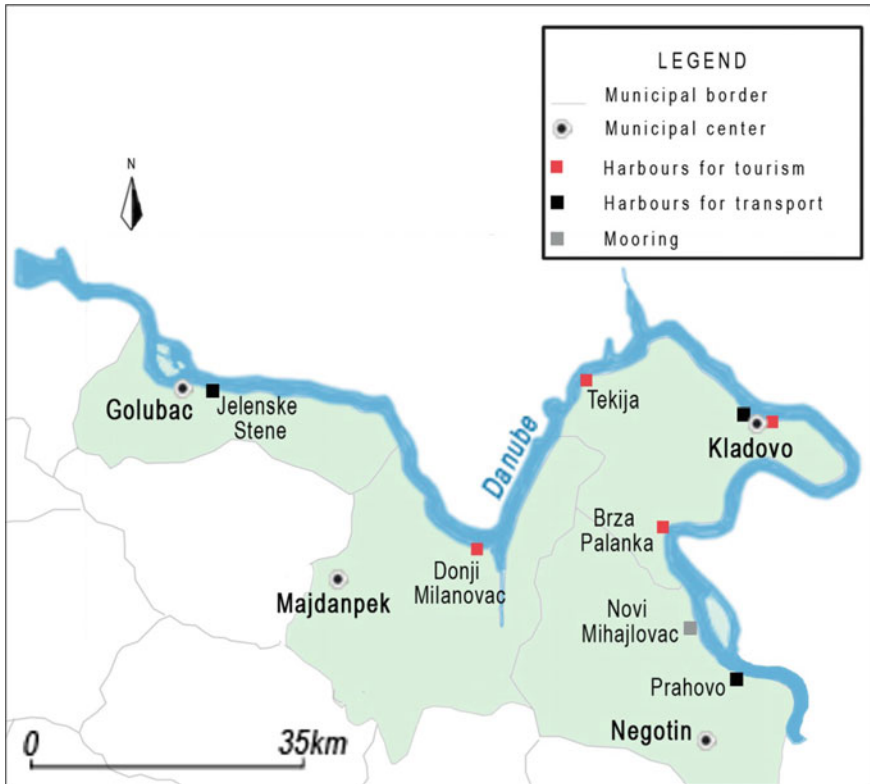


Fig. 4 Map of harbours in the Lower Danube River in Serbia

wealth includes: geological profiles (the geological column in Pesača, the geological profile in the canyon of Boljetinska Reka, and the geological profile Greben [99]); geomorphological features (e.g. Đerdap Gorge, in Fig. 5a, the most visited part of the Danube valley; the cave Velika Pećina in Duboka; the canyon of the Vratna River with its three natural stone bridges—Vratnanske prerasti; the canyon of the river Zamna; the natural stone bridge Šuplja Stena); the geomorphological–hydrological natural monument Beli Izvorac (tufa deposits with waterfalls) [22, 100, 101]; hydrological features (the Danube River with the Đerdap reservoir and tributaries, as well as waterfalls) [22, 96, 102]; biogeographical elements (forest ecosystems, endemic and relict species) and protected areas (Đerdap National Park, as well as other protected natural assets, such as the confluence of the Timok River into the Danube) [103]. Cultural heritage includes archaeological sites, religious and cultural monuments, artistic, ethnographic and festive values. The most important cultural heritage includes the archaeological sites (e.g. Lepenski Vir, in Fig. 5b; Trajan’s Bridge; Trajan’s Plaque etc.). There are also fortresses at Golubački Grad and Kladovo (Fetislam), which are the most important medieval fortress in this sector of the Danube valley [99, 101, 104–106]. These natural and anthropogenic values

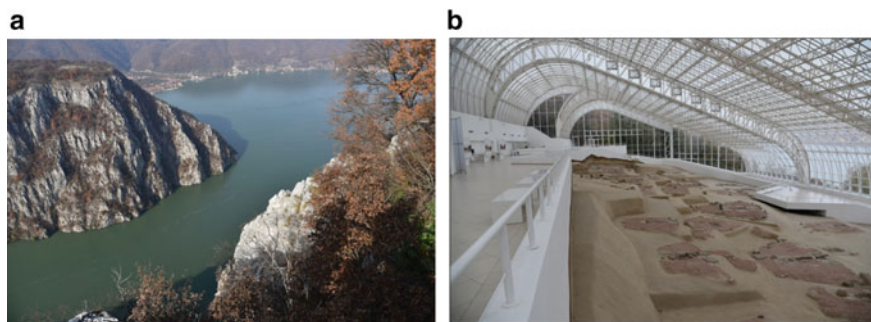


Fig. 5 a Đerdap Gorge b Museum of Lepenski Vir (Source Geographical Institute “Jovan Cvijić” SASA)

enable the development of different forms of tourism. The most pronounced are recreational and cultural tourism. The diversity of flora and fauna is favourable for the development of hunting and fishery tourism. Various water activities (such as swimming, water sports, sailing) as forms of river and nautical tourism are also present. Ecotourism is part of different programmes, such as bird-watching, hiking trails to viewpoints. Anthropogenic values have contributed to the development of city tourism (especially congress tourism), while festive tourism is developed both in rural and urban settlements. Over the past years, some households have specialized in rural tourism, based on authentic ethnographic motifs. Touristic activities are managed by touristic organizations in Golubac, Majdanpek (with the branch in Donji Milanovac), Kladovo and Negotin. In a regional context, the largest part of tourist traffic takes place in the municipalities of Majdanpek and Kladovo, which are the most developed in terms of tourism in the Lower Danube River area in Serbia, while tourist traffic is the least intensive in the municipalities of Negotin and Golubac [90].

Among the areas that have a potential for tourism development in the Lower Danube region in Serbia, the Đerdap National Park (NP) is especially distinguished. Keeping in mind that admission is free and that most tourists stay there for a day, it is difficult to determine the intensity of the tourist traffic. The data on the tourist traffic in the Đerdap NP for the 2010–2017 period presented in [99] have shown that local tourists have the greatest share in the total tourist traffic, while the number of international tourists is significantly lower (10.4–19.6% in total). Compared to the total tourist traffic in Serbia, the share of tourists visiting this NP is insignificant (1.89–3.09%). Tourist traffic measured by the number of overnight stays amounts to only 1.1–2.9 nights, suggesting that tourism potential in this area is insufficiently exploited. Similar conclusions about the insufficiently used potential of the Danube River for the geotourism development are made by [107]. Projects such as the *Fortresses on the Danube* and *Awake the Danube* have laid a good foundation for the formation of a unique nautical tourist product on the rivers, combining cultural and nature tours [98].

On the other hand, it is important to highlight that tourism development has also caused some pressures and negative consequences on water resources. Water quality was also affected by wastewater from the Golubac Municipality including hotels, restaurants, accommodation and other catering facilities. Due to the lack of a wastewater treatment plant, wastewater directly discharges into the Danube River [102].

4.5 Fishing

Fishing is practised in the following locations: from Golubac to Brnjica, Dobra, Donji Milanovac, Tekija, Karataš, and from Brza Palanka to the confluence of the Timok River into the Danube River [90]. According to [22], there are about 40 species of fish (seven under strict protection and 21 protected species) in the Đerdap sector of the Danube River. These include: sturgeon, pike, Prussian carp, carp, barbel, brook trout, mallard, chub, European bitterling, nase, carp bream, catfish, perch, etc. Fishing destinations in this area are favourable for the growth of perch, carp and catfish [90]. Two types of fishing are presented: sport (recreational) and commercial fishing. Commercial fishing is forbidden 500 m upstream of the Porečka River mouth, and 500 m downstream of the HPP Đerdap I, while recreational fishing is forbidden near the HPP Đerdap I [22].

As a consequence of the closure of the Đerdap dams, endangered medium-distance migratory fish, such as sterlet (*Acipenser ruthenus*) and huchen, Danube salmon (*Hucho hucho*) and large-distance migratory species, such as starred sturgeon (*Acipenser stellatus*) and beluga or great sturgeon (*Huso huso*) became extinct in the Upper Danube River [108]. Along with these fish species belonging to sturgeon, many other native species, such as common carp (*Cyprinus carpio*), common barbell (*Barbus barbus*), zander (*Stizostedion lucioperca*) and wels catfish (*Silurus glanis*), have been declining after the construction of the dam [109]. Apart from the negative impacts that the Đerdap dams have on river flow regulation, these fish species are impacted by unsustainable and illegal fishery and pollution [97, 110]. The anthropogenic habitat modification made this area suitable for invasive species [111].

5 Water Quality

Water quality plays a crucial role in all aspects of human life and activities and it is highly relevant for ecosystem sustainability.

5.1 Pollution Sources and Pollutants

In the studied area, water quality is affected by the HPPs Đerdap I and Đerdap II, an industrial zone in Mosna (electrical industry, wood industry and metal haberdashery industry), a copper mine in Majdanpek (Fig. 6), belonging to Copper Mining and Smelting Complex Bor (RTB), and Elixir Prahovo (Industry of Chemical Products) as well as wastewater from settlements, agriculture, road traffic, navigation and minor local sources of pollutants. The major pollution sources from mining and industry are shown in Table 2.

Pollution is generated mainly by the activities of these companies. The main activity of the RTB Bor is opencast mining and quarrying. Furthermore, the facility Sumporna produces basic organic chemicals, such as acids, including chromic acid, hydrofluoric acid, phosphoric acid, nitric acid, hydrochloric acid, sulphuric acid, sulphurous acid and oleum, on an industrial scale. The activities of Elixir Prahovo are focused on the production of phosphorus, nitrogen or potassium-based fertilizers on an industrial scale [112]. According to the investigations about environmental impact assessment of Elixir Prahovo from 2008 to 2013, wastewater from the factory's drain network (total wastewater from the factory grounds—wastewater collector) had a direct impact on the quality of Danube River [113].

Along with these companies, there are other potential anthropogenic pollution sources but the data about their emission into water are not available. These companies include: the Pig Farm Ramski Rit in Veliko Gradište and the Pig Farm Mustapić



Fig. 6 Copper mine Majdanpek (Source Geographical Institute “Jovan Cvijić” SASA)

Table 2 Mining and industry pollution in the Lower Danube River Basin in Serbia

Company	Facility	Pollutant
RTB	Copper mine Majdanpek open pit	Cu and compounds Pb and compounds
RTB	Copper mine Bor, open pit Cerovo	Zn and compounds
RTB	Copper mine Bor, open pit Veliki Krivelj	Zn and compounds Ni and compounds Cu and compounds Cd and compounds Pb and compounds
RTB	Copper mine Bor, open pit Jama	Cd and compounds Cu and compounds Ni and compounds Zn and compounds Pb and compounds
RTB	Sumporna	Cu and compounds
Elixir Prahovo	Elixir Prahovo	Fluorides Cd and compounds Total Phosphorus Zn and compounds

Source of data [112]

in Kučevo, which have facilities for the intensive poultry and pig growing [112]. Also, a potential source of pollution is the shipyard in Kladovo/Rhein–Donau Yard shipyard (in bankruptcy), the main activities of which include building new ships; repairs, overhauls and conversions of existing vessels; as well as the production of equipment and facilities for shipping and offshore industries. It is located on the Danube bank near Kladovo. In addition, it is noteworthy that the large industrial zone of Drobeta–Turnu Severin on the Romanian side towards Kladovo contributes to the pollution of the Danube.

Along the Lower Danube River in Serbia, collection and disposal of municipal wastewater through the sewage network is only partially organized. The greatest part of the infrastructure construction, which includes sewerage networks, took place in the Kladovo Municipality. The coverage of the municipal center of Kladovo with the sewerage network is about 80%, while the remaining 20% is solved by septic tanks [89]. In addition to the center, a complete sewerage network was built in five other settlements in this municipality. The municipal center of Golubac is covered by the sewerage network. However, these facilities are not available in other settlements within the municipality. In the town of Negotin, the drainage of municipal wastewater through the sewerage network is ensured only in one part of the town, whereas in other parts wastewater collection is managed through individual water-permeable septic tanks. The sewerage network is partially built in the municipal center of Majdanpek and in two smaller settlements. A fecal collector has not been built and fecal water is drained into Mali Pek River through a sedimentation tank. The settlement Boljetin, which is located in a strictly protected zone in the Đerdap National Park, has a big

problem with sewage wastewater because over 90% of households do not have a septic tank and wastewater flows directly into the Boljetinska River, a tributary of the Danube River [90].

Wastewater treatment plants in the Lower Danube River area in Serbia do not exist or are not operational. In Golubac and Majdanpek, no facilities have been built; construction has begun in Kladovo, while in Negotin, the existing plant is not operational. The wastewater treatment plant in Kladovo was designed in the 1980s, when the construction of the main facilities was undertaken, but it has not been put into operation yet. Currently, fecal sewage from the settlement flows directly into the Danube River through the emergency outlet in the incomplete facility. In Brza Palanka, there is a sewage network which brings wastewater to the fecal pumping station, which pumps it into the treatment plant. Through the overflow system, the deposited water is discharged into the Grobljanski Potok, which flows into the Danube River [89]. A wastewater treatment plant with a capacity of 5,000 m³ was built in Negotin. However it should be completely renovated and upgraded, as it is currently not operational. The construction of a sewerage network and a wastewater factory in Prahovo is planned, but currently there are no financial resources for its maintenance and operation. After rough treatment, wastewater is discharged into the melioration canal, into the Timok River, and the Danube River [92].

The amount of total discharged wastewater and the wastewater discharged into sewerage systems between 2009 and 2019 by municipalities located along the Lower Danube River in Serbia are presented in Fig. 7a, b, c, d. It is noteworthy that the total discharged wastewater is the sum of the wastewater discharged into wastewater collection systems and the estimated amount of wastewater discharged

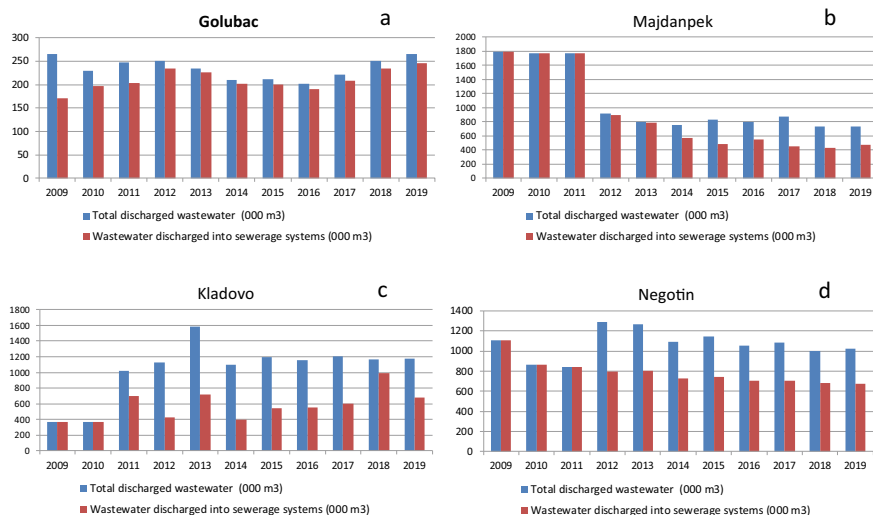


Fig. 7 Total discharged wastewater and the wastewater discharged into sewerage systems by municipalities located along the Lower Danube River in Serbia (*Source of data [85]*)

into other recipients. Figures 7a–d show that since 2013 more detailed estimates of wastewater discharged into other recipients are made. A significant decrease in the amount of discharged wastewater is observed only in the Majdanpek Municipality. Since 2013, in the municipalities of Majdanpek and Negotin, more than half of the discharged wastewater is conducted through wastewater drainage systems, while the worst situation is in Golubac, where this percentage varied significantly and usually amounted to about 40%, indicating the lack of a sewerage network.

Besides communal wastewater, it is important to highlight that the water quality of the Danube River is significantly affected by the Timok River, which is its largest tributary in the Lower Danube area in Serbia. Namely, the Timok River is from time to time severely polluted (III or IV water quality class) and it is endangered by organic and inorganic pollution [114]. This is a consequence of the untreated communal wastewater and the wastewater from the Bor mining industrial complex [114, 115]. Also, its tributary the Borska River is an out-of-class watercourse in terms of quality, due to wastewater from the mining process and wastewater from metallurgical and chemical processes in the industrial plants in Bor, which is directly discharged into this river [116, 117]. In addition, the water quality of the Danube tributaries in the Đerdap sector (Boljetinska, Brnjička, Porečka rivers) is especially endangered by nutrients, organic and inorganic pollution (due to the discharge of untreated municipal wastewater and drainage water from agriculture) and heavy metals (due to the breach of the dam at the flotation landfill Valja Fundata near Majdanpek). Some of the local wells are endangered by illegal landfills (in Sip), sewage discharges (in Kladovo, Tekija) and poor sanitation of the settlements [118]. All these facts have a significant influence on the water quality of the Lower Danube River in this area and downstream, in Romania and Bulgaria.

Combustion products from road traffic and navigation also impair the Danube's water quality. Illegal and industrial landfills belonging to the HPP Đerdap I and industrial zone in Mosna directly contaminate water resources. Furthermore, untreated municipal and industrial wastewater [10, 118] as well as drainage water from agriculture are released into watercourses [22]. Agriculture, especially in the Municipality of Golubac, leads to eutrophication and contamination of water with heavy metals, nitrogen and phosphorus due to agrochemical use [118].

5.2 Assessment of the Water Quality

The assessment of water quality is an important task and prerequisite for the protection and sustainable use of water resources. In order to examine water quality, various mathematical and statistical methods based on the use of water quality indices have been applied in many studies. The application of different water quality indices helps in the assessment of water quality and the ecological status of water resources, as well as in the identification of possible factors/sources that affect water bodies.

Table 3 SWQI categories

SWQI	Descriptor
90–100	Excellent
84–89	Very Good
83–72	Good
39–71	Bad
0–38	Very Bad

Source [148]

5.2.1 Data and Methodology

Data on water quality were obtained from the *Yearbooks III Water Quality* [119] published by the RHMS of Serbia and the SEPA for the 2009–2018 period, collected at the Tekija, Brza Palanka and Radujevac hydrological stations. The parameters were measured once monthly using relevant standard methods applied by the RHMS of Serbia. Frequency of recorded values was $N = 12$ per year.

Data were processed using the following types of the Water Quality Index (WQI): Serbian Water Quality Index (SWQI), Canadian Water Quality Index (CWQI), Agri-food Water Quality Index (AFWQI), and the Water Pollution Index (WPI). SWQI was calculated monthly. Based on monthly SWQI values, calculations of averaged yearly SWQI values were performed. Averaged yearly SWQI values were used for calculation of averaged SWQI value for ten-year (2009–2018) period. CWQI, AFWQI and WPI values were calculated yearly. Calculation of averaged ten-year period CWQI and AFWQI values were performed based on yearly values of these indices.

The Water Quality Index (WQI) methodology was developed by the Scottish Development Department in 1976, and it is often used for water quality assessment [120–126]. Types of the WQI, applied in this study were also used for water quality assessment in previous investigations: Serbian Water Quality Index (SWQI) in [127–133]; Canadian Water Quality Index (CWQI) in [126, 127, 129, 134–136]; Agri-food Water Quality Index (AFWQI) in [129, 137] and Water Pollution Index (WPI) in [114, 116, 138–147].

The mentioned WQI types rely on a different set of water quality parameters and they are used to calculate and compare obtained results in order to provide a better insight into the water quality status in study area.

Serbian Water Quality Index (SWQI)

Serbian Water Quality Index (SWQI) is an officially accepted methodology for water quality assessment in Serbia, developed by SEPA. The SWQI value is dimensionless—a single number, ranging from 0 to 100 (best quality) within the five categories, presented in Table 3.

The SWQI methodology uses ten quality parameters: oxygen saturation, biochemical oxygen demand (BOD), ammonium, pH, total nitrogen oxides, orthophosphate, suspended solids, temperature, conductivity and the most probable number of coliform bacteria (E.Coli/MPN). Each of these parameters has the value q_i and the weight unit w_i [148, 149]. The SWQI is calculated as a sum of the values of each parameter:

$$SWQI = \sum q_i \times w_i \quad (1)$$

This methodology is simple for application and can be used as indicator of urban sustainability. SWQI presents information about spatial distribution of surface water quality downstream of municipal wastewater discharge [150]. The main limitation is the small number of parameters and the possibility to calculate the index when some parameters are missing and even when only one parameter is available. SWQI is adequate for the evaluation of organic pollution, but it does not provide information about inorganic pollution, because parameters of heavy metal concentrations are not included [127].

Canadian Water Quality Index (CWQI)

The Canadian Water Quality Index (CWQI) was developed by the Canadian Council of Ministers of the Environment, based on the British Columbia Ministry of Environment formulation, in 1995 [151]. The CWQI is calculated based on the parameters presented in the Annex 1. Most of these parameters have their objectives (limit values) defined. This methodology makes possible to calculate the index even if some parameters are missing.

The Canadian Water Quality Index 1.0 Calculator (EXCEL application) is used to perform calculations using this methodology [151]. CWQI is based on three factors of water quality that relate to water quality objectives:

Scope (F_1):—the percentage of water quality variables that do not meet the objectives in at least one sample (“failed variables”).

$$F_1 = \left(\frac{\text{Number of failed variables}}{\text{Total Number of variables}} \right) \times 100 \quad (2)$$

Frequency (F_2):—the percentage of individual tests that do not meet the objectives (“failed tests”).

$$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of tests}} \right) \times 100 \quad (3)$$

Amplitude (F_3): The number of failed test that do not meet the objectives. F_3 is calculated in three steps [151], as follows:

1. The number of times by the value of the variable is greater than (or less than, when the objective is a minimum) the objective is termed as “excursion”. When the test value must not exceed the objective:

$$\text{excursion}_i = \left(\frac{\text{Failed Test Value}_i}{\text{Objective}_i} \right) - 1 \tag{4}$$

For the cases in which the test value must not be less than the objective:

$$\text{excursion}_i = \left(\frac{\text{Objective}_j}{\text{Failed Test Value}_i} \right) - 1 \tag{5}$$

2. The collective amount is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests. This ratio is referred to as the normalized sum of excursions, or *nse*.

$$nse = \frac{\sum_{i=1}^n \text{excursion}_i}{\neq \text{ of tests}} \tag{6}$$

3. F_3 ranges between 0 and 100 and is calculated as follows:

$$F_3 = \left(\frac{nse}{0.01 nse + 0.01} \right) \tag{7}$$

When all factors are obtained, CWQI is calculated by summing up the three factors. In this model, the index changes are in direct proportion to changes in all three factors:

$$CWQI = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \tag{8}$$

For each CWQI range a descriptive quality indicator has been defined [151], with the following ranges: excellent (95–100), good (80–94), fair (65–79), marginal (45–64) and poor (0–44):

- Excellent—there is no threat to the water quality; conditions are very close to natural or pristine level;
- Good—there is a minor threat or impairment; conditions rarely depart from natural or desirable levels;
- Fair—water quality is usually protected but occasionally threatened; conditions sometimes depart from natural or desirable levels;
- Marginal—water quality is frequently threatened; conditions often depart from natural or desirable levels;
- Poor—water quality is almost always threatened; conditions usually depart from natural or desirable levels [151].

Agri-food Water Quality Index (AFWQI)

Agri-food Water Quality Index (AFWQI) has also been developed by the Canadian Council of Ministers of the Environment, based on the British Columbia Ministry of Environment formulation, in 1995 [152]. The AFWQI methodology is based on the parameters, which upper limits are presented in Annex 2.

For each AFWQI range, a descriptive quality indicator has been defined ranging from poor (0–44), marginal (45–64), fair (65–79), good (80–89), very good (90–94), excellent (95–100). The AFWQI index provides information on the suitability of water for agricultural purposes, such as irrigation and livestock watering, and it is important for the assessment of pesticide pollution. The program used for AFWQI calculation is Agri-food Water Quality Index 1.0 Calculator. Calculation is performed in the same way as for the Canadian Water Quality Index [153]. In both cases, it is possible to calculate the indices even if some parameters are missing. Both indices share the same limitation: it is impossible to calculate the index in a single measurement (it is necessary to perform at least four measurements).

Water Pollution Index (WPI)

The Water Pollution Index (WPI) is an arithmetical method for integrating parameters to assess the chemical and ecological status of inland waters [154, 155]. Its advantage is the possibility to combine different parameters (physical, chemical, biological); also, there is no limitation as to the number or types of the used parameters. Therefore, the WPI is widely applied as an indicator in the evaluation of the water quality status in different water bodies, which allows for a simple and objective interpretation of results. It allows a simple and objective interpretation of results.

According to [154] the WPI is the sum of the ratios of the measured annual average value of parameters (C_i) and the prescribed maximum values for water quality class I (SFQS) for each parameter, divided by the number of used parameters (n):

$$WPI = \sum_{i=1}^n \frac{C_i}{SFQS} \times \frac{1}{n} \quad (9)$$

The calculated WPI values for watercourses can be classified into six different classes (Table 4).

The WPI involves a comparative analysis between the average annual concentration values of the observed parameters and the limit concentration values determined in the ecological classification for class I according to the national legislation. The standard threshold values for all parameters of the ecological status are defined for each country. In Serbia, they are established at the national level by several abovementioned regulations [39–41].

To calculate the WPI in this study, data relating to 18 physical, chemical and biological parameters, collected between 2009 and 2018 were used. Based on [39],

Table 4 Water quality classification according to WPI

WPI	Class	Characteristics
≤ 0.3	I	Very pure
0.31–1.0	II	Pure
1.01–2.0	III	Moderately polluted
2.01–4.0	IV	Polluted
4.01–6.0	V	Impure
>6.01	VI	Heavily impure

Source [154]

rivers in Serbia are divided into six types. The Danube, which is the subject of this study, belongs to Type 1; threshold values of the some parameters analyzed for this river type are shown in Annex 3.

The threshold values for other analyzed parameters in this study are presented in Annexes 4 and 5. For these parameters there are unique threshold values for classes, i.e. the rivers are not divided by different types.

A combination of indices was used in order to mitigate the limitations of individual indices and to obtain as precise results as possible. This approach provides more information about water quality and could be applied in various purposes.

5.2.2 Results and Discussion

Judging by the monthly parameters values for a ten-year period (2009–2018), averaged SWQI values were very good at all stations (84 at Tekija, 87 at Radujevac and 88 at Brza Palanka). However, an analysis of SWQI values for individual years reveals oscillations at all stations ranging from good to excellent (83–91 at Radujevac, 85–92 at Brza Palanka, and 74–91 at Tekija). The highest SWQI values at all stations were recorded during the same year (2012), while the lowest SWQI values for individual stations were recorded during different years (2013 at Tekija, 2016 at Radujevac and 2017 at Brza Palanka). Exceptions were noticed for the Tekija station during summer, when bad SWQI values were calculated (69 in August 2010 and 70 in June 2014). High water temperatures caused a decline in oxygen saturation in both cases. Furthermore, increased concentrations of suspended solids in June 2014 and an increased number of coliform bacteria in August 2010 also contributed to the decline of SWQI values.

The main sources of suspended solids are flotation tailings, metallurgical and heating plants [22]. The Đerdap reservoir is also an important source of suspended solids, as well as organic contaminants [3].

During the same period, at same stations, the CWQI values for overall water quality were significantly lower than SWQI values (Fig. 8a, b, c), ranging from marginal (50 at Radujevac) to fair (66 at Tekija and 68 at Brza Palanka). Oscillations were also greater for individual years, compared to SWQI, and they ranged from

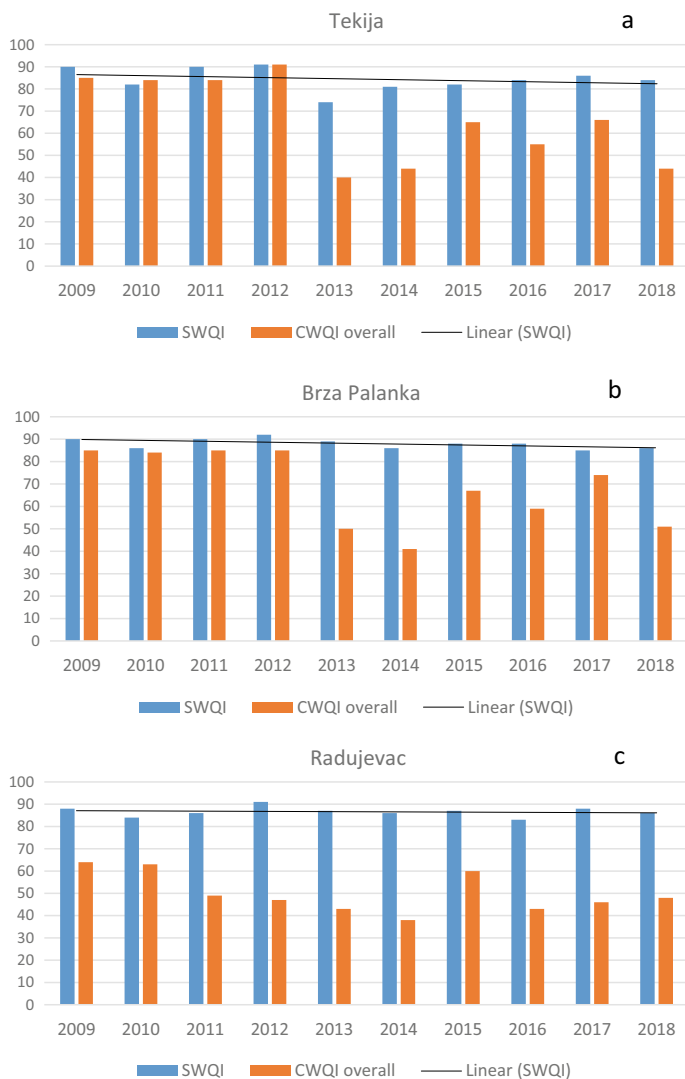


Fig. 8 SWQI and CWQI at Tekija (a), Brza Palanka (b) and Radujevac (c) stations on the Lower Danube River in Serbia

poor to good (41–85 at Brza Palanka and 40–91 at Tekija) and from poor to marginal (38–64 at Radujevac). The highest CWQI value was recorded at Tekija 2012, while the lowest value for the same station was recorded in 2013, which was in the line with SWQI. The highest CWQI value at Brza Palanka was recorded in 2012, as well as in 2009 and 2011, while the highest CWQI value at Radujevac was recorded in 2009. The lowest CWQI values at Radujevac and Brza Palanka were recorded in 2014.

The differences between the two indices could be explained by increased metal concentrations, which are calculated by CWQI. Between 2009 and 2012, good CWQI value was due to the missing parameters of metal concentration for the stations at Brza Palanka and Tekija. For both stations, the variable with the most failed tests was dissolved oxygen. The variables with the highest *nse* were turbidity (2010 for both stations and 2009 for Brza Palanka), and dissolved oxygen (2011 and 2012 for both stations, and 2009 for Tekija). The increased metal concentration had the greatest impact on the CWQI decline from 2013 to 2018 for Brza Palanka and Tekija, and throughout the whole study period (2009–2018) for Radujevac. In 2013–2018, the variable with the highest *nse* was aluminium for the Brza Palanka and Tekija stations, and for Radujevac, in 2011–2018. The variables with the most failed tests were mainly aluminium and copper for the Tekija (2013–2018) and Radujevac stations (2009–2018), and, in some cases, chromium. The variables with the most failed tests were dissolved oxygen, for Brza Palanka, and aluminium and copper in three cases.

Increased copper concentrations, which caused the decline of water quality, were mainly a result of the flotation process at the copper mine in Majdanpek [156] during which copper was released; it further reached water via soil and air. It also generated from untreated wastewater of the copper mine in Bor [117]. Organic pollution was caused by untreated wastewater, illegal landfills and inadequate sanitation in settlements [118].

The CWQI values for drinking water were good (Fig. 9) throughout the ten-year period for all stations (86 at Radujevac, 88 at Brza Palanka and 89 at Tekija). Some oscillations were recorded during individual years and they ranged from fair to excellent (79–96 at Brza Palanka and 72–100 at Tekija) and from fair to good (72–92 at Radujevac). The years with the highest CWQI for drinking water were 2012 (at Tekija and Radujevac) and 2017 (at Tekija and Brza Palanka). The lowest values were recorded in 2014 (at Brza Palanka and Radujevac) and 2013 (at Tekija). The variables that affected the CWQI for drinking water the most were iron and turbidity. Iron was the variable with the most failed tests and with the highest *nse* for all years with two exceptions: during 2010, turbidity was the variable with the most failed tests and with the highest *nse*, while manganese had the highest *nse* in 2017. In 2009 and 2010, the variable with the greatest number of failed tests and the highest *nse* was turbidity, while the pH was the variable with the most failed tests and the highest *nse* in 2011 for Brza Palanka and Tekija, as well as for Brza Palanka in 2012. Turbidity was the variable with the most failed tests and the highest *nse* in 2016 and 2017 for Brza Palanka and with the most failed tests in 2016 for Tekija and 2018 for Brza Palanka. In 2013, turbidity and iron had the most failed tests for Brza Palanka. In all other years, iron was the variable with the most failed tests for Brza Palanka and Tekija, with two exceptions: 2012 and 2017, when there were no failed tests for Tekija.

The copper mine in Majdanpek and the industrial zone in Mosna also produce other heavy metals, such as iron and chromium, as well as suspended solids, which cause increased turbidity [22]. Iron also is generated from open pits Veliki Krivelj and Jama of copper mine in Bor [157]. Besides these pollution sources, the Đerdap reservoir acts as a sink for fine sediments and pollutants [158].

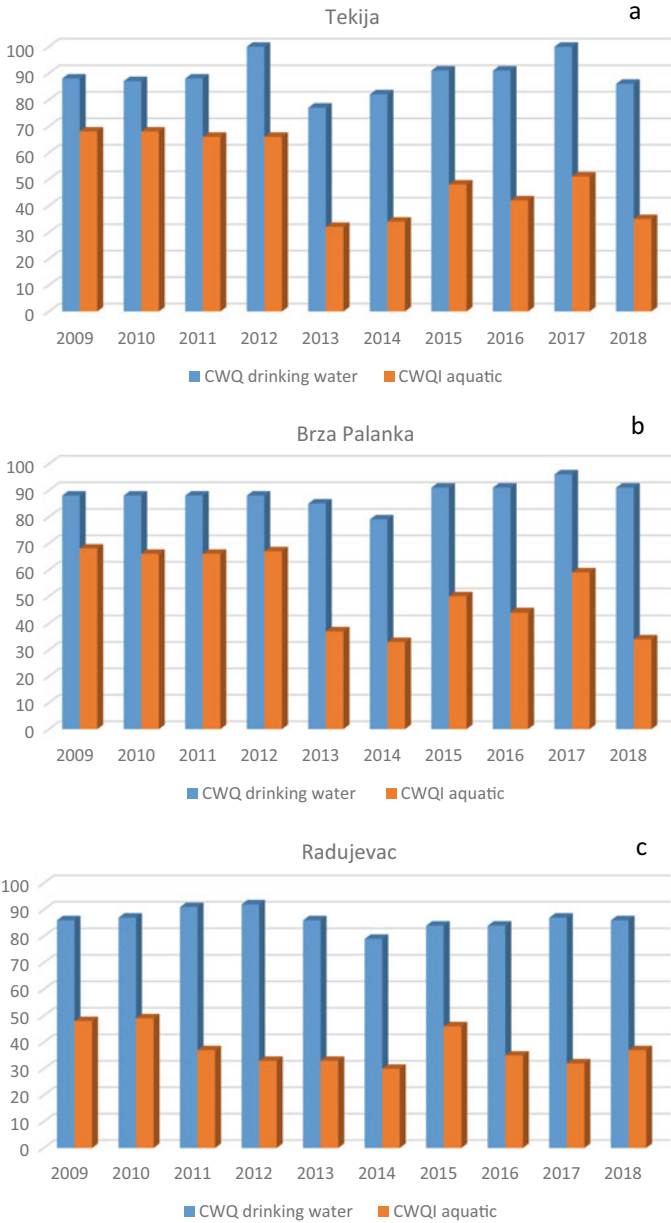


Fig. 9 CWQI for drinking water and aquatic life at Tekija (a), Brza Palanka (b) and Radujevac (c) stations on the Lower Danube River in Serbia

Over the ten-year period, the CWQI values for aquatic life (Fig. 9a, b, c) were marginal (51 at Tekija and 52 at Brza Palanka) and poor (38 at Radujevac). Oscillations during individual years ranged from poor to fair (33–68 at Brza Palanka and 32–68 at Tekija), and from poor to marginal (30–49 at Radujevac). The years with the highest CWQI for aquatic life were 2009 (at the Brza Palanka and Tekija) and 2010 (at Tekija and Radujevac), while the years with the lowest CWQI were the same as those when the CWQI the overall water quality was the lowest. The variables with the most failed tests and the those with the highest *nse* were in line with the CWQI for the overall water quality (for all stations and all years) with the following exceptions: dissolved oxygen was the variable with the highest *nse* in 2009 and 2010, at Brza Palanka, and 2010, at Tekija, whereas turbidity was the variable with the highest *nse* for the overall water quality.

Over the ten-year period, the CWQI for irrigation (Fig. 10 a, b, c) showed high values: good (94 at Radujevac) and excellent (98 at Tekija and 99 at Brza Palanka). Minor oscillations were observed in individual years, ranging from good to excellent (94–100 at Brza Palanka, 88–100 at Tekija, and 92–95 at Radujevac). Lower values were recorded in 2013 (Tekija and Radujevac) and 2014 (Brza Palanka). Chromium caused a slight decline in the CWQI for irrigation in all cases when CWQI had a value lower than 100. The only exception was Radujevac in 2017, when manganese was the variable with the most failed tests and the highest value of *nse*. In all other years, chromium had the most failed test and the highest *nse* for Radujevac, Brza Palanka (2014 and 2018), and Tekija (2013 and 2018). The CWQI for livestock was excellent (100) at all stations and in all years. CWQI did not reach the maximum value only in Radujevac in 2010 due to a slightly increased arsenic value in one measurement, causing a minor decline in CWQI (95). Increased chromium concentrations could be explained by the presence of chromic acid, which is the product of the facility Sumporna within the Copper Mining and Smelting Complex Bor (RTB) [112].

A comparison of the CWQI for irrigation and the AFWQI for irrigation reveals some similarities, but also some differences (Fig. 10a, b, c). Over the ten-year period, AFWQI values were mainly in line with CWQI for irrigation and were very good (89 at Tekija and 93 at Radujevac) and excellent (97 at Brza Palanka). Oscillations during individual years for Brza Palanka were not high and they ranged from good to excellent (88–100). However, significant oscillations were recorded for Tekija and Radujevac and they ranged from fair to excellent (68–100 at Tekija and 70–100 at Radujevac). The highest AFWQI value was recorded in 2010 and 2011 for all stations, as well as in 2009 for Brza Palanka and Radujevac, and in 2013, 2015 and 2016 for Brza Palanka. The lowest AFWQI values were recorded in 2014 at Tekija, 2015 at Radujevac, and in 2017 at Brza Palanka. Lower AFWQI values were mainly caused by the increased number of Coliforms total and Coliforms fecal. These variables had the most failed tests and the highest *nse*. Exceptions are registered in two single cases at Tekija: in 2009, linuron exceeded the limit in one measurement, and in 2013, cadmium was also above the limit in one measurement. Apart from these cases, manganese and Coliform total were the variables with the most failed tests in 2017 for Radujevac. Linuron is a herbicide that can also be found in the sediment of

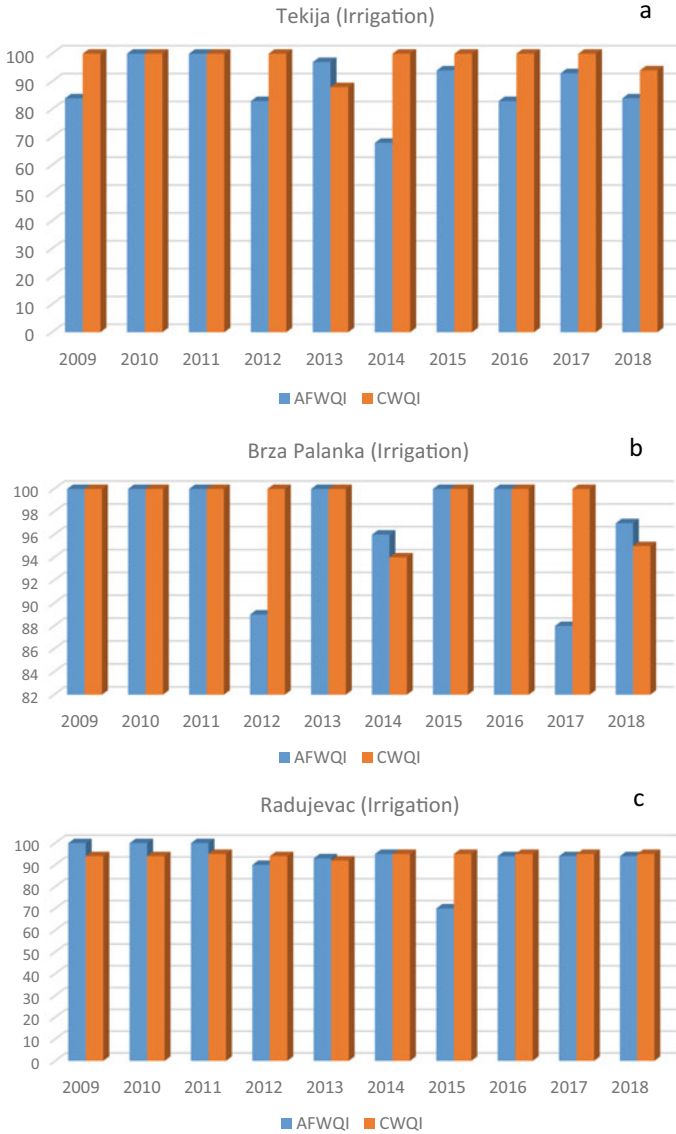


Fig. 10 AFWQI and CWQI for irrigation at Tekija, Brza Palanka and Radujevac stations on the Lower Danube River in Serbia

the Đerdap reservoir. The primary source of this environmental pollutant is its use in agriculture [3].

The AFWQI for livestock was in line with the CWQI for livestock and it usually had the maximum value (100). In 2012 at Tekija and Radujevac, as well as in 2011 and 2014 at Radujevac, increased concentrations of phenols (in one measurement

each year) caused a slight decline and AFWQI did not reach the maximum value: it was 96 at Tekija and 97 at Radujevac. Slightly increased arsenic concentration in one measurement in 2010 at Radujevac caused a slight decline in the AFWQI value (97), which was also in the line with the CWQI in the same case.

Some WPI analyses for the Serbian part of the Danube River have been presented in several previous studies. Based on data from ten hydrological stations the WPI was calculated for the entire Serbian part of the Danube River for 2014 [145]. The WPI was calculated for the Hydrosystem Danube–Tisa–Danube based on data from nine hydrological stations between 2004 and 2009 [138] and for the Đerdap sector of the Danube for a ten-year period (2007–2016) based on data from three hydrological stations [102]. As far as the water quality and pollution of the Danube's tributaries in Serbia are concerned, the WPI index was calculated for the Timok River at four hydrological stations [114], and for its tributary Borska Reka at one hydrological station [116] for two periods: 1993–1996 and 2006–2009.

In order to assess the ecological status of water quality of the Lower Danube River in Serbia in the present study, WPI was calculated based on the yearly parameters values from the aforementioned three hydrological stations. The results of the study conducted in 2009–2018 are presented in Table 5 and they were used to determine water pollution levels in this area. The results indicate that class III (moderately polluted water) was the most frequent in the Lower Danube River for a ten-year period. These results are similar to the literature data, which indicates moderate pollution of the Danube River in Serbia [145, 159]. Based on the analysis of WPI according to the locations of hydrological stations, the worst quality is at the Tekija, which is located in the Đerdap National Park. It is important to highlight that pollution of the Lower Danube River (especially in the Đerdap region) is different from the pollution of other Danube River sectors because of the relief, a small number of tributaries and small discharge. However, the Danube River receives pollutants from the upper sector of the river basin, where large industrial centres are located [160].

At the Tekija hydrological station, the WPI values ranged from 1.02 to 2.30, corresponding to class III (moderately polluted water) and class IV (polluted water). In addition to the aforementioned facts, one of the reasons for this situation was the insufficiently developed and poorly regulated utility infrastructure in the Đerdap National Park [102]. None of the accommodation and catering capacities of within the Đerdap National Park had their own wastewater treatment systems and they discharged wastewater into the city sewage. Also, as already pointed out, the municipalities have not fully resolved the issue of wastewater disposal.

At the Brza Palanka hydrological station, located downstream from the Đerdap I dam, the WPI values were in the 0.72–1.80 range, i.e. from class II (pure water) to class III (moderately polluted water). It is noticeable that class IV was not recorded in this period. One of the reasons for this could be the dam, which became an artificial barrier depositing sediment, accumulating pollutants and creating significant environmental problems [160]. The Đerdap dams and reservoirs significantly influence the sediment transport in two ways: on the one hand, they are a trap for suspended sediments [5, 27], and on the other, they are an important nutrient sink and deposition area for hazardous toxic matters causing pollution [161]. During the 1972–1994

Table 5 WPI values and water classes at Tekija, Brza Palanka and Radujevac stations on the Lower Danube River in Serbia

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
<i>Tekija</i>										
WPI	1.96	2.21	1.52	1.26	1.25	2.30	1.18	1.51	1.02	1.63
Class	III	IV	III	III	III	IV	III	III	III	III
Characteristics	Mod. polluted	Polluted	Mod. polluted	Mod. polluted	Mod. polluted	Polluted	Mod. polluted	Mod. polluted	Mod. polluted	Mod. polluted
<i>Brza Palanka</i>										
WPI	1.51	1.56	0.77	0.72	0.91	1.03	1.29	0.83	1.80	0.95
Class	III	III	II	II	II	III	III	II	III	II
Characteristics	Mod. polluted	Mod. Polluted	Pure	Pure	Pure	Mod. polluted	Mod. polluted	Pure	Mod. polluted	Pure
<i>Radujevac</i>										
WPI	1.33	1.25	1.11	1.05	2.90	1.00	1.17	1.06	0.97	1.09
Class	III	III	III	III	IV	II	III	III	II	III
Characteristics	Mod. polluted	Mod. polluted	Mod. polluted	Mod. polluted	Polluted	Pure	Mod. polluted	Mod. polluted	Pure	Mod. polluted

period, about 325 million tonnes of sediments (10% of the entire reservoir) were retained by the Đerdap dams, leading to a strong decline in suspended sediment transport along the Lower Danube River [162]. However, the process of the sediment deposition does not exhibit constant features: it takes place within the river channel only at low discharges, while at high discharges of the Danube River (when the hydraulic regime is close to natural), fluvial erosion takes place and removes previously-deposited sediment from the riverbed [27].

At the Radujevac hydrological station, located close to the place where the Danube River exits Serbia, the WPI values ranged from 0.97 to 2.90, i.e. from class II (pure water) to class IV (polluted water). It is noteworthy that at this station, the WPI values most frequently indicated class III (moderately polluted water), while class IV was recorded once and class II twice in a ten-year period. A higher degree of pollution was recorded at Radujevac than at Brza Palanka, as an upstream station. This is partly a consequence of the production in Elixir Prahovo (former IHP Prahovo), a factory for the production of phosphoric acid and mineral fertilizers.

The analysis of the WPI values over years for the same stations (Table 5) did not reveal any distinct trend on the Lower Danube River. Higher pollution levels were recorded at Tekija in 2010 and 2014, and at Radujevac, only in 2013. It is important to emphasize that at Brza Palanka, a lower degree of water pollution was noticed than at the other two stations. Also, a trend of water quality improvement was recorded in 2011–2013, when, based on the WPI value, water belonged to class II (clean water). Kindly check and confirm Table 10 citation is provided. But relevant table is missing. Kindly provide relevant table or delete this citation. We have corrected it. It is Table 5.

Taking into consideration the parameters used to calculate the WPI at all three hydrological stations, it can be concluded that out of the 18 analyzed parameters, six (pH, Mn, Ni, Cu, Hg and SO_4^{2-}) always belonged to class I. The values of four analyzed parameters (suspended solids, S, COD, Cd) mainly belonged to class I, with minor occasional deviations. In the 2009–2018 period, two analyzed parameters (oxygen saturation and BOD) belonged to class I and class II by half of the period, and two analyzed parameters (Fe and coliform bacteria) were classified as class I to class III. The other four analyzed parameters (dissolved oxygen, NO_2^{2-} , $\text{NH}_4\text{-N}$, PO_4^{3-}) deviated more or less from the permissible values for class I, thereby affecting the WPI values. Therefore, it can be concluded that the elements that served as the indicators of organic pollution had a significant impact on water pollution. Our results are reflective of other results reported in the literature. Calculation of nutrient loads (dissolved inorganic nitrogen—DIN), orthophosphates (PO_4^{3-}) and total phosphorus (TP) for Serbian part of the Danube River and its main tributaries in 2001–2010 and comparison to stations in other Danube countries showed that values mainly overlap with the general increasing trend in the downstream direction [163]. Concentrations of PO_4^{3-} and TP were higher at Radujevac compared with the upstream stations and belonged to the III class in terms of values. According to the WPI results for the Danube River in 2014, concluded that PO_4^{3-} and TP, the indicators of organic pollution, were the major nutrients that influenced the primary production in aquatic ecosystems of the Danube River [145]. Also, a chemical water quality assessment of the Danube River in the sector between the area 2 km downstream from HPP

Đerdap I to Drobeta–Turnu Severin showed that the most important variables that affected water quality were $\text{NH}_4\text{-N}$, TP, temperature and total suspended solids [164], indicating organic pollution. It is noteworthy that NO_2^{2-} , $\text{NH}_4\text{-N}$ and PO_4^{3-} have an important role in the formation of nutrition loads in rivers, causing eutrophication, oxygen depletion and water quality deterioration.

Other studies found anthropogenic sources of pollution in the area of the Đerdap reservoir [3, 10, 165]. Hagemann et al. [10] found organic pollution in the sediments. Matić Bujagić et al. [3] reported the presence of four classes of emerging pollutants in the sediment core (pharmaceuticals, pesticides, steroids and perfluorinated compounds). Pollution indices revealed that the concentration of minor elements (inorganic pollutants) in sediments had anthropogenic sources in some periods [165].

Calmuc et al. [126] also found the existence of pollution sources from agricultural and industrial activities. Their results also show differences between WPI, CCME WQI and WQI. According to WPI, water quality was ranked as class II (pure quality), according to CCME WQI, 98% of the sampling stations were ranked as class II, while according to WQI, 53% of the sampling stations were ranked as class III and 47% as class II. Based on this study, WQI should be applied in the evaluation of potentially toxic pollutants, CCME WQI in areas with permanent sources of pollution, while WPI should be used in the general characterisation of watercourses. It was emphasized that the most suitable index for water quality assessment is WQI because it takes into account various types of pollution sources [126].

6 Protective Measures by International Projects

The main aim of international projects in this area is to establish fish migration routes. Sturgeon fish species are considered endangered and nearly extinct. The International Commission for the Protection of the Danube River (ICPDR) has adopted the Sturgeon Strategy with the aim of ensuring the recovery and survival of sturgeon in the Danube River Basin. Three critically endangered species of the sturgeon include beluga or great sturgeon (*Huso huso*), Danube or Russian sturgeon (*Acipenser gueldenstaedti*), and starred sturgeon (*Acipenser stellatus*). Both short-distance migration populations (spawning downstream of Đerdap Gorge) and long-distance migrating populations (spawning upstream the Đerdap Gorge) are blocked in the spawning migration by HPPs Đerdap I and II. The priority is to take measures to save the genetic fingerprint of sturgeon in the Danube River Basin, specifically those sturgeon species that are nearly extinct and the few individuals born upstream of Đerdap Gorge. When they return to Đerdap Gorge, they are trapped because their migration upstream is blocked. The ICPDR Sturgeon Strategy seeks to involve stakeholders in the discussion and facilitate dialogue with the operators of Đerdap hydropower and navigation industry and infrastructure sector players in order to solve the issues related to interruptions/barriers and other hydromorphological alterations [166].

One of the projects is *Restoring fish migration routes in the Danube River Basin*, based on the grant agreement between the ICPDR and the Commission's Directorate-General for Regional and Urban Policy (DG REGIO). It aims to preserve fish stocks at the Romanian-Serbian border. This action is an important part of the central objective of the EU Strategy for the Danube Region: saving the Danube sturgeon from extinction. The Danube sturgeon (*Acipenser gueldenstaedti*) is endangered due to the construction of the Đerdap dams: the disruption of the river continuity constitutes an obstacle for migratory fish, including the sturgeon species, Danube salmon (*Hucho hucho*) and European eel (*Anguilla anguilla*).

According to the EU Strategy for the Danube Region, the EU Water Framework Directive, the EU Habitats Directive and the Bern Convention, stakeholders and international experts provided the framework for the development of specific conservation measures. The first phase, from 2011 to 2016, facilitated dialogue between the ICPDR, stakeholders and EU Commission—represented by DG REGIO and The Directorate-General for Environment (DG ENV). The second phase is the feasibility study. The third and fourth phases regard technical design (2021–2023) and implementation (2024 and onwards). In line with the feasibility study, the ICPDR will coordinate and implement activities jointly with the Danube Delta National Institute for Research and Development (DDNI) from Romania and the Jaroslav Černi Institute for Water Resources Development (JCI) from Serbia [167].

A similar project is an initiative *We Pass*, which aims to facilitate fish migration in the Danube River Basin with the focus on preservation and reestablishment of the migration routes of endangered fish species in the Danube River and its tributaries, specifically at the Đerdap Gorge. This initiative is set up by the ICPDR, JCI, DDNI, CDM Smith OAK consultants, and the Norwegian Institute for Nature Research (NINA). One of the projects in the scope of this initiative is *Study on environmental and ecological thematic in the framework of macro-regional strategies (MRS) and policy coordination with the Directorate-General for Neighbourhood and Enlargement Negotiations (DG NEAR) and DG ENV: Support for the implementation of the Feasibility Study analyzing options for characteristic Danube fish migration at Đerdap I & II*. The Serbian side has proposed the construction of a third, smaller hydropower plant (Đerdap III) with the assurance of no adverse impacts on the ecosystem area. The specific objective of this project is to restore and preserve water and soil quality, and biodiversity in the Danube Region. Addressing the blockage of a fish migration route around the Đerdap dams is the central concern in preserving biodiversity in the entire Danube, before and beyond the Serbian-Romanian border area. In order to achieve these objectives, the following tasks are proposed: project management, analysis of the current situation and data gathering, monitoring fish behavior at Đerdap Gorge, communication activities, data quality assurance and quality checks, 3D basis model [168].

The Đerdap National Park in Serbia and the Iron Gate Nature Park in Romania were the subject of the transnational cooperation project BioREGIO Carpathians (2011–2013). The objectives of the project were conservation, restoration and valorization of the Carpathian ecological continuum in order to enable wild animals to live in coexistence with modern society. The projects applied a multi-disciplinary approach (physical, legal and socio-economic) to identify the most influential

barriers regarding connectivity throughout the Carpathians. A part of this project was the case study *The Lynx in the Pilot Area Đerdap National Park (Serbia)/Iron Gate Nature Park (Romania)*. The aim of the study was to find the Least Coast Paths (LCP) for Lynx in this area and potential barriers. The final recommendation which related to this case study concentrated on animal–vehicle collision (highlighting the absence of mitigation structures and the driving behaviour—special focus on the road 25-1 in Đerdap National Park). This study could help in identifying the most important corridors for both wildlife movements and the human–wildlife coexistence [169]. Crossborder cooperation of the Đerdap National Park is also realized through IPA crossborder programmes between Serbia, Romania and Bulgaria and it is related to the formation of the European Green Belt (i.e. the Lower Danube Green Corridor along the borders with Romania), the European Road of Culture (Danube Road), the Euroregion “Danube 21”, etc. [118].

7 Conclusion and Recommendation

Water resources around the world are overexploited due to population growth and an increased demand for water. Large rivers, such as the Danube River, are especially under pressure, because of multipurpose use. This chapter deals with the human impact and pressures on the Lower Danube River Basin in Serbia, which is presented through an overview of the water resources use in this area. The water resources of the Lower Danube River are used for hydropower production, navigation, water supply of settlements, agriculture, industry, fishing, tourism and recreation. Đerdap Hydropower and Navigation System has especially significant role for multipurpose Danube’s water use, with very favourable conditions for hydropower production and navigation. However, these potentials are not completely valorized. Groundwater from local sources (often accumulated in karst massifs) is prevalingly used for water supply. Tourist values are numerous including natural assets and cultural heritage. All these uses affect water quality and aquatic ecosystems. Fishing is also impacted by Đerdap dams. In this study, assessment of water quality in Lower Danube River in Serbia was made at three stations (Tekija, Brza Palanka and Radujevac), based on the following indices: Serbian Water Quality Index (SWQI), Canadian Water Quality Index (CWQI), Agri-food Water Quality Index, and Water Pollution Index (WPI). Depending on the parameters used, the results show some oscillations and variations. However, general conclusion is that water quality at the Radujevac station is somewhat lower because the station is the farthest downstream. The low values of the CWQI for aquatic life suggest that living organisms are especially endangered. The major anthropogenic pollution sources are the Copper Mine in Majdanpek, the industrial zone in Mosna, the production of phosphoric acid and mineral fertilizers in Elixir Prahovo, untreated wastewater and landfills, emissions from road traffic and navigation, pesticides and other chemicals from agriculture. Along with pollution, aquatic ecosystems are also affected by hydromorphological alterations, such as the construction of the Đerdap reservoir, which had a negative impact on migratory fish

species. Several international projects seek to address the decreased fish population by establishing fish migration routes.

Considering the above-mentioned water supply of municipalities in the Lower Danube Region in Serbia, the recommendations would be: the reconstruction of the existed water distribution network (to reduce losses in the water supply network); revitalization and protection of reservoirs; the reconstruction of the plants for drinking water production; establish group water supply systems in the rural settlements of this municipality (especially in the hinterland of the Danube River); the protection of the water sources in order to prevent water pollution from mines; the supply of industrial facilities with technological water provided from local watercourses with mandatory recirculation of technological water.

In the context of water protection, these recommendations among others, include the following: construction of wastewater treatment plants, both for wastewaters from households in municipal centers and in industrial plants for industrial wastewater; increasing the level of coverage of the population by sewage systems; control of the use of mineral and organic fertilizers and pesticides in order to reduce the pollution from agriculture; introduction of good agricultural practice; reduce water pollution by sediments and associated pollutants from agricultural land (phosphorus, nitrogen, pesticides, herbicide, etc.) through soil erosion control; improving municipal waste management through the construction of sanitary landfills and the closure of uncontrolled (illegal) dumping sites; implementation of the Guiding principles on sustainable hydropower development in the Danube River Basin [170], which, among other things, includes a technical upgrade of existing hydropower plants, strategic planning of new hydropower development, as well as ecological restoration measures to ensure sustainable use of hydropower; the improvement of navigation conditions; construction and maintenance of marinas, harbours and anchorages [22]; the reactivation of a national river fleet; increasing awareness among the population on environmental problems through environmental education and by organizing various events, such as the Danube Day in order to raise awareness of the social impact on water pollution.

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Annex 1: CWQI Parameters with Limit Values

Variables	Units	Overall		Drinking		Aquatic		Recreation		Irrigation		Livestock	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Color	TCU		15		15								15
Turbidity (Turb)	NTU		1		1								
Dissolved Oxygen (DO)	mg/l	9.5				9.5							
pH		6.5	8.5	6.5	8.5	6.5	9	5	9				
Calcium (Ca)	mg/l		1000										1000
Sodium (Na)	mg/l		200		200								
Sulphate (SO ₄ ²⁻)	mg/l		500		500								1000
Chloride (Cl ⁻)	mg/l		110		250					110			
Fluoride (F ⁻)	mg/l		1		1.5		1.2			1			1
Nitrate, Nitrite (NO ₃ ⁻ NO ₂ ⁻)	mg/l		100										100
Aluminium (Al)	mg/l		0.005				0.005			5			5
Arsenic (As)	mg/l		0.005		0.025		0.005			0.1			0.025
Barium (Ba)	mg/l		1		1								
Cadmium (Cd)	mg/l		0.005		0.005					0.0051			0.08
Cromium (Cr)	mg/l		0.001		0.05		0.001			0.0049			0.05
Copper (Cu)	mg/l		0.002		1		0.002			0.2			0.5
Iron (Fe)	mg/l		0.3		0.3		0.3			5			
Mercury (Hg)	µg/l		0.003		1		0.1						0.003
Manganese (Mn)	mg/l		0.05		0.05					0.2			
Molybdenum (Mo)	mg/l		0.073				0.073						
Nickel (Ni)	mg/l		0.025				0.025			0.2			1

(continued)

(continued)

Variables	Units	Overall		Drinking		Aquatic		Recreation		Irrigation		Livestock	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Lead (Pb)	mg/l		0.001		0.01								0.05
Zinc (Zn)	mg/l		0.03		5							1	50

Source Adapted from [151]

Annex 2: AFWQI Parameter Limits

Parameter	Unit	Irrigation	Livestock
Aldicarb	µg/l	54.9	11
Aluminum (Al)	µg/l	5,000	5,000
Arsenic (As)	µg/l	100	25
Atrazine	µg/l	10	5
Beryllium (Be)	µg/l	100	100
Boron (B)	µg/l	6,000	5,000
Bromacil	µg/l	0.2	1,100
Bromoxynil	µg/l	0.33	11
Cadmium (Cd)	µg/l	5.1	80
Calcium (Ca)	µg/l		1,000,000
Captan	µg/l		13
Carbaryl	µg/l		1,100
Carbofuran	µg/l		45
Chloride (Cl ⁻)	µg/l	700,000	
1,2-Dichloroethane	µg/l		5
1,1,2-Trichloroethene (TCE)	µg/l		50
Chlorothalonil	µg/l	5.8	170
Chlorpyrifos	µg/l		24
Trivalent Chromium (Cr(III))	µg/l	4.9	50
Hexavalent Chromium (Cr(VI))	µg/l	8	50
Cobalt (Co)	µg/l	50	1,000
Coliforms, fecal (E. Coli)	in 100 ml	100	
Coliforms Total	in 100 ml	1,000	
Copper (Cu)	µg/l	1,000	5,000
Cyanazine	µg/l	0.5	10
Deltamethrin	µg/l		2.5
Dibromochloromethane	µg/l		100
Dicamba	µg/l	0.006	122
Dichlorobromomethane	µg/l		100
Dichloromethane	µg/l		50
Diclofop-methyl	µg/l	0.18	9
Diisopropanolamine (DIPA)	µg/l	2,000	
Dimethoate	µg/l		3
Dinoseb	µg/l	16	150
Ethylbenzene	µg/l		2.4

(continued)

(continued)

Parameter	Unit	Irrigation	Livestock
Fluoride (F ⁻)	µg/l	1,000	2,000
Glyphosate	µg/l		280
Hexachlorobenzene	µg/l		0.52
Iron (Fe)	µg/l	5000	
Lindane	µg/l		4
Linuron	µg/l	0.071	
Lithium (Li)	µg/l	2,500	
Manganese (Mn)	µg/l	200	
4-chloro-2-methyl-phenoxy (MCPA)	µg/l	0.025	25
Mercury (Hg)	µg/l		3
Metolachlor	µg/l	28	50
Metribuzin	µg/l	0.5	80
Molybdenum (Mo)	µg/l	50	500
Nickel (Ni)	µg/l	200	1,000
Nitrate + Nitrite (NO ₃ ⁻ + NO ₂ ⁻)	µg/l		100,000
Nitrite (NO ₂ ⁻)	µg/l		10,000
Phenols (C ₆ H ₆ O)	µg/l		2
Phenoxy herbicides	µg/l		100
Picloram	µg/l		190
Selenium (Se)	µg/l	50	50
Simazine	µg/l	0.5	10
Sulfolane	µg/l	500	
Sulphate	µg/l		1,000,000
Tebuthiuron	µg/l	0.27	130
Tetrachloromethane	µg/l		5
Toluene	µg/l		24
Total Dissolved Solids (TDS)	µg/l	3,500,000	3,000,000
Triallate	µg/l		230
Tribromomethane	µg/l		100
Tributyltin	µg/l		250
Trichloromethane	µg/l		100
Tricyclohexiltyn	µg/l		250
Trifluralin	µg/l		45
Triphenyltin	µg/l		820
Uranium (U)	µg/l	10	200
Vanadium (V)	µg/l	100	100
Zinc (Zn)	µg/l	5,000	50,000

Source: Adapted from [152]

Annex 3: Threshold Values for the Parameters of the Ecological Status for Rivers Belonging to Type 1 in Serbia (for the Danube River)

Parameter	Unit	Prescribed maximum values between ecological status classes			
		I–II	II–III	III–IV	IV–V
Type 1					
<i>Chemical and physico-chemical parameters of ecological status assessment</i>					
pH value (pH)		6.5–8.5	6.5–8.5	6.5–8.5	<6.5 or >8.5
Dissolved oxygen (DO)	mg/l	8.5 ²	7.0	5.0	4.0
Biochemical oxygen demand (BOD)	mg/l	2	5	8	20
Ammonium (NH ₄ -N)	mg/l	0.1	0,3	0,8	1.0
Orthophosphate (PO ₄ ³⁻)	mg/l	0.02	0.1	0.2	0,5
<i>Biological parameters of ecological status assessment</i>					
Saprobic index (S)		2.10	2.65	2.90	3.20
<i>Microbiological parameters of ecological status assessment</i>					
Coliform bacteria (CB)	nb/100 ml	500	10,000	100,000	1,000,000

Source [39]

Annex 4: Limit Values of Pollutants in Surface Waters in Serbia

Parameter	Unit	Prescribed maximum values between classes				
		I	II	III	IV	V
Suspended solids (SS)	mg/l	25	25	–	–	–
Oxygen saturation (OS)	%	90–110	90–110	90–110	90–110	90–110
Chemical oxygen demand (COD)	mg O ₂ /l	5	10	20	50	>50
Nitrite (NO ₂ ²⁻)	mg N/l	0.01	0.03	0.12	0.3	>0.3
Sulfate (SO ₄ ²⁻)	mg/l	50	100	200	300	>300
<i>Metals</i>						
Iron (Fe)	μg/l	200	500	1000	2000	>2000
Manganese(Mn)	μg/l	50	100	300	1000	>1000

(continued)

(continued)

Parameter	Unit	Prescribed maximum values between classes				
		I	II	III	IV	V
Copper (Cu)	µg/l	5 (<i>T</i> = 10) 22 (<i>T</i> = 50) 40 (<i>T</i> = 100) 112 (<i>T</i> = 300)	5 (<i>T</i> = 10) 22 (<i>T</i> = 50) 40 (<i>T</i> = 100) 112 (<i>T</i> = 300)	500	1000	>1000

Source [40]

Annex 5: Limit Values for Priority and Priority Hazard Substances in Surface Waters in Serbia

Priority hazard substance	Average annual concentration (AAC) (µg/l)	Maximum allowed concentration (MAC) (µg/l)
Mercury (Hg)	–	0.07
Cadmium (Cd)	<0,08 (Class I) 0,08 (Class II) 0,09 (Class III) 0,15 (Class IV) 0,25 (Class V)	<0,45 (Class I) 0,45 (Class II) 0,6 (Class III) 0,9 (Class IV) 1,5 (Class V)
Nickel (Ni)	4	34

Source [41]

References

1. Pletterbauer F, Melcher A, Graf W (2018) Climate change impacts in riverine ecosystems. In: Schmutz S, Sendzimir J (eds) Riverine ecosystem management: science for governing towards a sustainable future. Springer Open, Cham, pp 203–223
2. Trautwein C, Pletterbauer F (2018) Land use. In: Schmutz S, Sendzimir J (eds) Riverine ecosystem management: science for governing towards a sustainable future. Springer Open, Cham, pp 241–252
3. Matic Bujagić I, Grujić S, Laušević M, Hofmann T, Micić V (2019) Emerging contaminants in sediment core from the Iron Gate I reservoir on the Danube River. *Sci Total Environ* 662:77–87. <https://doi.org/10.1016/j.scitotenv.2019.01.205>
4. Sendzimir J, Schmutz S (2018) Challenges in riverine ecosystem management. In: Schmutz S, Sendzimir J (eds) Riverine ecosystem management: science for governing towards a sustainable future. Springer Open, Cham, pp 1–16

5. Habersack H, Jäger E, Hauer C (2013) The status of the Danube River sediment regime and morphology as a basis for future basin management. *Int J River Basin Manag* 11(2):153–166. <https://doi.org/10.1080/15715124.2013.815191>
6. Habersack H, Hein T, Stanica A, Liska I, Mair R, Jäger E, Hauer C, Bradley C (2016) Challenges of river basin management: Current status of, and prospects for, the River Danube from a river engineering perspective. *Sci Total Environ* 543:828–845. <https://doi.org/10.1016/j.scitotenv.2015.10.123>
7. Vukovic D, Vukovic Z, Stankovic S (2014) The impact of the Danube Iron Gate Dam on heavy metal storage and sediment flux within the reservoir. *CATENA* 113:18–23. <https://doi.org/10.1016/j.catena.2013.07.012>
8. Hohensinner S, Hauer C, Muhar S (2018) River morphology, channelization, and habitat restoration. In: Schmutz S, Sendzimir J (eds) *Riverine ecosystem management: science for governing towards a sustainable future*. Springer Open, Cham, pp 41–65
9. Schmutz S, Moog O (2018) Dams: ecological impacts and management. In: Schmutz S, Sendzimir J (eds) *Riverine ecosystem management: science for governing towards a sustainable future*. Springer Open, Cham, pp 111–127
10. Hagemann L, Kašanin-Grubin M, Gajica G, Štrbac S, Šajnović A, Jovančićević B, Vasić N, Schwarzbauer J (2019) Four decades of organic anthropogenic pollution: a compilation for Djerdap Lake sediments. Serbia. *Water Air Soil Pollut* 230:246. <https://doi.org/10.1007/s11270-019-4277-8>
11. Weigelhofer G, Hein T, Bondar-Kunze E (2018) Phosphorus and nitrogen dynamics in riverine systems: human impacts and management options. In: Schmutz S, Sendzimir J (eds) *Riverine ecosystem management: science for governing towards a sustainable future*. Springer Open, Cham, pp 187–202
12. Haidvogel G (2018) Historic milestones of human river uses and ecological impacts. In: Schmutz S, Sendzimir J (eds) *Riverine ecosystem management: science for governing towards a sustainable future*. Springer Open, Cham, pp 19–39
13. Panić M, Urošev M, Milanović Pešić A, Miljanović D (2014) Hydropower development in Serbia: current state, perspectives and challenges. In: Burke L (ed) *Hydroelectricity and power electronics: environmental impact, emerging technologies, and challenges*. Nova Science Publishers, New York, pp 1–54
14. Greimel F, Schülting L, Graf W, Bondar-Kunze E, Auer S, Zeiringer B, Hauer C (2018) Hydropeaking impacts and mitigation. In: Schmutz S, Sendzimir J (eds) *Riverine ecosystem management: science for governing towards a sustainable future*. Springer Open, Cham, pp 91–110
15. Unfer G, Pinter K (2018) Recreational fisheries: the need for sustainability in fisheries management of alpine rivers. In: Schmutz S, Sendzimir J (eds) *Riverine ecosystem management: science for governing towards a sustainable future*. Springer Open, Cham, pp 253–270
16. International Commission for the Protection of the Danube River (ICPDR) (2015) *The Danube River Basin Management Plan*. <https://www.icpdr.org/flowpaper/app/#page=1>. Accessed 22 Apr 2022
17. Waidbacher H, Drexler S-S, Meulenbroek P (2018) Danube under pressure: hydropower rules the fish. In: Schmutz S, Sendzimir J (eds) *Riverine ecosystem management: science for governing towards a sustainable future*. Springer Open, Cham, pp. 473–489
18. International Commission for the Protection of the Danube River (ICPDR) (2020) *Countries of the Danube Basin*. <https://www.icpdr.org/main/danube-basin/countries-danube-river-basin>. Accessed 20 Nov 2020
19. Uredba o utvrđivanju Prostornog plana područja posebne namene međunarodnog vodnog puta E 80—Dunav (Panevropski koridor VII) (Decree on Determining the Spatial Plan of the Special Purpose Area of International Waterway E 80—the Danube (Pan-European Corridor VII), *Official Gazette of the Republic of Serbia* 14/2015
20. Directorate for Inland Waterways Plovpud (2020) *Navigation Chart of the Danube River in the Republic of Serbia (km 1433.1—km 845.5)*. Directorate for Inland Waterways Plovpud, Belgrade. <https://danubeportal.com/application/cache/uploads/charts/paper/RS/118/1560771184.pdf>. Accessed 20 Nov 2020

21. Statistical Office of the Republic of Serbia (2011) Popis stanovništva, domaćinstava i stanova 2011. u Republici Srbiji — prvi rezultati: Knjiga 540 (2011 Census of Population, Households and Dwellings in the Republic of Serbia—First Results Book 540). http://media.popis2011.stat.rs/2011/prvi_rezultati.pdf. Accessed 20 Oct 2020
22. Milanović Pešić A (ed) (2015) Leksikon Nacionalnog parka Đerdap (Lexicon of the Đerdap National Park). Public Enterprise Official Gazette, Public Enterprise “Đerdap National Park”, Geographical Institute “Jovan Cvijić” SASA, Belgrade
23. Gavrilović Lj, Dukić D (2014) Reke Srbije (Rivers of Serbia). Zavod za udžbenike i nastavna sredstva, Belgrade
24. Strategija upravljanja vodama na teritoriji Republike Srbije do 2034. godine (Water Management Strategy for the Territory of the Republic of Serbia until 2034), Official Gazette of the Republic of Serbia 3/2017
25. Stanković S (2005) Jezera Srbije (Lakes of Serbia). Zavod za udžbenike i nastavna sredstva, Belgrade
26. Javno preduzeće “Elektroprivreda Srbije” (2020) Public Enterprise “Elektroprivreda” Serbia. Branches. <http://www.eps.rs/cir/Pages/Ogranci.aspx> Accessed Dec 10 2020
27. Babic Mladenovic M, Kolarov V, Damjanovic V (2013) Sediment regime of the Danube River in Serbia. *Int J Sediment Res* 28(4):470–485. [https://doi.org/10.1016/S1001-6279\(14\)60006-8](https://doi.org/10.1016/S1001-6279(14)60006-8)
28. Urošev M, Kovačević-Majkić J, Štrbac D, Milanović Pešić A, Milijašević D, Jakovljević D, Petrović A (2017) Vode Srbije (Water of Serbia). In: Radovanović M (ed) Geografija Srbije (Geography of Serbia) (Special issues 91). Geographical Institute “Jovan Cvijić” SASA, Belgrade, pp 160–235
29. Zakon o nacionalnim parkovima (Law on National Parks), Official Gazette of the Republic of Serbia 84/2015, 95/2018
30. Public Enterprise Đerdap National Park (2020) About the Park. <https://npdjerdap.rs/o-parku/> Accessed 20 Oct 2020
31. Amidžić L, Krasulja S, Belij S (eds) (2009) Protected natural areas in Serbia. Ministry of Environmental Protection, Institute for Nature Conservation of Serbia, Belgrade
32. Maran Stevanović A (2017) Activities on the establishment of Đerdap Geopark (Serbia) and candidature of the area to the UNESCO Global Geoparks Network. *Bulletin Natl Hist Museum* 10:7–28. <https://doi.org/10.5937/bnhmb1710007M>
33. Public Enterprise Đerdap National Park (2020) Područje Đerdap proglašeno za Ramsarsko područje (The “Đerdap” area designated as Ramsar site) <https://npdjerdap.rs/podrucje-dje-rdap-proglaseno-za-ramsarsko-podrucje/>. Accessed 20 Dec 2020
34. Institute for Nature Conservation of Serbia (2020) Đerdap designated as a the wetland of international importance. <https://www.zzps.rs/wp/djerdap-proglasen-za-medjunarodno-znacajno-vlazno-podrucje-ramsarsko-podrucje/>. Accessed 20 Dec 2020
35. Ministry of Environmental Protection (2020) Đerdap jedanaesto Ramsarsko područje u Republici Srbiji (Đerdap eleventh Ramsar site in Serbia) <https://www.ekologija.gov.rs/saopstinja/vesti/djerdap-jedanaesto-ramsarsko-podrucje-u-republici-srbiji>. Accessed 20 Dec 2020
36. DANUBEPARKS (2020) Associations <https://www.danubeparks.org/association> Accessed 20 Dec 2020
37. Zakon o vodama (Water Law), Official Gazette of the Republic of Serbia 30/2010, 93/2012, 101/2016, 95/2018, 95/2018
38. Uredba o graničnim vrednostima emisije zagađujućih materija u vode i rokovima za njihovo dostizanje (Regulation on Emission Limit Values of Pollutants in Water and Deadlines for Their Achievement), Official Gazette of the Republic of Serbia 67/2011, 48/2012, 1/2016
39. Pravilnik o parametrima ekološkog i hemijskog statusa površinskih voda i parametrima hemijskog i kvantitativnog statusa podzemnih voda (Rulebook on Parameters of the Ecological and Chemical Status of Surface Waters, and Parameters of the Chemical and Quantitative Status of Ground Waters), Official Gazette of the Republic of Serbia 74/2011
40. Uredba o graničnim vrednostima zagađujućih materija u površinskim i podzemnim vodama i sedimentu i rokovima za njihovo dostizanje (Regulation on Limit Values of Pollutants in

- Surface and Ground Waters and Sediments and Deadlines for Their Achievement), Official Gazette of the Republic of Serbia 50/2012
41. Uredba o graničnim vrednostima prioritetnih i prioritetnih hazardnih supstanci koje zagađuju površinske vode i rokovima za njihovo dostizanje (Regulation on Limit Values of Priority and Priority Hazardous Substances that Pollute the Surface Waters and Deadlines for Their Achievement), Official Gazette of the Republic of Serbia 24/2014
 42. Pravilnik o načinu i uslovima za merenje količine i ispitivanje kvaliteta otpadnih voda i sadržini izveštaja o izvršenim merenjima (Rulebook on the Method and Conditions for Measuring the Quantity and Testing the Quality of Wastewater and the Content of the Report on the Performed Measurements), Official Gazette of the Republic of Serbia 33/2016
 43. Odluka o određivanju granica vodnih područja (Decision on Determining the Boundaries of Water Areas), Official Gazette of the Republic of Serbia 92/2017
 44. Pravilnik o utvrđivanju metodologije za izradu karte ugroženosti i karte rizika od poplava (Rulebook on Defining the Methodology for Designing of Vulnerability Map and Flood Risk Map), Official Gazette of the Republic of Serbia 13/2017
 45. Ministry of Agriculture, Forestry and Water Management, Republic Water Directorate (2020) Podzakonska akta (Bylaws). <http://www.rdvode.gov.rs/podzakonska-akta.php>
 46. Ministry of European Integration of the Republic of Serbia (2018) Nacionalni program za usvajanje pravnih tekovina Evropske Unije – treća revizija (National Programme for the Adoption of the *Acquis*—Third revision). https://www.mei.gov.rs/upload/documents/nacionalna_dokumenta/npaa/npaa_2018_2021.pdf. Accessed 20 Nov 2020
 47. Nacionalna strategija za aproksimaciju u oblasti životne sredine za Republiku Srbiju (National Environmental Approximation Strategy for the Republic of Serbia), Official Gazette of the Republic of Serbia 80/2011
 48. Ministry of Environment, Mining and Spatial Planning of the Republic of Serbia (2012) Strategija aproksimacije za sektor voda (Water Sector Approximation Strategy). Ministry of Environment, Mining and Spatial Planning of the Republic of Serbia, Belgrade
 49. Veljković N, Petrović Z, Šotić A, Cibulić V (2018) Perspective on implementation of the EU Urban Waste Water Treatment Directive in Serbia). Voda i sanitarna tehnika 47(1):5–16. <https://www.sepa.gov.rs/download/radovi/2018/UrbanWasteWaterTreatmentDirectiveInSerbia.pdf>. Accessed 10 Oct 2020
 50. Lekić D, Perunović Čulić T (eds) (2019) Izveštaj od stanju životne sredine u Republici Srbiji za 2018 godinu (The Report on the Environmental State in the Republic of Serbia in 2018). <http://www.sepa.gov.rs/download/Izvestaj2018.pdf>. Accessed 10 Oct 2020
 51. Drobňaković M, Spalević A (2017) Naselja Srbije (The settlements in Serbia). In: Radovanović M (ed) Geografija Srbije (Geography of Serbia) (Special issues 91). Geographical Institute “Jovan Cvijić” SASA, Belgrade, pp 566–613
 52. Živanović Z, Tošić B, Nikolić T, Gatarić D (2019) Urban system in Serbia—the factor in the planning of balanced regional development. Sustainability 11(15):4168. <https://doi.org/10.3390/su11154168>
 53. Miljanović D, Miletić R, Đorđević J (2010) Regional inequality in Serbia as development problem. Acta Geogr Slov 50(2):253–275. <https://doi.org/10.3986/AGS50204>
 54. Drobňaković M, Panić M, Đorđević J (2015) Traditional undeveloped municipalities in Serbia as result of regional inequality. Eur Plan Stud 24(5):926–949. <https://doi.org/10.1080/09654313.2015.1129396>
 55. Veljković N, Denić Lj, Jovičić M, Dopuđa Glišić T, Domanović M (2020) Komparativna analiza trendova koncentracija nitrata u vodotokovima Srbije (Comparative trend analysis nitrate concentrations in Serbian watercourses). Voda i sanitarna tehnika (Water Sanitary Technol) 60(1–2):25–29. http://www.sepa.gov.rs/download/radovi/2020/KOMPARATIVNA_ANALIZA_TRENDOVA_NITRATA-Nebojsa_Veljkovic.pdf. Accessed 10 Nov 2020
 56. Zakon o zaštiti životne sredine (Law on Environmental Protection), Official Gazette of the Republic of Serbia 135/2004, 36/2009, 72/2009, 43/2011, 14/2016
 57. Zakon o proceni uticaja na životnu sredinu (Law on Environmental Impact Assessment), Official Gazette of the Republic of Serbia 135/2004, 36/2009

58. Zakon o strateškoj proceni uticaja na životnu sredinu (Law on Strategic Environmental Impact Assessment), Official Gazette of the Republic of Serbia 135/2004, 88/2010
59. Zakon o integrisanom sprečavanju i kontroli zagađivanja životne sredine (Law on the Integrated Prevention and Control of Environmental Pollution), Official Gazette of the Republic of Serbia 135/2004, 25/2015
60. Miljanović D (2018) Geosistemske osnove upravljanja životnom sredinom (Geosystem foundations of environmental governance) (Unpublished Doctoral Dissertation). University of Belgrade, Belgrade, Faculty of Geography
61. Zakon o planiranju i izgradnji (Law on Planning and Construction), Official Gazette of the Republic of Serbia 72/2009, 81/2009, 64/2010, 24/2011, 121/2012, 42/2013, 50/2013, 98/2013, 132/2014, 145/2014, 83/2018, 31/2019, 37/2019, 9/2020
62. Kovačević-Majkić J, Panić M, Miljanović D, Miletić R (2014). Vulnerability to natural disasters in Serbia: spatial and temporal comparison. *Nat Hazards* 72(2):945–968. <https://doi.org/10.1007/s11069-014-1045-3>
63. Zakon o zaštiti prirode (Law on Nature Conservation), Official Gazette of the Republic of Serbia 36/2009, 88/2010, 91/2010, 14/2016, 95/2018
64. Zakon o zaštiti i održivom korišćenju ribljeg fonda (Law on Protection and Sustainable Use of Fish Resources), Official Gazette of the Republic of Serbia 118/2014, 95/2018
65. Zakon o javnom zdravlju (Law on Public Health), Official Gazette of the Republic of Serbia 15/2016
66. Zakon o plovidbi i lukama na unutrašnjim vodama (Law on Navigation and Ports on Inland Waterways), Official Gazette of the Republic of Serbia 73/2010, 121/2012, 18/2015, 96/2015, 96/2016, 104/2016, 113/2017, 41/2018, 95/2018, 37/2019, 9/2020
67. Zakon o energetici (Energy Law), Official Gazette of the Republic of Serbia 145/2014, 95/2018
68. Zakon o upravljanju otpadom (Law on Waste Management), Official Gazette of the Republic of Serbia 36/2009, 88/2011, 14/2016, 95/2018
69. Zakon o meteorološkoj i hidrološkoj delatnosti (Law on Meteorological and Hydrological Activities), Official Gazette of the Republic of Serbia 88/2010
70. Zakon o komunalnim delatnostima (Law on Communal Activities), Official Gazette of the Republic of Serbia 88/2011, 104/2016, 95/2018
71. Zakon o lokalnoj samoupravi (Law on Local Government), Official Gazette of the Republic of Serbia 129/2007, 83/2014, 101/2016, 47/2018
72. Zakon o smanjenju rizika od katastrofa i upravljanju vanrednim situacijama (Law on Disaster Risk Reduction and Emergency Situations Management), Official Gazette of the Republic of Serbia 87/2018
73. Zakon o ministarstvima (Law on Ministries), Official Gazette of the Republic of Serbia 128/2020
74. Zakon o ministarstvima (Law on Ministries), Official Gazette of the Republic of Serbia 16/2011
75. Veljković N, Denić Lj, Dopuđa Glišić T, Jovičić M, Milovanović J, Domanović M (2015) Reporting on surface water quality in Serbia based on national legislation and cooperation with European Union. *Voda i sanitarna tehnika* 45(3–4):23–32. http://www.sepa.gov.rs/download/radovi/2015/KvalitetPovrsinskihVodaSrbije_112015.pdf.
76. Javno vodoprivredno preduzeće (JVP) “Srbijavode” (Public Water Management Company (PWMC) “Srbijavode”) (2017) Statut JVP “Srbijavode” Beograd (Statute PWMC “Srbijavode” Belgrade). <http://www.srbijavode.rs/web/images/dokumenti/Statut-2017-godina.pdf>. Accessed 1 Oct 2020
77. Institut za vodoprivredu “Jaroslav Černi” (2020). The Jaroslav Černi Institute for the Development of Water Resources (JCI). <https://www.jcerni.rs/> Accessed 20 Oct 2020
78. Uredba o utvrđivanju vodoprivredne osnove Republike Srbije (Decree on Determining Water Management Plan of the Republic of Serbia), Official Gazette of the Republic of Serbia 11/2002
79. Ministry of Construction, Transport and Infrastructure of the Republic of Serbia (2021) Prostorni plan Republike Srbije od 2021 do 2035. godine - Nacrt (Spatial Plan of the Republic

- of Serbia from 2021 to 2035—Draft). <https://www.mgsi.gov.rs/sites/default/files/PPRS%20Nacrt.pdf>
80. Nacionalna strategija održivog korišćenja prirodnih resursa i dobara (National Strategy of Sustainable Use of Natural Resources and Goods), Official Gazette of the Republic of Serbia 33/2012
 81. Stanišić J, Maksić S (2014) Environmental education in Serbian primary schools: challenges and changes in curriculum, pedagogy, and teacher training. *J Environ Educ* 45(2):118–131. <https://doi.org/10.1080/00958964.2013.829019>
 82. Stern MJ, Powell RB, Dawn H (2014) Environmental education program evaluation in the new millennium: what do we measure and what have we learned? *Environ Educ Res* 20(5):581–611. <https://doi.org/10.1080/13504622.2013.838749>
 83. Kovačević-Majkić J, Milošević MV, Panić M, Miljanović D, Čalić J (2014) Risk education in Serbia. *Acta Geogr Slov* 54(1):163–178. <https://doi.org/10.3986/AGS54305>
 84. Bosschaart A, van der Scheec J, Kuipere W, Schoonenboom J (2016) Evaluating a flood-risk education program in the Netherlands. *Stud Educ Eval* 50:53–61. <https://doi.org/10.1016/j.stueduc.2016.07.0020>
 85. Statistical Office of the Republic of Serbia (2010–2020) Municipalities and regions in the Republic of Serbia, 2009–2019 <https://www.stat.gov.rs/en-US/publikacije/?d=13&r=>. Accessed 20 Oct 2020
 86. United Nations development Programme (UNDP) (2006) Human Development Report 2006. Beyond Scarcity: Power, Poverty and the Global Water Crisis. New York: United Nations Development Programme. ISBN 0–230–50058–7. <https://www.undp.org/content/undp/en/home/librarypage/hdr/human-development-report-2006.html>. Accessed 20 Nov 2020
 87. Prostorni plan opštine Golubac (Spatial Plan of the Golubac Municipality) (2011) Arhiplan d.o.o, Arandelovac
 88. Prostorni plan opštine Majdanpek (Spatial Plan of the Majdanpek Municipality) (2012) Direkcija za izgradnju, urbanizam i građevinsko zemljište Smederevo JP, Smederevo
 89. Prostorni plan opštine Kladovo (Spatial Plan of the Kladovo Municipality) (2006) Centar za planiranje urbanog razvoja- CEP d.o.o, Beograd
 90. Scientific Research Center (2007) Master plan turističke destinacije “Donje Podunavlje” (Master Plan for Tourist Destination Donje Podunavlje). <https://mtt.gov.rs/download/sektor-za-turizam/master-planovi/MasterplanDonjePodunavlje.pdf>. Accessed 10 Dec 2020
 91. Jaroslav Černi Institute for the Development of Water Resources (JCI) (2001) Vodoprivredna osnova Republike Srbije (Water Management Plan of the Republic of Serbia). Jaroslav Černi Institute for the Development of Water Resources, Belgrade
 92. Prostorni plan opštine Negotin (Spatial Plan of the Negotin Municipality) (2011) Faculty of Geography, University of Belgrade, Belgrade
 93. Milanović Pešić A, Jakovljević D, Radovanović M (2017) Water supply issues in Serbia. In: Materials of the international scientific-practical conference “Water resources, hydraulic facilities and environment” (part I). “AZERSU” OJSC, Baku, pp 450–454
 94. Public Enterprise Electric Power Industry of Serbia (2019) <http://www.eps.rs/cir/Pages/Ogranci.aspx>. Accessed 20 Nov 2020
 95. Smederevac Lalić MM, Kalauzi AK, Regner SB, Lenhardt MB, Naunovic ZZ, Hegediš AE (2017) Prediction of fish catch in the Danube River based on long-term variability in environmental parameters and catch statistics. *Sci Total Environ* 609:664–671. <https://doi.org/10.1016/j.scitotenv.2017.07.177>
 96. Brankov J (2020) Water resource management in national parks in Serbia—towards an integrated protection and sustainable tourism use. In: Milanović Pešić A, Jakovljević D (eds) Water resources management: methods, applications and challenges. Nova Science Publishers, New York, pp 195–230
 97. Jovičić K, Višnjić Jeftić Ž, Jarić I, Subotić S, Hegediš A, Lenhardt M (2018) Literature survey on fish tissues contamination by heavy metals and elements in the Danube River from 1433–845 rkm. In: Poleksić V, Rašković B, Marković Z (eds) Conference Proceedings of the VIII International Conference Water & Sea. Faculty of Agriculture, University of Belgrade,

- International Aquatic Veterinary Biosecurity Consortium Ludwig-Maximilians-University Munich, Belgrade, pp 386–393
98. Port Governance Agency (2019) Annual Bulletin. Nb.4, Marinas new development opportunity
 99. Milanović Pešić A (2019) Identification and valorisation of Danube as a hydrological touristic attractiveness in Serbia—Example of National park Djerdap. In: Proceedings of the VII International scientific-practical conference “Innovative aspects of the development service and tourism”. Faculty of Social and Cultural Service and Tourism, Stavropol State Agrarian University, Stavropol, pp 84–90
 100. Belij M, Đurđić S, Stojković S (2018) The evaluation of geoheritage for ecotourism development: case study on the potential Geopark Djerdap. Collection of papers—Faculty of Geography, University of Belgrade 66(2):121–132. <https://doi.org/10.5937/zrgfub1802121B>
 101. Lukić D, Petrović MD, Vuković DB (2018) Potential of geotourism for regional development: the case of “Iron Gates” park in Serbia. R-ECONOMY 4(4):158–166. <https://doi.org/10.15826/recon.2018.4.4.021>
 102. Milanović Pešić A, Brankov J, Milijašević Joksimović D (2020) Water quality assessment and populations’ perceptions in the National park Djerdap (Serbia): key factors affecting the environment. Environ Dev Sustain 22:2365–2383. <https://doi.org/10.1007/s10668-018-0295-8>
 103. Institute for Nature Conservation of Serbia (2020) Pregled zaštićenih područja u Republici Srbiji (Overview of protected areas in Republic of Serbia). <https://www.zzps.rs/wp/pdf/centraInregistar/2020%203%20Pregled%20zasticenih%20podrucja%20Srbije.pdf>. Accessed 20 Nov 2020
 104. Terzić A (2014) Perspektive razvoja kulturne rute “Tvrđave na Dunavu” u funkciji obogaćivanja turističke ponude Srbije (Development perspectives of the cultural route “Fortress along the Danube” for enriching the tourist offer in Serbia) (Special Issues 88). Geographical Institute “Jovan Cvijić” SASA, Belgrade
 105. Belij M (2017) Cultural tourist motives in national parks in Serbia. In: Filipović D, Gosar A, Koderman M, Đurđić S (eds) Tourism in protected areas of nature in Serbia and Slovenia. University of Belgrade, Belgrade, Faculty of Geography, pp 113–128
 106. Lukić D, Petrović M (2020) Uloga objekata geonasleđa u turizmu Podunavlja Srbije (The role of geoheritage sites in tourism of Serbian Podunavlje Region) (Special Issues 97). Geographical Institute “Jovan Cvijić” SASA, Belgrade
 107. Tomić N, Marković SB, Antić A, Tešić D (2020) Exploring the potential for geotourism development in the Danube region of Serbia. Int J Geoheritage Parks 8:123–139. <https://doi.org/10.1016/j.ijgeop.2020.05.001>
 108. Seliger C, Zeiringer B (2018) River connectivity, habitat fragmentation and related restoration measures. In: Schmutz S, Sendzimir J (eds) Riverine ecosystem management: science for governing towards a sustainable future. Springer Open, Cham, pp 171–186
 109. Macura B, Bojović P, Petrić I, Čosić N, Tadić M, Jarić I, Knežević J, Šripić J, Jarić M (2013) Local communities and management of the Djerdap protected area in Serbia. In: Healy H, Martínez-Alier J, Temper L, Walter M, Gerber JF (eds) Ecological economics from the ground up. Routledge, Abingdon, pp 366–389
 110. Lenhardt M, Višnjić-Jeftić Ž, Navodaru I, Jarić I, Vassilev M, Gačić Z, Nikčević M (2012) Fish stock management cooperation in the lower Danube Region: a case study of sturgeons and pontic shad. In: Lagutov V (ed) Environmental security in watersheds: the Sea of Azov. NATO science for peace and security series c: environmental security. Springer, Dordrecht, pp 127–140. https://doi.org/10.1007/978-94-007-2460-0_7
 111. Smederevac Lalić M, Regner S, Lenhardt M, Nikolić D, Cvijanović G, Jaćimović M, Hegediš A (2019) Review of allochthonous fish species with the marine origine in Serbian freshwater system. Studia Marina 32(1):33–46. <https://doi.org/10.5281/zenodo.3274548>
 112. Serbian Environmental Protection Agency (SEPA) (2014) PRTR registar (PRTR register) <http://www.sepa.gov.rs/PRTR/search.html?lang=de>. Accessed 10 Jan 2021

113. Faculty of Mining and Geology, University of Belgrade (2015) Elixir Prahovo, Industrija Hemijskih Proizvoda, DOO Prahovo—Non-Technical Summary of the Environmental Impact Assessment Study on the Phosphogypsum Storage. http://www.mmediu.ro/app/webroot/uploads/files/2015-04-08_Sumar.pdf. Accessed 10 Jan 2021
114. Brankov J, Milijašević D, Milanović A (2012) The assessment of the surface water quality using the Water Pollution Index: a case study of the Timok River (The Danube River Basin), Serbia. *Arch of Environ Prot* 38:49–61. <https://doi.org/10.2478/v10265-012-0004-x>
115. Šerbula S, Stanković V, Živković D, Kamberović Ž, Gorgievski M, Kalinović T (2016) Characteristics of wastewater streams within the Bor copper mine and their influence on pollution of the Timok River, Serbia. *Mine Water Environ* 35:480–485. <https://doi.org/10.1007/s10230-016-0392-6>
116. Milijašević D, Milanović A, Brankov J, Radovanović M (2011) Water quality assessment of the Borska river using the WPI (Water Pollution Index) method. *Arch Biol Sci* 63(3):819–824. <https://doi.org/10.2298/ABS1103819M>
117. Gardić VR, Petrović JV, Đurđević-Ignjatović LV, Kolaković SR, Vujović SR (2015) Procena uticaja rudničkih drenažnih i komunalnih otpadnih voda na kvalitet površinskih voda u Boru i okolini (Impact assessment of mine drainage water and municipal wastewater on the surface water in the vicinity of Bor). *Hem Ind* 69(2):165–174. <https://doi.org/10.2298/HEMIND140128031G>
118. Prostorni plan područja posebne namene Nacionalnog parka Đerdap (Spatial Plan for the Special Purpose Area of the Đerdap National Park) (2013) Resource document. <https://www.rapp.gov.rs/sr-Latn-CS/zasticena-i-turisticka-podrucja/cid294-83243/prostorni-plan-podrucja-posebne-namene-nacionalnog-parka-Đerdap>. Accessed 10 Dec 2020
119. Republic Hydrometeorological Service of Serbia (2009–2018). Yearbook III-Water Quality (2009–2018). Republic Hydrometeorological Service of Serbia, Belgrade
120. Lumb A, Sharma TC, Bibeault JF (2011) A review of genesis and evolution of Water Quality Index (WQI) and some future directions. *Water Qual Expo Health* 3:11–24. <https://doi.org/10.1007/s12403-011-0040-0>
121. Karbassi AR, Mir Mohammad Hosseini F, Baghvand A, Nazariha M (2011) Development of Water Quality Index (WQI) for Gorganrood River. *Int J Environ Res* 5(4):1041–1046. <https://doi.org/10.22059/ijer.2011.461>
122. Rubio-Arias H, Contreras-Caraveo M, Quintana RM, Saucedo-Teran RA, Pinales-Munguia A (2012) An overall Water Quality Index (WQI) for a man-made aquatic reservoir in Mexico. *Int J Environ Res Public Health* 9:1687–1698. <https://doi.org/10.3390/ijerph9051687>
123. Iticescu C, Georgescu LP, Topa CM (2013) Assessing the Danube Water Quality Index in the City of Galati, Romania. *Carpath J Earth Env* 8(4):155–164. Accessed 10 Dec 2020
124. Venkatramanan S, Chung SY, Lee SY, Park N (2014) Assessment of river water quality via environmentric multivariate statistical tools and Water Quality Index: a case study of Nakdong River Basin, Korea. *Carpath J Earth Env* 9(2):125–132. <http://www.ubm.ro/sites/CJEES/viewTopic.php?topicId=426>. Accessed 10 Dec 2020
125. Şener Ş, Şener E, Davraz A (2017) Evaluation of water quality using Water Quality Index (WQI) method and GIS in Aksu River (SW Turkey). *Sci Total Environ* 584–585:131–144. <https://doi.org/10.1016/j.scitotenv.2017.01.102>
126. Calmuc M, Calmuc V, Arseni M, Topa C, Timofti M, Georgescu LP, Iticescu C (2020) A comparative approach to a series of physico-chemical quality indices used in assessing water quality in the Lower Danube. *Water* 12(11):3239. <https://doi.org/10.3390/w12113239>
127. Jakovljević D (2012) Serbian and Canadian Water Quality Index of Danube River in Serbia in 2010. *J Geogr Inst Cvijic* 62(3):1–18. <https://doi.org/10.2298/IJGI1203001J>
128. Veljković N (2013) Sustainable development indicators: case study for South Morava River Basin. *Hem Ind* 67(2):357–364. <https://doi.org/10.2298/HEMIND111226059V>
129. Jakovljević D (2015) Geoekološke determinante zaštite i revitalizacije tekućih voda u funkciji održivog razvoja AP Vojvodine (Geocological determinants of the protection and revitalization of water courses in the terms of the sustainable development of AP Vojvodina) (Unpublished Doctoral Dissertation). Faculty of Geography, University of Belgrade, Belgrade

130. Walker D, Jakovljević D, Savić D, Radovanović M (2015) Multi-criterion water quality analysis of the Danube River in Serbia: A visualisation approach. *Water Res* 79:158–172. <https://doi.org/10.1016/j.watres.2015.03.020>
131. Pantelić M, Dolinaj D, Savić S, Leščešen I, Stojanović V (2016) Water quality and population standpoints as factors influencing the utilization for agricultural purposes of the Great Backa Canal, Serbia. *J Environ Sci Manage* 19(2):8–14. <https://ovcre.uplb.edu.ph/journals-uplb/index.php/JESAM/article/view/141/123>
132. Milijašević Joksimović D, Gavrilović B, Lović Obradović S (2018) Application of the Water Quality Index in the Timok River Basin (Serbia). *J Geogr Inst Cvijic* 68(3):333–344. <https://doi.org/10.2298/IJGI180610007M>
133. Milanović Pešić A, Jakovljević D, Milijašević Joksimović D (2020) Water resources management in Serbia. In: Milanović Pešić A, Jakovljević D (eds) *Water resources management: methods, applications and challenges*. Nova Science Publishers, New York, pp 231–299
134. Hurley T, Sadiq R, Mazumder A (2012) Adaptation and evaluation of the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) for use as an effective tool to characterize drinking source water quality. *Water Res* 46:3544–3552. <https://doi.org/10.1016/j.watres.2012.03.061>
135. Jakovljević D, Lozanov-Crvenković Z (2015) Water quality changes after Kraljevo earthquake in 2010. *Nat Hazards* 79(3):2033–2053. <https://doi.org/10.1007/s11069-015-1943-z>
136. Jakovljević D (2020) Assessment of water quality during the floods in May, 2014. Serbia. *J Geogr Inst Cvijic* 70(3):215–226. <https://doi.org/10.2298/IJGI2003215J>
137. Blessing NRW, Benedict S (2017) Computing principles in formulating water quality informatics and indexing methods: an ample review. *J Comput Theor Nanosci* 14(4):1671–1681. <https://doi.org/10.1166/jctn.2017.6531>
138. Milanović A, Milijašević D, Brankov J (2011) Assessment of polluting effects and surface water quality using water pollution index: a case study of Hydro-system Danube-Tisa-Danube. Serbia. *Carpath J Earth Env* 6(2):269–277
139. Nachiyunde K, Ikeda H, Tanaka K, Kozaki D (2013) Evaluation of portable water in five provinces of Zambia using a Water Pollution Index. *Afr J Environl Sci Technol* 7(1):14–29. <https://www.ajol.info/index.php/ajest/article/download/88667/78259>
140. Al Obaidy AHMJ, Talib AH, Zaki SR (2015) Application of Water Pollution Index for assessment of Tigris River ecosystem. *Int J Adv Res* 3(2):219–223
141. Proskurnin OA, Komaristaja BN, Smirnova SA (2015) Calculation of the surface Water Pollution Index in the evaluation of environmental component of product life cycle. *ScienceRise* 5/2(10):32–35. <https://doi.org/10.15587/2313-8416.2015.42379>
142. Wang Q, Wu X, Zhao B, Qin J, Peng T (2015) Combined multivariate statistical techniques, Water Pollution Index (WPI), and Daniel trend test methods to evaluate temporal and spatial variations and trends of water quality at Schanchong River in the Northwest Basin of Lake Fuxian, China. *PLoS ONE* 10(4):e0118590. <https://doi.org/10.1371/journal.pone.0118590>
143. Popović N, Đuknić J, Čanak Atlagić J, Raković M, Marinković N, Tubić B, Paunović M (2016) Assessment of the ecological status of rivers: a case study of the Sava River. Serbia. *Acta Zool Bulgar* 68(1):97–102
144. Li R, Zou Z, An Y (2016) Water quality assessment in Qu River based on fuzzy Water Pollution Index method. *J Environ Sci* 50:87–92. <https://doi.org/10.1016/j.jes.2016.03.030>
145. Takić Lj, Mladenović-Ranisavljević I, Vasović D, Đorđević Lj (2017) The assessment of the Danube River water pollution in Serbia. *Water Air Soil Pollut* 228:380. <https://doi.org/10.1007/s11270-017-3551-x>
146. Hassan AA, Dawood AS, Al-Mansori NJ (2018) Assessment of water quality of Shatt Al-Basrah Canal using Water Pollution Index. *Int J Eng Technol* 7(4.19):757–762. <https://doi.org/10.14419/ijet.v7i4.19.27994>
147. Hossain M, Patra PK (2020) Water Pollution Index—a new integrated approach to rank water quality. *Ecol Indic* 117:106668. <https://doi.org/10.1016/j.ecolind.2020.106668>
148. Veljković N, Lekić D, Jovičić M, Pajčin N (2010) Internet application Serbian Water Quality Index. *Voda i sanitarna tehnika* 40(3):15–18

149. Stojanović Z, Deršek Timotić I, Novaković B, Veljković N (2018) Surface water quality assessment in Serbia—Water Quality Index and ecological status comparison. *Int J Mod Eng Res* 8(10):7–14
150. Veljković N, Perunović T, Jovičić M, Denić Lj, Dopuđa Glišić T, Redžić N, Radić S (2020) Indikator urbane održivosti na nacionalnom nivou – studija slučaja za Srbiju (Urban sustainable indicator at the national level—case study for Serbia). *Voda i sanitarna tehnika* 50(3–4):47–52. <http://www.sepa.gov.rs/download/radovi/2020/IndikatorUrbaneOdrživostiNV.pdf>. Accessed 20 Nov 2020
151. Canadian Council of Ministers of the Environment (CCME) (2005) Canadian Water Quality Index 1.0 calculator. <http://www.env.gov.nl.ca/env/waterres/quality/background/cwqi.html>. Accessed 20 Oct 2020
152. Canadian Council of Ministers of the Environment (CCME) (2008) Agri-food Water Quality Index 1.0. calculator. <https://www.gov.nl.ca/eccm/waterres/quality/background/afwqi/>. Accessed 20 Oct 2020
153. Water Resources Management Division (WRMD) (2008) Agri-food Water Quality Index (AFWQI) Help manual. Water Resources Management Division, Department of Environment and Conservation, Newfoundland, Labrador <https://www.gov.nl.ca/eccm/files/waterres-quality-background-afwqi.pdf>. Accessed 20 Oct 2020
154. Lyulko I, Ambalova T, Vasiljeva T (2001) To integrated water quality assessment in Latvia. International workshop on information for sustainable water management, MTM (Monitoring Tailor-Made) III, Netherlands, 449–452
155. Filatov N, Pozdnyakov D, Johannessen O, Pettersson L, Bobylev L (2005) White Sea: its marine environment and ecosystem dynamics influenced by global change. Springer & Praxis Publishing, Chichester
156. Šerbula S, Ristić A, Manasijević S, Doli N (2015) Teški metali u otpadnim vodama Rudnika bakra Majdanpek (Heavy metal ions in the wastewater of the Majdanpek Copper Mine). *Zaštita materijala* 56(1):52–58. <https://scindeks-clanci.ceon.rs/data/pdf/0351-9465/2015/0351-94651501052S.pdf>
157. Bogdanović GB, Trumić MŽ, Stanković V, Antić DV, Trumić MS, Milanović Z (2013) Rudničke vode iz rudnika RTB Bor — resurs za dobijanje bakra ili zagađivač životne sredine (Mine waters from Mining & Smelting Basin Bor—a resource of the recovery of copper or polluter of the environment). *Reciklaža i održivi razvoj* 6:41–50. www.ror.tf.bor.ac.rs
158. Vuković Ž, Vuković D, Radenković M, Stanković S (2012) A new approach to the analysis of the accumulation and enrichment of heavy metals in the Danube River sediment along the Iron Gate reservoir in Serbia. *J Serb Chem Soc* 77(3):381–392. <https://doi.org/10.2298/JSC110217169V>
159. Voza D, Vuković M, Takić Lj, Nikolić Dj, Mladenović-Ranisavljević I (2015) Application of multivariate statistical techniques in the water quality assessment of Danube river. *Serbia Arch Environ Prot* 41(4):96–103
160. Milanović A, Kovačević-Majkić J, Milivojević M (2010) Water quality analysis of Danube River in Serbia—pollution and protection problems. *Bull Serb Geogr Soc* 90(2):47–68. <https://doi.org/10.2298/GSGD1002047M>
161. Dogterom J (2001) Assessment practices and environmental status of 10 transboundary rivers in Europe. International Water Assessment Centre under the UNECE Convention on Protection and Use of Transboundary Watercourses and International Lakes. Helsinki, 1992. International Water Assessment Centre/riza (Pub.).
162. International Commission for the Protection of the Danube River (ICPDR) (2006) Management problems of sediment quality and quantity in the Danube River Basin, Draft Issue Paper. International Commission for the Protection of the Danube River, Vienna
163. Urošev M, Milanović Pešić A, Kovačević Majkić J (2013) Биогенная нагрузка Дуная и ее основных притоков в Сербии (Assessment of nutrient load on Danube River and its main tributaries in Serbia). In: Sobol SV (ed) Proceedings from the 15th International scientific and industrial forum “Great Rivers” 2013 (Volume 1). NNGASU, N. Novgorod, pp 48–52

164. Ismail A, Robescu D (2017) Chemical water quality assessment of the Danube River in the lower course using water quality indices. *U.P.B. Sci Bull Ser B* 79(4):51–62. https://www.scientificbulletin.upb.ro/rev_docs_arhiva/rez90c_587393.pdf Accessed 20 Oct 2020
165. Kašanin-Grubin M, Hagemann L, Gajica G, Štrbac S, Jovančičević B, Vasić N, Šajnović A, Djogo Mračević S, Schwarzbauer J (2020) Geochronological investigation of the Danube Djerdap Lake sediments (Serbia): sedimentology and inorganic composition. *Environ Geochem Health* 42:693–707. <https://doi.org/10.1007/s10653-019-00403-6>
166. International Commission for the Protection of the Danube River (ICPDR) (2018) ICPDR Sturgeon Strategy. https://www.icpdr.org/main/sites/default/files/nodes/documents/om-20_-3.4_icpdr_sturgeon_strategy_endorsed_version_final.pdf. Accessed 20 Oct 2020.
167. International Commission for the Protection of the Danube River (ICPDR) (2020) Restoring fish migration routes in the Danube River Basin—feasibility study on Iron Gate dams commissioned to explore joint solutions. <https://www.icpdr.org/main/restoring-fish-migration-routes-danube-river-basin-feasibility-study-iron-gate-dams-commissioned>. Accessed 20 Nov 2020
168. WePass (2020) Facilitating Fish Migration and Conservation at the Iron Gates. <https://www.we-pass.org>. Accessed 20 Nov 2020
169. Favilli F, Hoffmann C, Elmi M, Ravazzoli E, Streifeneder T (2015) The BioREGIO Carpathians project: aims, methodology and results from the “Continuity and Connectivity” analysis. *Nat Conserv* 11:95–111. <https://doi.org/10.3897/natureconservation.11.4424>
170. International Commission for the Protection of the Danube River (ICPDR) (2013) Guiding Principles for Sustainable Development of Hydropower in the Danube Basin. https://www.icpdr.org/flowpaper/viewer/default/files/nodes/documents/icpdr_hydropower_final.pdf. Accessed 20 Nov 2020