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SUSTAINABLE MANAGEMENT OF WATER RESOURCES IN URBAN AREAS: CASE STUDY RASINA DISTRICT

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Analysis of the state and quality of surface waters on the territory of Rasina district was performed based on the calculation of the BDE Index (Basin Demographic Emission Index) into the Zapadna Morava basin, on the Jasika profile, as well as by defining SWQI (Serbian Water Quality Index) at two hydrological stations on the Zapadna and Južna Morava river courses in the period from 2009 to 2023. The basin demographic emission index (index BDE) represents a criterion of sustainability in the management of urban water supply and wastewater drainage systems. This indicator links key parameters (the number of inhabitants and quantities of outpoured waste waters, the official and average flow in the river) into one single number (index) and enables an easier overview of the state of water resources in time and space. In the analyzed fifteen-year period, the basin demographic emission index show that there is a pronounced upward trend line, which indicates a positive development tendency of the indicator from the point of established sustainability criteria. Water quality was analyzed based on the following selected parameters: oxygen saturation, BOD5, ammonium, pH value, TON, orthophosphates, suspended solids, temperature, conductivity and coliform bacteria. The obtained results show that poor water quality (WQI-61-62) was registered on both profiles on an annual basis. The worst water quality was recorded at the Maskare hydrological station, on the

Zapadna Morava in 2015 (WQI-57). The waters of the Rasina district are mostly loaded with organic matter which originates from waste sewage and industrial waters from urban and rural areas. The aim of this paper is to point out the need to define a planned system for water management, which would enable their rational use both in the present and in the future. By applying the concept of sustainable development, we are creating a basis for the rational use of all natural resources, as well as the basis for the improvement of the environment as a whole.

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1. Introduction

Water is the source of life and is probably the most valuable natural asset in the world (Janicka et al., 2023). Human demand for water resources is continually increasing as a result of the continuous advancement of science and technology, the rapid development of social economy, and the improvement of people's living standards, particularly in developing countries (Cao et al., 2020). At the same time, the impacts of climate change, including altered precipitation patterns and increased frequency of extreme weather events, can lead to variability in water availability and exacerbate water scarcity (Iqtiar, 2022). Population growth, urbanization, water pollution, and unsustainable development are all increasing pressure on water resources across the world, and that pressure is further exacerbated by climate change. Pressure affects both surface water and groundwater (Pilar et al., 2020).

The world's population has reached 8 billion, and more people live in cities than in rural areas (Bahri, 2012). Water is a critical natural resource for the world's growing urban areas. Currently, 55% of the world's population lives in urban areas, and this figure is predicted to grow to 68% by 2050, adding more than 3 billion people to urban populations (Warsia et al., 2022). IPCC projections in the context of urban development indicate a progressive expansion (urbanization) of 0.4–0.7% per year (Janicka et al., 2023). With industrial and domestic water demand expected to double by 2050 (UNDP, 2006), competition among urban, peri-urban, and rural areas will likely worsen. At the same time, because of climate change, more frequent and extreme weather events are expected to alter the quality, quantity, and seasonality of water available to urban centers and their surroundings. The goals of urban water management are to ensure access to water and sanitation infrastructure and services, manage rainwater, wastewater, stormwater drainage, and runoff pollution; control waterborne diseases and epidemics and reduce the risk of water-related hazards, including floods, droughts, and landslides (Bahri, 2012). The United Nations World Water Development Report, 2018, warns that by 2030, the global demand for fresh water will likely have exceeded supply by 40%. Added to population growth, climate change has the potential to lead to changes in rainfall regimes, with the potential of increased flooding and drought. Currently, 1.2 billion people are at risk from flooding, but this is predicted to increase to about 1.6 billion, i.e., nearly 20% of the world population, by 2050 (Charlesworth & Lashford, 2020). Food and Agriculture Organization of the United Nations (2016) reported that 67% of the world's population could be living with water stress and 1.8 billion people could be living in countries or regions with absolute water scarcity by 2025. In addition, there are other water issues like water pollution that could also seriously influence people's living environment (Gvozdenac, 2015). Thus, analysis and evaluation of current regional water resources are important first steps in managing these problems.

The study of water resources and their rational usage in accordance with modern society needs can be carried out on a global and national level, as well as within smaller territorial units, such as the Rasina district. This paper presents some of the challenges in the process of managing water resources, primarily in the urban areas of the analyzed territory. The aim was to investigate the level of implementation of sustainability goals related to water resources management, analyzing water usage in urban areas from the aspects of available water resources from the surface and underground waters, water supply systems, waste water and the state of water quality. Supplying settlements and industry with water, purification of the used water and adequate protection of water can be considered the most important issues of communal infrastructure and they directly depend on the number of inhabitants and the development of the country and region. In recent years, the analyses of watercourse quality based on mathematical indexes have become increasingly common. Authors most frequently refer to the WQI (Water Quality Index) as a simple indicator of watersheds pollution or to a modified index, such as the Oregon Water Quality Index, as a tool for evaluating water quality management effectiveness (Yotova et al., 2020). The WQI was used as the indicator of the surface water quality in the rivers of Bulgaria (Yotova et al. 2020), Romania (Dunca, 2018), as well as for the assessment of the water quality and pollution in the rivers of Serbia: Sava (Bjelajac et al., 2013), Tisa (Leščešen et al., 2014, Babić et al., 2019), Timok (Milijašević Joksimović et al., 2018), Drina (Leščešen et al., 2013).

This paper gives an account of the state of available surface and underground water resources in the Rasina district and the possibility of their exploitation for water management purposes. Changes in the quality of surface waters of the Rasina district at hydrological stations Maskare (the Zapadna Morava River) and Mojsinje (the Južna Morava River) were also analyzed in the period from 2009 to 2023, using the indicator of surface waters quality, Serbian Water Quality Index. The waste water discharge index (index BDE) was also calculated, which, from the point of view of sustainability criteria, is an indicator of the degree of fulfillment of watercourse protection requirements (Veljković, 2006 and 2007). The results of the paper can serve as a basis for further analysis of the state and improvement of water resources in the analyzed territory in accordance with the national and global water management policy, based on the principles of sustainable development.

2. Sustainable Development and Water

Water is an essential resource for socio-economic development, human life sustenance, and ecosystem preservation. Therefore, it is necessary to ensure the sustainability of water resources and their efficient and equitable allocation to enable an acceptable level of economic and social welfare.

Urban water sustainability aims to manage water in cities to provide for human health and wellbeing within hydrological and ecological limits. Urban water systems include drinking water supply, waste water disposal, surface water drains and the rivers, streams, wetlands and aquifers of urban water catchments. The sustainability of urban water infrastructure must account for the relationship between the city and its hydrological catchments. Urban water use and pollution have impacts in the catchments beyond the city limits. How water is managed in cities affects health, wellbeing and the environment locally, regionally and globally (Bell, 2018).

Figure 1. Sustainability Development Goals

Source: Sustainabledevelopment.un.org

Sustainable development is the centerpiece and key to water resource quantity and quality, as well as national security, economic health, and societal well-being (Flint, 2004). According to The Brundtland Commission's definition, "Sustainable development is a development that meets the needs of the current generation without compromising the opportunities of future generations to meet their needs" (Kate et al., 2005). United Nations General Assembly adopted the Sustainable Development Goals as an integral part of the 2030 Agenda for Sustainable

Development. The total number of Sustainable Development Goals (SDGs) is 17, as shown in Figure 1. Each of these has its importance in sustainable development, including the availability and sustainable management of water and sanitation, which is the central topic of this research paper. The sixth goal – to ensure the availability and sustainable management of water and sanitation for all, is closely linked to the goals related to infrastructure, cities and human settlements as well as climate change (Fidani & Gesovska, 2019).

Figure 2. Water management process

Source: Razmjoo et al., 2020

Water sources are essential for urban inhabitants from the different aspects of quality of life. In urban perspective, water management has a critically important role in urban growth and achieving sustainability. Without a doubt, many urban problems can be eliminated in the water field with proper and regular planning, which then leads to enhancing the quality of life for inhabitants. Figure 2 shows a given plan from the first step, that is, the river to the final step, that is, the products, and also shows that water management is essential for preventing the waste of water. Water sustainability is also a remarkable issue for urban planners and policymakers. Therefore, achieving urban water sustainability is required to investigate and use related indicators and implement them. The implementation of these indicators and strategies helps to improve water use in urban areas. Also, correct selection and use of proper indicators are a confident tool to achieve urban water sustainability (Razmjoo et al., 2020).

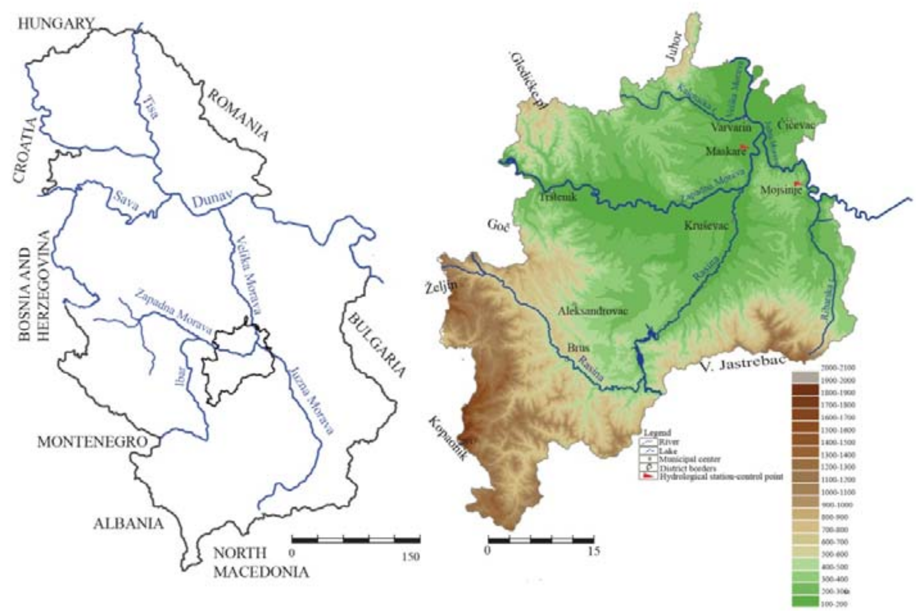
Sustainable water management requires a multidisciplinary approach to this problem, to reach conditions for rational water exploitation, planning and water management on a scientific and expert basis, avoiding conflict among interest groups, participation of the population in planning and management, as well as strengthening of institutional, financial and other mechanisms by works (Gourbesville, 2008; Biswas, 2008; Vučijak et al., 2011; Van der Zaag & Savenije, 2014). One of the most important documents in the area of water resources management is the EU/WFD – Water Framework Directive, 2000/60/EC, adopted by the part of European Parliament and European Union Counsel. The main goal of the Framework Directive is to bring all the natural waters in a "good state", that is, to provide a good hydrological, chemical, and ecologic state of waters based on the principles of sustainable management which do not endanger life environment (Marković, 2011). Each country – a member of the European Union or a country obliged to implement the Directive is required to make an integrated management plan for each river basin on its territory. Sustainable water management in Serbia is based on the implementation of the Law on waters (Official Gazette of the Republic of Serbia, no. 30/10, 2010.), as well as on the implementation of the following key plan documents: The Strategy of water management on the territory of Serbia, The Plan for water management for the Danube basin, The Plans for water management for water areas, as well as the plans which systemize the protection from harmful effects of waters (Filipović & Stričević, 2017). Sustainable development can broadly be defined as a way to achieve the greatest possible long-term benefit to humanity, taking into account the costs of environmental degradation (Šušić, 2006).

Water is a unique and irreplaceable natural resource of limited quantities and uneven spatial and temporal distribution. The key issues related to water management in Serbia are water quality, water quantity and water regime. These issues include: insufficient investment in water resources management, inappropriate price for water, low service level, unplanned water exploitation, low level of wastewater treatment, poor quality of surface water, lack of efficient integrated water management system, etc. (Jakovljević et al., 2019). Water management in Serbia takes place through the preparation and implementation of key planning documents presented in this paper.

3. Study area

Rasina district is situated in the south part of Central Serbia on the surface of 2668 km^2. The district is bounded by mountain grounds of Goč, Ljukten, Crni vrh and Željin on the south-west and west. The south-west part of the district is represented by Kopaonik Mountain, to which the mountain range of Jastrebac is attached east of the river of Blatašnica. The northeast border of the district is represented by the Mojsinjske Mountains, while the north border is represented by the south slopes of Juhor and the Gledićke Mountains (Figure 3). In the north and northeast is the Kruševac Basin, which is connected to the Ribarska Basin in the east and the Župa Basin in the southwest (Stričević, 2015).

Figure 3. Geographical location of the Rasina district



Source: according to Geographical atlas (Geozavod, 2002) and Topographical maps 1:200,000 (Military Geographical Institute Belgrad

The district comprises the municipalities of Kruševac, Trstenik, Aleksandrovac, Brus, Varvarin and Ćićevac. In the north it borders with Moravički district, in the south with Toplički, in the west with Raški, whereas it borders with Nišavski district in the east. According to a census in 2022 (Statistical Office of the Republic of Serbia), there are 208,087 inhabitants in total on the territory of the Rasina District located in 6 urban and 290 rural settlements.

The Zapadna Morava River flows through the territory of the Rasina district, from Trstenik to its confluence with the Južna Morava; the Južna Morava, from Đunis to Stalać, and the Velika Morava, from Stalać to Obrež. The largest part of the district belongs to the Zapadna Morava Basin – 2,023.9 km^2 (75.9% of the total surface of the district), then the Južna Morava Basin – 404.8 km^2 (15.2% of the district surface) and the Velika Morava Basin – 239.3 km^2 (8.9% of the district surface).

The elevation ranges from 125 m to 2017 m above sea level. The average altitude of the Rasina district is 479.7 m. The district is located in an area under the influence of a moderate continental climate. The average annual air temperature in the basin is 9.1ºC (Republic Hydrometeorological Service of Serbia, Meteorological yearbook).

Average multiannual discharge values of the Rasina district in the period from 1961 to 2023 ranged from 103.20 m^3/s in Jasika on the Zapadna Morava, to 200.40 m^3/s in Varvarin on the Velika Morava (Republic Hydrometeorological Service of Serbia, Hydrological yearbook). On average, 795 mm of precipitation falls on the territory of the Rasina district. Out of that amount, from 28 to 30% flows on the surface. The flow is uneven throughout the year. Most of the precipitation falls during the spring months (40-43%), most of it in March, and the least of it in September. Evaporation on the territory of the district is high. From the total amount of precipitation that falls, 70 to 72% evaporates annually. The highest evaporation happens during the summer months, while the lowest evaporation happens during winter. Only about 15% of the total amount of precipitation that infiltrates the soil reaches watercourses, while the rest 85% is used up by plants or evaporates,water supply, etc., which indicates an unfavorable mode of filling watercourses with underground water (Stričević, 2015).

The long-term water supply plan for the municipalities of the Rasina district envisages the use of surface waters of the Rasina River for the water supply of the municipalities of Kruševac, Aleksandrovac, Varvarin, and Ćićevac. The municipality of Kruševac will be supplied with water exclusively from the "Ćelije" reservoir, while the other municipalities will supplement their capacities with the existing underground water sources. The municipality of Brus is oriented toward underground water for its water supply, while the municipality of Trstenik, apart from underground water and water from the "Ćelije" reservoir, could also be connected to the regional system Lopatnica – Studenica (Stričević, 2015). Underground water resources will represent a significant water supply source for both the population and the industry in the future. According to the data from the Water management framework of Serbia (2002), the estimated capacity of existing underground water in up to 2021 is 525 l/s. The largest capacity of underground water in Rasina District is related to alluvial and neogene sediments - 425 l/s, while the capacity of karst spring is around 70 l/s.

4. Data and metodology

The analysis of the state and quality of surface waters on the territory of the Rasina district was done based on the calculation of the wastewater flow from the sewage systems into the watercourse of the Zapadna Morava, on the Jasika profile, as well as by defining the WQI (Water Quality Index) for two profiles on the river courses of the Zapadna and Južna Morava (Maskare and Mojsinje).

The calculation of the Basin Demographic Emission Index was done based on average multiannual discharge, taken from the database of the Republic Hydrometeorological Institute of Serbia, for the period from 1961 to 2023 as well as data from the Statistical Office of the Republic of Serbia, where the data on the estimated number of inhabitants for the period 2009-2023 were taken from, as well as the data on the total amount of wastewater discharged from the same period. The population is represented by the total number of inhabitants in the Zapadna Morava River basin, upstream from the Jasika station (covering the Rasina, Raška, Moravički and part of the Zlatibor districts)

According to Veljković (2007), the availability and accessibility of water are defined as an indicator that shows how rich or poor a given area is in water. This indicator compares the amount of available renewable water resources with the amount of water that meets the needs of the population, industry, irrigation and represents an index of water deficit (Equation 1):

$$\frac{Current\ water\ availability}{number\ of\ inhabitants} \leftrightarrow \frac{Consumption\ of\ available\ courses}{number\ of\ inhabitants} \quad (1)$$

From the aspect of watercourse protection, it is important to take into account the amount of waste water discharged from sewage systems into watercourses and to consider the ratio of this amount to the total number of inhabitants on the analyzed territory. This ratio should, regardless of the quality of the water recpient, define a change in the trend of the amount of discharged waste water according to the relevant small and medium waters in the watercourse. The amount of waste water discharged from the sewage systems into watercourses of the basin in relation to the total number of inhabitants in the area of the basin (DE) is a measure of the load on the watercourse and is labeled as Q_{ww}/P, where Q_{ww} is the amount of waste waters discharged in m^3/year, and P is the number of inhabitants (Veljković, 2006):

$$DE=\frac{Qww}{P}, (m^3/inhabitant/year) \quad (2)$$

In addition to this key indicator, the relevant indicator can also be the average multiannual discharges of watercourses expressed per inhabitant per year (IR, IR_{95}). Thus, the availability (wealth) of water resources is obtained as the ratio of the average multiannual basin discharge per inhabitant per year and is expressed by the ratio:

$$IR=\frac{Qr}{P}\ (m^3/inhabitant/year) \quad (3)$$

where Qr is the average monthly (multiannual) discharge in (m^3/year), and P is the number of inhabitants.

The availability of water resources can also be expressed as the ratio of the minimum average monthly discharge of the basin with 95% usefulness per inhabitant per year and expressed as the ratio:

$$IR95=\frac{Q_{95}}{P}, (m^3/inhabitant/year) \quad (4)$$

Using the above expressions for the key indicators DE, IR and IR_{95}, the Wastewater Runoff Index was defined as:

$$\text{Index BDE}=\frac{\log IR_{95}-\log DE}{\log IR-\log IR_{95}} \quad (5)$$

The BDE index represents the criterion of sustainability in managing urban water supply systems and waste water drainage. The empirical dependence of the variables used to define the BDE index indicates that the reduction of specific water consumption is a long-term strategic commitment in the concept of sustainable water resource management.

The value of the index is lower (BDE index < 1) if the amount of wastewater discharged into the watercourse increases over time.That is, the value of the index decreases if the critical load/amounts of discharged wastewater (DE, (m^3/inhabitant/year) approach the carrying capacity/relevant minimum discharge in the recipient (IR95 m^3/inhabitant/year) (Veljković, 2013).

The database of the Serbian Environmental Protection Agency (SEPA) for the period 2009–2023 was used to present the existing state of water quality of the Rasina district. Parameters of physical, chemical and microbiological water quality were measured on the two control points (approximately once a month): Maskare on the Zapadna Morava and Mojsinje on the Južna Morava River. The data obtained at each measurement station were averaged using the annual arithmetic average. We thereby obtained a series of 12 values per year for four hydrological stations for the 15 years (2009–2023). Water quality was analyzed based on Serbian Water Quality Index (SWQI) method (Pantelić et al., 2012; Stričević et al., 2015; Leščešen et al., 2018; Milijašević Joksimović et al., 2018; Babić et al., 2019). This method is based upon the fact that ten chosen parameters (oxygen saturation, BOD_5, ammonium, pH value, total oxidized nitrogen, orthophosphates, suspended solids, temperature, conductivity, and coliform bacteria) with their quality (q_i) represent features of surface water reducing them at one index number. The influence of each of the ten chosen parameters on general water quality is not the same, so each of them was assigned the weight (w_i) and score of points according to its contribution to water quality endangering. The result ($q_i \cdot w_i$) gives the index 100, as an ideal summation of weights of all parameters. Index points from 0 to 100 will be assigned to a particular waterbody according to the points assigned to particular parameters (Petz, 2007; Pantelić et al., 2012, Leščešen et al., 2014). According to SWQI category, values for SWQI descriptive quality indicator are defined as follows: very bad – 0-38; bad – 39-71; good – 72-83; very good – 84-89 and excellent – 90-100 (Table 1). To interpret the obtained results and assess the quality of watercourses, we used the method of comparing quality indicators according to the classification of waters in Serbia as well as the Water Quality Index method. To the quality of surface water which corresponds to Class I WQI method assigns 84-85 points, Class II 72-78 points, Class III 48-63 points, and Class IV 37-38 points (Veljković, 2006).

Table 1. Classification of Surface Waters Based on SWQI

SWQI	Points	Class	Description
Excellent	100-90	I	Quality of water satisfies the criteria to be used in natural state and after filtration and disinfection, for feeding of water supply system for settlements, the food industry, and surface water for noble fish (Salmonidae) rearing as well.
Very good	89-84	II	Quality of water satisfies the criteria to be used in natural state, for bathing and recreation, water sports, for the cultivation of other species of fish (Cyprinidae), or after subjecting to modern methods of treatment can be used to supply the settlements with drinking water and in food industry.
Good	83-72		
Poor	71-39	III	Quality of water satisfies the criteria to be used for irrigation or, after modern methods of treatment, in most sectors of industry, except food industry.
Very poor	38-0	IV	Water quality adversely affects the environment, and can only be used after the application of specific methods of treatment.

Source: Markovski et al., 2015

5. Results and disscusion

For the territory of the Rasina district in the period from 2009 to 2023, the wastewater flow index (index BDE) was calculated, which from the aspect of sustainability criteria indicates the degree of fulfillment of watercourse protection requirements (Veljković, 2013). This indicator connects key parameters (number of inhabitants and the amount of discharged wastewater, relevant and average discharge in the river) into one number (index) and enables an easier overview of the state of water resources in time and space.

The Rasina district extends in the southern part of Central Serbia and administratively includes six municipalities: Kruševac, Aleksandrovac, Brus, Trstenik, Varvarin and Ćićevac. According to a census from 2022, on the territory of the district, there are 208,087 inhabitants. A decrease in the total number of inhabitants was recorded on the territory of the district in the last inter-census period in rural areas. A significant increase in the number of inhabitants was recorded in the urban centers of the district, which is a consequence of the mechanical movement of the population. In the last inter-census period (2011-2022), the total number of inhabitants in the Rasina District decreased by 14% (Statistical Office of the Republic of Serbia).

The amounts of wastewater discharged from public sewage systems depend on the number of residents connected to the network and the specific water consumption of users. General specific consumption in all sectors depends on the economic structure, housing conditions and habits of the population. The amount of inflow of industrial waste water depends on the specific consumption, the technological process and the size of the industrial complex (Veljković, 2007). According to the basics of long-term water supply in Serbia, water consumption norms were defined. They ranged from 580 l/inhabitant/day in 2010 to 600 l/inhabitant/day, which was assumed to be necessary in 2021 (Gavrilović & Dukić, 2014). Forecast norms of water consumption are defined based on trends in demographic, socio-economic and communal development. The water management basis of the Republic of Serbia (2002) defines water consumption needs of 500 l/inhabitant/day for rural settlements and 600 l/inhabitant/day for urban settlements. According to Dokmanović and Nikić (2014), these norms are significantly over-dimensioned, as well as demographic forecasts on the increase in the number of inhabitants on the territory of Serbia. Given that at the beginning of the 21st century, a tendency to reduce the number of inhabitants was observed, as well as that industrial production recorded stagnation or a negative trend, water consumption could range from 350 to 380 l/inhabitant/day in rural areas, and from 580 to 620 l/inhabitant/day in urban areas (Radović et al. 2000). Water consumption in the cities in developed countries ranges from 300 to 600 l/inhabitant/day (Amidžić, 2021).

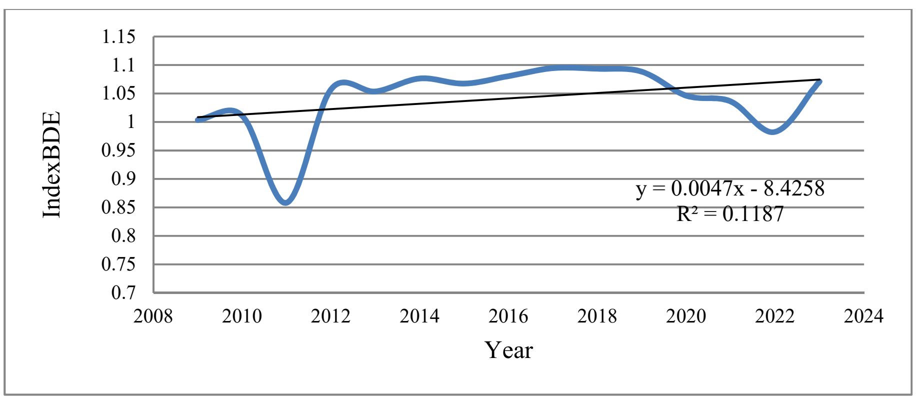
Table 2. Wastewater runoff index (index BDE) for Jasika profile (Zapadna Morava) in the period 2009-2023.

Year	No. of inhabitants	Wastewater discharged into the Zapadna Morava basin Jasika profile (x$10^3$$m^3$/year)*	Index BDE
2009	870,821	40,097	1,003
2010	869,761	39,456	1,011
2011	867,734	55,174	0,858
2012	869,706	35,614	1,058
2013	866,193	35,920	1,054
2014	863,191	34,163	1,076
2015	851,904	34,847	1,067
2016	910,532	33,847	1,081
2017	904,239	32,827	1,095
2018	720,327	32,910	1,093
2019	883,614	33,276	1,088
2020	861,614	36,511	1,046
2021	874,032	37,320	1,036
2022	856,471	41,980	0,983
2023	850,042	34,570	1,071

*The population is represented by the total number of inhabitants in the Zapadna Morava River basin, upstream from the Jasika station (covering the Rasina, Raška, Moravički, and part of the Zlatibor districts), for the period 1980–2006, based on data from the Statistical Office of the Republic of Serbia's annual reports.

In addition to the amount of waste water discharged into water recipients, the index BDE methodology creation also includes the average discharge and the minimum average discharge of 95% usage. The wastewater flow index (index BDE) was calculated for the period 2009 to 2023 (Table 2). In the analyzed fifteen-year period, the results of the wastewater runoff index show that there is a pronounced upward trend line, which indicates a positive development tendency of the indicator from the point of established sustainability criteria. The minimum values of the index BDE were recorded in the period from 2012 to 2015, as well as from 2019 to 2022. The value of the index is mostly greater than 1, which indicates that the amount of wastewater discharged into the watercourse does not increase significantly over time. The decreasing value of the index indicates that the wastewater load (DE, m^3/inhabitant/year) is approaching the relevant minimum discharge in the recipient (IR_{95} m^3/inhabitant/year), which negatively affects the quality of the water recipient in a significant manner. The minimum value of the index BDE was recorded in 2011 – 0.858, while the maximum value – 1.095 was recorded in 2017.

Figure 4. Wastewater runoff index for Jasika profile (Zapadna Morava) in the period 2009-2023, with a linear trend and equation



From 2009 to 2011.year the amount of discharged wastewater increased by 37%, while the number of inhabitants decreased slightly (0.11%). This state could have been caused by an increase in specific water consumption and non-purposeful usage in households and industrial plants. From 2012. Year there is a lower disbalance in the amount of wastewater discharged compared to the changes in the total number of inhabitants. The quoted results may arise from a positive attitude towards water resources and the development of awareness about the preservation and protection of this important natural resource. The central role in the process of constant progress toward the goals of sustainable development is represented by monitoring, assessment, and evaluation according to established indicators. Analyses based on the BDE calculations enable users to assess the progress made.

The key step in formulating an achievable strategy for sustainable management of urban water supply and wastewater disposal systems is to discover priority problems that need to be solved with the help of appropriate action plans. The long-term strategic determination in the concept of sustainable water resources management is the reduction of specific water consumption.

The problem of waste water, its purification and discharge into watercourses as the main recipient has not been adequately solved on the entire territory of the Rasina district. Sewage networks are arranged only in the territories of municipal centers and partially in suburban settlements, while this problem has not been solved at all in rural settlements.

Data from the Statistical Office of the Republic of Serbia show that in 2021- 80% of households in the Rasina district obtained their drinking water from an organized water system, while 49% of households discharged their wastewater into organized sewage systems. The most favorable situation is observed on the territory of the municipality of Kruševac, where 95% of households connected to the water supply network, and 61% to the sewage network. On the territory of Serbia, organized water supply covers 82% of the population, while 57.8% of the population has access to the drainage system. These values are significantly lower compared to many European cities, where about 95% of the population has access to the drainage system (Markovski, 2015).

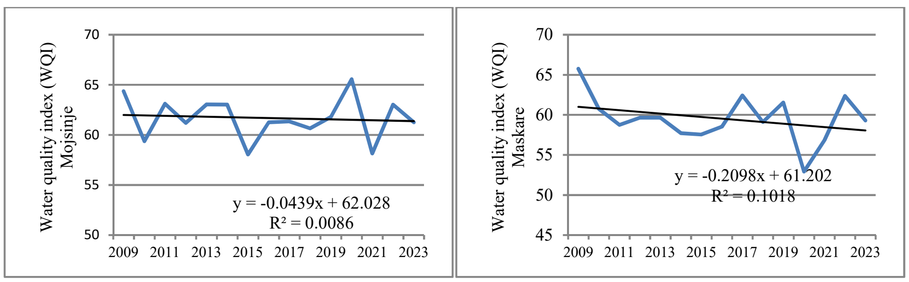
The existence of a sewage network is certainly a basic prerequisite for the regulated removal of wastewater, but a big issue is the fact that all those waters, fecal, industrial, and atmospheric go into watercourses completely unpurified. The wastewater treatment plant was built only on the territory of the town of Kruševac and it was put into operation in 2020. The plant was built to process wastewater equivalent to 90 thousand inhabitants and has an average daily capacity to process 22.000 cubic meters of wastewater (Milenković et al., 2021). The collector and sewage system for wastewater processing currently covers 75% of the town Kruševac network. On the territories of other municipalities, waste water from sewage systems is discharged unpurified into the watercourses of the Zapadna, Velika, Južna Morava and their tributaries, which significantly affects the deterioration of their quality and often places them in Class III and IV waters (Stričević, 2015).

Table 3. Mean Annual and Seasonal SWQI in the Rasina District for the period from 2009 to 2023.

Station	Maskare (Zapadna Morava)	Mojsinje (Južna Morava)
Spring	58	61
Summer	59	59
Autumn	61	62
Winter	65	67
Annual Average	61	62

We used the indicator Serbian Water Quality Index (SWQI) to grade the quality of watercourses in the Rasina district. Table 3 shows mean SWQI values on the annual level and at the level of the seasons for each of the analyzed stations. Analysis of water quality using the WQI indicates that bad water quality was registered on both profiles on an annual basis, with WQI values ranging from 61 (Maskare) to 62 (Mojsinje). Both rivers have the best water quality (WQI = 65-67) during winter, while during all the other seasons the water is of bad quality, with the lowest values during spring in Zapadna Morava (WQI = 58) and during summer on both stations (WQI = 59). The waters of the Rasina District mainly belong to Class III waters (WQI = 39–71).

Figure 5. The linear trend of the change in water quality of the Rasina District on Maskare and Mojsinje stations in the period 2009-2023 expressed using the WQI method



Deterioration in water quality in the Rasina District is confirmed by the obtained results for SWQI. Values of SWQI for the research period fluctuate from 53 in 2020 to 66 in 2009 (Maskare) and from 58 in 2015 to 66 in 2020 in Mojsinje. Average WQI value in the reference period on Maskare station drop in each year amounted to 0.04 index points, while on Mojsinje station, drop in each year is amounted to 0.21 index points (Figure 5). All values are classified, according to SWQI descriptive quality indicator as bad waters (39–71). The water quality of the Rasina District rivers is worse in the warmer period of the year with a mean index value of 60 (bad), while the mean value for the cold period of the year is 64 (bad). Numerous researchers stated the same trend in Serbia, e.g. Veliki Bački Channel (Pantelić et al. 2012), the Drina River (Leščešen et al. 2013), the Sava River (Bjelajac, et al. 2013), the Tisa River (Leščešen et al., 2014; Babić et al., 2019), the Timok River (Brankov et al., 2012). Based on these results, the predominant source of pollution cannot be precisely determined. Surface and ground waters in the Rasina District are exposed to the impact of numerous pollutants. According to the Water management strategy on the territory of the Serbia (Official Gazzete of RS, No. 3/2017), around 75% of the population of Serbia lives in settlements with more than 2,000 inhabitants, where the average connection to the public sewage system is about 72%. In the settlements with less than 2,000 inhabitants, about 5% of the population is connected to sewage systems. The problem of waste water, its treatment, and discharge into watercourses as the main recipients have not been adequately solved in most of the Rasina District. According to the data of the SORS (2009–2023), out of the total of 74,834 households on the territory of the Rasina District, about 79% are connected to the water supply network, while 51% of the households are connected to the sewage network. The problem of waste water is regulated only in the town of Kruševac, where household, atmospheric, and industrial waste water is purified. On the territory of the municipality of Kruševac, a waste water treatment plant has been operating since 2020. The lowest water quality of the course of Zapadna Morava was recorded on the profiles of Kraljevo and Trstenik, where it is most often on the crossing between class III and IV (Obradović et al., 2009). In the upstream part, near the town of Čačak and Gugaljski Bridge, water quality is better and it pertains to class II and III, as well as in the most downstream profile in Jasika. The regulated water quality class on all the profiles in the basin of Zapadna Morava is II, IIa, and IIb (Popović et al., 1998, 2000). Downstream from Kraljevo, the river Zapadna Morava is burdened by a large amount of waste water from agricultural areas, as well as communal and industrial waters from Kraljevo and Trstenik (dairy industry, meat industry, metal processing industry). In the lower part of the Zapadna Morava River, communal and most of the industrial waste water from Kruševac and the surrounding areas (chemical, machine industry) affect water quality the most. In the basin of Južna Morava waters all the profiles belong to either class III or class IV. In the surrounding area, the lowest water quality was recorded in the Toplica River basin. Waters of the lowest quality were registered on the river of Toplica. These waters sometimes come out of the scope of class IV because of excessive pollution (Samardžić, 2013). The waters of these rivercourses are mostly loaded with organic compounds, originating from the wastewater of the settlements. Waste water from industrial plants is also a big problem, but its share is much smaller compared to municipal water. Waste water from industrial plants is usually loaded with nitrogen and phosphorus (Popović et al., 1998).

6. Conclusion

This paper analyzes the available water resources on the territory of the Rasina district, as well as restricting factors for their further usage. There are significant surface and underground water resources on the analyzed territory. The analysis of the water regimes of these waters indicates their spatial and temporal unevenness, which is one of the limiting factors in future planning. A major threat to the sustainable management of water resources is waste water from settlements and industrial plants, which is discharged into watercourses mostly without any purification. The problem of waste water is partially solved only in municipal centers, while in other settlements waste water is discharged into septic tanks which are usually inadequately built without any plans.

Basin Demographic Emission Index (index BDE) as an indicator of urban sustainable development examines the relationship between the amount of waste water discharged from sewage systems into water recipients, the relevant discharge and the number of inhabitants in the analyzed territory. The amount of discharged waste water must not be greater than the minimum discharge of the river, in any period of the year. In this way, the self-purification of the watercourse is enabled and it consequently enables the survival of the living world in the river. In the analyzed fifteen-year period, the results of the wastewater runoff index for the Rasina district show that there is a pronounced upward trend line, which indicates a positive development tendency of the indicator from the point of view of established sustainability criteria.

This paper analyzes the state of water quality in the Rasina District, through analyzing ten indicators of water quality in a fifteen-year period. SWQI values show that Zapadna and Južna Morava River have poor water quality (WQI = 61-62). From 2010 to 2017, there has been a slight decrease in the water quality in Maskare (Zapadna Morava). High levels of coliform bacteria were recorded on both profiles, as well as increased BOD5, TON, and phosphates concentration, which indicates that the waters of the Zapadna Morava River and its tributaries are mostly loaded with organic compounds originating from the waste water from the settlements which are discharged into watercourses without any treatment. The water from the industrial plants also represents a big problem, but their share in relation to communal water is much lower. Improving the quality of surface water in the Rasina District lies in the construction of appropriate devices and systems for industrial and municipal water treatment, removal of illegal landfills, improvement and increase of municipal infrastructure capacity (especially in rural areas), and educating the population about the necessity of water protection. If these activities are absent, further deterioration of water quality will result in the endangerment of the principle of sustainable use of this renewable natural resource.

Urban sustainable development as a part of the sustainable development strategy is a concept for solving the issue of progress in terms of achieving goals at the state, national, and local levels. Water is the most important natural resource – survival and health of people, food security and ecosystem survival depend on it. Water resources represent the basis for the social and economic development of a certain territory, but the plan for their exploitation must be realistic, and precisely defined, with clear possibilities for implementation with adhering to and application of the prescribed legal regulations. Legal regulations are a prerequisite for the successful realization of the concept of sustainable management of natural resources, but only their adequate application can give satisfactory results. Water is necessary for life and it is the duty of each person to use water as a common good.

Planned and sustainable management of water resources implies their exploitation to satisfy the current needs of the population, but also leaves the possibility for future generations to do the same.

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ODRŽIVO UPRAVLJANJE VODNIM RESURSIMA U URBANIM SREDINAMA: STUDIJA SLUČAJA RASINSKI OKRUG

Abstract: Analiza stanja i kvaliteta površinskih voda na teritoriji Rasinskog okruga izvršena je na osnovu proračuna Indeksa demografske emisije (Index BDE) sliva Zapadne Morave, na profilu Jasika kao i definisanjem SWQI (Serbian Water Quality Index) na dve hidrološke stanice na rečnim tokovima Zapadne i Južne Morave u periodu od 2009 do 2023 godine. Indeks BDE predstavlja kriterijum održivosti u upravljanju urbanim sistemima za vodosnabdevanje i odvodjenje otpadnih voda. Ovaj indikator povezuje kljucne parametre (broj stanovnika i kolicine izlivenih otpadnih voda, merodavni i prosecni proticaj u reci) u jedan broj (index) i omogućava lakše sagledavanje stanja vodnih resursa u vremenu i prostoru. U analiziranom petnaestogodišnjem periodu rezultati indeksa oticanja otpadnih voda pokazuju da je izražena uzlazna linija trenda, što ukazuje na pozitivnu razvojnu tendenciju indikatora sa gledišta utvrđenih kriterijuma održivosti. Kvalitet vode je analiziran na osnovu sledećih odabranih parametara: zasićenost vode kiseonikom, pH vrednost, oksidi azota, fosfati, BPK_5, suspendovane materije, mutnoća, elektroprovodljivost i koliformne bakterije. Dobijeni rezultati pokazuju da je na analiziranim profilima na godišnjem nivou registrovan loš kvalitet vode (WQI 61-62). Najlošiji kvalitet vode zabeležen je na hidrološkoj stanici Maskare, na Zapadnoj Moravi, 2015. godine (WQI-57). Vode Rasinskog okruga su u najvećoj meri opterećene organskim materijama poreklom iz otpadnih kanalizacionih i industrijskih voda urbanih i ruralnih područja. Cilj rada je da se ukaže na potrebu za definisanjem planskog sistema za upravljanje vodama, čime bi se omogućilo njihovo racionalno korišćenje i u sadašnjosti i u budućnosti. Primenom koncepta održivog razvoja, stvara se osnova za racionalno korišćenje svih prirodnih resursa, kao i za unapređivanje životne sredine u celini.

Keywords: Upravljanje vodnim resursima, Indeks kvaliteta vode (WQI), Indeks BDE, Rasinski okrug

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