

Original Research

ASSESSMENT OF GROUNDWATER SUITABILITY FOR IRRIGATING URBAN GREEN SPACES IN ALLUVIAL AQUIFERS

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Abstract

A methodological framework has been developed to assess the suitability of groundwater from alluvial aquifers for the systematic irrigation of urban green spaces. The approach is based on a multi-criteria analysis of the groundwater regime within the alluvial aquifer, systemic long-term monitoring of groundwater quality, and, finally, an evaluation of irrigation suitability that considers national legislation, internationally recognized criteria, and the applicable technical irrigation solution. The proposed approach was verified through monitoring of groundwater regime (quantity and quality) conducted in a section of the right-bank alluvial plain of the Sava River in Belgrade, serving as a representative case of a heterogeneous and anisotropic alluvial environment within an urbanized zone. The results confirm that the developed methodological framework provides a reliable and transferable tool for verifying the reliability of groundwater resources intended for sustainable irrigation in urban areas located on heterogeneous alluvial aquifer systems.

Keywords: alluvial aquifers, groundwater, irrigation, water quality, urban green spaces.

INTRODUCTION

In urbanized areas situated on alluvial plains, groundwater represents a significant and convenient resource for the irrigation of green spaces. The underlying geological layers, composed of heterogeneous and anisotropic sand and gravel, are characterized by high porosity and permeability, which favours the formation of abundant aquifer systems. At the same time, such properties make alluvial aquifers particularly vulnerable to the rapid migration of pollutants, especially under conditions of intensive urbanization and pronounced anthropogenic impact. As a result, changes in groundwater quality may occur, potentially limiting its suitability for irrigation purposes.

Assessing the suitability of groundwater for the irrigation of urban green spaces is a key component of sustainable water resource management in alluvial environments. The quality of these waters directly affects soil properties and the physiological response of plants. An inappropriate chemical composition of irrigation water may lead to e.g., salt accumulation in the soil, soil structure degradation, reduced vitality of green areas, and a range of other

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adverse effects. Consequently, a robust suitability assessment must integrate relevant water quality indicators while accounting for the natural and anthropogenic factors influencing aquifer conditions. Furthermore, given the pronounced spatial and temporal heterogeneity inherent to alluvial aquifers, a systematic and reliable assessment approach is essential.

MATERIALS AND METHODS

The methodological framework presented in this study is based on a multi-criteria analysis encompassing:

- characterization of the groundwater regime within the alluvial aquifer,
- systematic monitoring of groundwater quality over a selected time period, and
- evaluation of groundwater suitability for irrigation in accordance with national criteria, internationally recognized guidelines, and the specific characteristics of the applied irrigation system.

The proposed framework was implemented in the riparian zone along the right bank of the Sava River in Belgrade (Serbia), within an intensively urbanized area [1]. The collected data were analyzed in accordance with current national regulations [2], as well as internationally recognized irrigation water quality guidelines [3,4], while adapting the obtained results to the specific characteristics of urban irrigation systems and green areas. Based on the integration of these criteria, a classification of groundwater quality and an assessment of its suitability for the irrigation were performed. Hence, the outcome of the study is the identification of suitable micro-locations for groundwater exploitation for the irrigation of green spaces in urbanized environments.

RESULTS AND DISCUSSION

Analysis of the groundwater regime

The results of thirty years of continuous monitoring [1], supplemented by data obtained from 10 piezometers installed for the purposes of this study, confirm the dominant influence of the Sava River on the groundwater regime in the riparian alluvial aquifer. The influence of the vertical water balance is of secondary importance. Further inland, groundwater levels are additionally affected by inflows from adjacent higher terrains, and locally by contributions from the underlying limestone formations. Figure 1 presents the results of daily monitoring conducted during the 2025–2026 period.

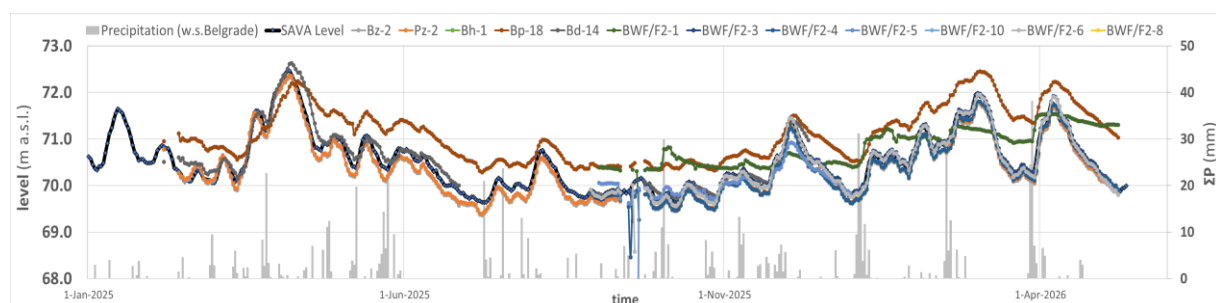


Figure 1 Variations in groundwater levels within the right-bank alluvial aquifer in relation to the Sava River water levels during the 2025–2026 period

Furthermore, four parallel sampling campaigns of the Sava River and the adjacent alluvial aquifer conducted during 2025–2026 revealed a similar ionic composition in river and groundwater (Figure 2), indicating the strong hydraulic connection between the two systems. Elevated HCO_3^- concentrations in groundwater likely reflect carbonate mineral dissolution during subsurface flow, while variations in Ca^{2+} concentrations may result from site-specific geochemical processes. The relatively low concentrations of SO_4^{2-} , Cl^- , Na^+ , K^+ , and Mg^{2+} indicate that carbonate weathering is the principal process controlling groundwater chemistry.

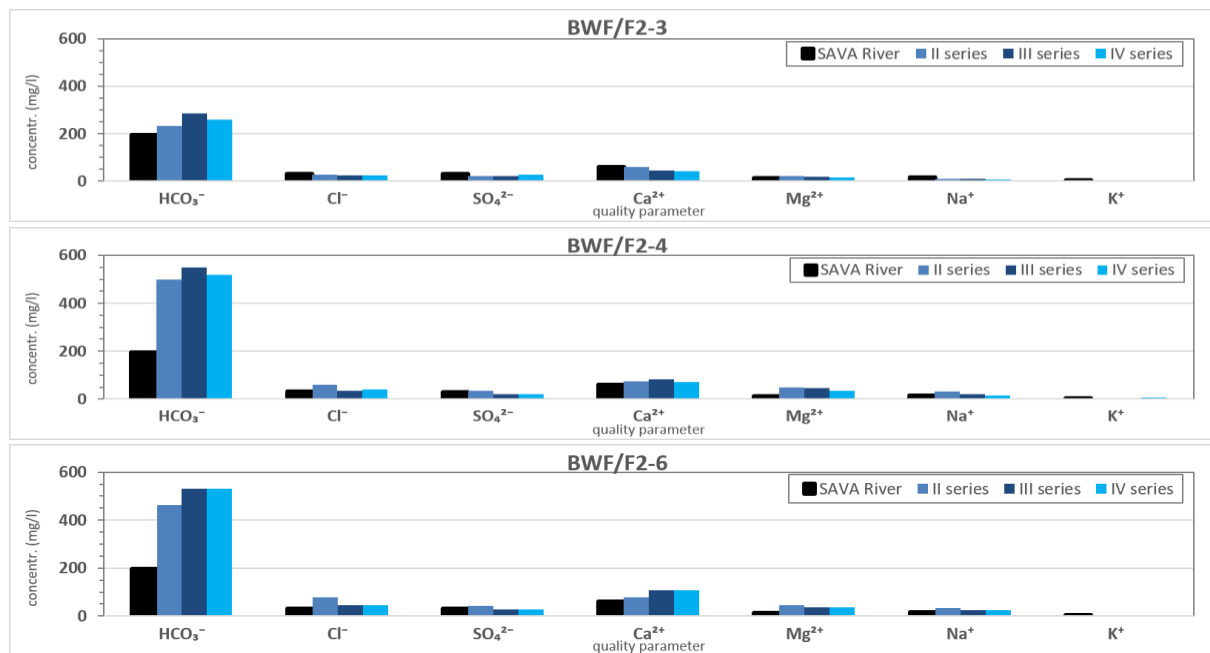


Figure 2 Changes in the concentrations of ionic species in groundwater and the Sava River

Groundwater quality monitoring during the selected period

Continuous groundwater quality monitoring has been systematically conducted in the study area for more than 30 years [1]. For the purposes of this study, additional targeted investigations were carried out within the expanded monitoring network during the 2025–2026 through four seasonal sampling campaigns (May, September, and December 2025, and March 2026). A total of 18 groundwater samples collected during this period were subjected to comprehensive chemical analyses.

Groundwater quality at locations identified as potentially suitable for groundwater abstraction for irrigation purposes, primarily within the riparian zone of the alluvial aquifer, was assessed during all four campaigns. Attention was devoted to parameters that may exert long-term impacts on soil properties, vegetation, and the sustainability of irrigation systems. The obtained results were used to evaluate the spatial and seasonal variability of groundwater quality, identify samples exhibiting stable or variable hydrochemical characteristics, detect potentially critical groundwater conditions, and establish a qualitative zoning of the aquifer. The results further served as the basis for verifying the proposed methodology for assessing groundwater suitability and its sustainable use in irrigation systems for urban green areas.

Assessment of groundwater suitability for irrigation

The assessment of groundwater suitability for irrigation purposes is based on the application of valid national regulations and internationally recognized criteria, with the aim of protecting soil, crops, and the environment, as well as ensuring the sustainable use of water over the long term. The following criteria were applied:

- regulations of the Republic of Serbia,
- internationally recognized criteria (FAO, USSL).

Assessment of irrigation water quality according to regulations of the Republic of Serbia

The required quality of irrigation water is defined by the valid bylaw of the Republic of Serbia [2], which prescribes the maximum allowable concentrations (MAC) of hazardous substances (cadmium, lead, mercury, arsenic, chromium, nickel, and fluorine) and harmful substances (copper, zinc, and boron) in irrigation water.

In most samples collected during the four monitoring campaigns conducted in 2025–2026, groundwater exhibited satisfactory quality for irrigation purposes, while the concentrations of the analyzed elements remained within the permissible limits prescribed by the Regulation. Temporary exceedances of mercury concentrations in one sampling series at three locations, as well as arsenic in one sample collected in September 2025, were not observed in the remaining campaigns and may be attributed to short-term, incidental anthropogenic impacts (Table 1).

The results indicate that the groundwater of the alluvial area can be considered suitable for irrigation, whereas the observed deviations were limited in extent and temporary in nature, and therefore do not affect the overall assessment of its usability.

Table 1 Changes in element concentrations in water

Sample	Series	Date	Measured concentration in the sample (µg/l)								
			As	Zn	Cd	Ni	B	Cu	Cr	Pb	Hg
Bz-2	I	08.05.25.	<10	14.0	<2	7.3	512.3	<3	<2	<10	<1
Bp-18	I	08.05.25.	<10	16.5	3.1	<5	172.0	<3	<2	<10	<1
Bp-18	IV	09.03.26.	<10	<10	<2	<5	220.3	<3	<2	<10	<0.2
BWF/F2-2	III	11.12.25.	<10	<10	<2	7.3	185.0	<3	3	<10	<0.2
BWF/F2-2	IV	09.03.26.	11.0	<10	<2	<5	158.8	<3	<2	<10	<0.5
BWF/F2-3	II	18.09.25.	<10	<10	<2	<5	<100	<3	<2	<10	9.0*
BWF/F2-3	III	11.12.25.	<10	<10	<2	<5	<100	<3	<2	<10	<0.2
BWF/F2-3	IV	09.03.26.	<10	<10	<2	<5	<100	<3	<2	<10	<0.2
BWF/F2-4	II	18.09.25.	<10	<10	<2	<5	194.8	<3	<2	<10	4.0*
BWF/F2-4	III	11.12.25.	<10	<10	<2	<5	188.6	3.2	<2	<10	<0.2
BWF/F2-4	IV	09.03.26.	<10	<10	<2	<5	163.5	<3	<2	<10	<0.2
BWF/F2-5	III	11.12.25.	<10	<10	<2	<5	340.4	4.9	3.3	<10	<0.2
BWF/F2-5	IV	09.03.26.	<10	<10	<2	<5	378.9	<3	<2	<10	<0.2
BWF/F2-6	II	18.09.25.	<10	<10	<2	<5	223.0	<3	<2	<10	2.0*
BWF/F2-6	III	11.12.25.	23.1	<10	<2	<5	195.5	<3	<2	<10	<0.2
BWF/F2-6	IV	09.03.26.	10.7	<10	<2	<5	257.9	<3	<2	<10	<0.5
BWF/F2-8	III	11.12.25.	<10	<10	<2	<5	770.8	<3	<2	<10	<0.2
BWF/F2-10	II	18.09.25.	70.2*	<10	<2	5.9	701.2	<3	2.1	<10	<0.2
MAC			50	1000	10	100	1000	100	500	100	1

Values marked with (*) deviate from the aforementioned Regulation („OG RS“, 23/94)

Assessment of irrigation water quality according to internationally recognized criteria

Due to the lack of comprehensive national guidelines or bylaws addressing all aspects of irrigation water quality, it is necessary to apply other internationally recognized guidelines, namely those of the Food and Agriculture Organization of the United Nations (FAO, [3]) and the US Salinity Laboratory, United States Department of Agriculture (USSL USDA, [4]). FAO recommends the use of Guidelines for evaluation of water quality for irrigation [3]. These guidelines evaluate common water constituents in all forms of their action as potential causes of problems arising from the use of irrigation water. The USSL proposes a water classification system based solely on the salinity and sodium hazard, according to the values of electrical conductivity (EC) and sodium adsorption ratio (SAR). In addition, parameters that may adversely affect irrigation system components must also be considered, particularly clogging of drippers or sprinklers, as well as the formation of deposits or biofilms in pipes or laterals [3]. These guidelines enable a systematic analysis of key water quality parameters that may potentially have adverse effects on soil quality and on plant growth and development.

A synthesis of the results was performed based on the combined interpretation of electrical conductivity (EC) and sodium adsorption ratio (SAR) values, together with accompanying recommendations in accordance with the aforementioned FAO and USSL criteria. Such a methodological approach provides a framework for assessing groundwater suitability which, in addition to its local significance, is also applicable to other urban areas formed under specific alluvial aquifer conditions.

SAR values were low in all samples (<3), indicating a negligible sodium hazard risk and suggesting that, from this aspect, all analyzed waters can be considered safe for the irrigation of various green areas.

From the perspective of salinization risk, most samples exhibited low to moderate EC values, with samples having EC below 0.75 dS/m classified as water of good to very good quality [4]. Samples with elevated EC values (0.9–1.5 dS/m) were classified as waters posing a low risk to plants and can be used for irrigation provided that basic control measures are applied.

Assessment of water quality according to irrigation method and technique

The selection of an irrigation technique represents a key factor influencing water use efficiency, as well as plant growth and development. The choice of irrigation technique depends on the requirements of the cultivated crop, the type and characteristics of the irrigated soil, and the quality of the water available for irrigation [5]. Accordingly, the selection of an irrigation system must be aligned with the assessment of groundwater quality in order to minimize risks and ensure the long-term sustainability of urban green areas.

The interaction between groundwater quality and irrigation techniques was analyzed using the USSL (C–S) classification, which defines salinization and alkalization risks [4]. Water classified as C1–S1 (low salinity – low sodium hazard) can be used for the irrigation of most plant species and soil types and is therefore suitable for all irrigation techniques. Water classified as C2–S1 (moderate salinity – low sodium hazard) can also be used with all irrigation techniques, provided that occasional soil leaching is performed. Water classified as C3–S1 (high salinity – low sodium hazard) cannot be used for the irrigation of soils with poor

filtration characteristics, nor for the irrigation of plants sensitive to salinization. The use of such water requires the implementation of measures for the control or prevention of soil salinization, as well as continuous monitoring of soil electrical conductivity (EC).

Analysis of groundwater suitability for the irrigation of green areas and selection of locations for groundwater source development

Based on the aforementioned criteria, an integrated assessment of groundwater suitability for different irrigation techniques (surface irrigation – flooding, sprinkler irrigation, and drip irrigation) was performed, relying on the USSL classification and identified limiting factors, with a final evaluation of applicability for urban green areas (Table 2).

Table 2 Assessment of groundwater suitability for different irrigation techniques according to the FAO/USSL classification

Sample	Series	Date	Surface irrigation	Sprinkling	Drip	USSL	Key limiting factors	General assessment
Bz-2	I	08.05.25.	3	2	2	C3 / S1	EC, bicarbonates	2
Bp-18	I	08.05.25.	1	1	1	C2 / S1	nothing significant	1
Bp-18	IV	09.03.26.	#N/D	#N/D	#N/D	#N/D	#N/D	#N/D
BWF/F2-2	III	11.12.25.	2	2	2	C2 / S1	EC, bicarbonates	2
BWF/F2-2	IV	09.03.26.	2	2	2	C2 / S1	EC, bicarbonates	2
BWF/F2-3	II	18.09.25.	1	1	1	C2 / S1	nothing significant	1
BWF/F2-3	III	11.12.25.	1	4	4	C1 / S1	Fe, pH, bicarbonates	4
BWF/F2-3	IV	09.03.26.	1	1	1	C2 / S1	nothing significant	1
BWF/F2-4	II	18.09.25.	2	2	2	C3 / S1	EC, bicarbonates	2
BWF/F2-4	III	11.12.25.	2	2	2	C3 / S1	EC, bicarbonates	2
BWF/F2-4	IV	09.03.26.	2	2	2	C3 / S1	EC, bicarbonates	2
BWF/F2-5	III	11.12.25.	4	4	3	C3 / S1	EC, Cl, bicarbonates	4
BWF/F2-5	IV	09.03.26.	4	4	3	C3 / S1	EC, Cl	4
BWF/F2-6	II	18.09.25.	2	4	4	C3 / S1	bicarbonates	4
BWF/F2-6	III	11.12.25.	2	2	2	C3 / S1	Bicarbonates, pH, Fe	2
BWF/F2-6	IV	09.03.26.	2	2	2	C3 / S1	EC, Cl	2
BWF/F2-8	III	11.12.25.	4	4	3	C3 / S1	B, bicarbonates	4
BWF/F2-10	II	18.09.25.	4	4	4	C2 / S1	EC, bicarbonates, Mn	4

GW Suitability: 1- high, 2- moderate, 3- conditional, 4- low; #N/D – no data

Based on the selected criteria, the samples were classified into four groups according to their degree of suitability for the irrigation of urban green areas, together with recommendations for their application:

- water suitable for irrigation (1) – BWF-2-3, Bp-18. Water from these locations represents primary sources for irrigation, with generally favorable characteristics, provided that regular monitoring is established in order to track seasonal variations.
- water moderately suitable for irrigation (2) – BWF-2-2, BWF-2-4, BWF-2-6. Water from these locations is conditionally suitable for irrigation, with mandatory implementation of water, soil, and plant quality monitoring measures, as well as periodic flushing of (parts of) the irrigation system and soil, particularly when cultivating sensitive crops.
- water of low suitability for irrigation (4) – BWF-2-5, BWF-2-8, BWF/F2-10. Water from these locations is not recommended for irrigation without appropriate pretreatment and/or

without mandatory implementation of monitoring measures for water, soil, and plant quality, as well as flushing of (parts of) the irrigation system and soil.

It is assumed that the irrigated soil is properly prepared for crop cultivation, has good filtration characteristics, and/or has an installed drainage system in areas irrigated with water belonging to the C3 category. The integrated analysis of groundwater suitability indicates that seasonal variations in groundwater quality within the alluvial aquifer may significantly affect the possibility of its use for irrigation.

CONCLUSION

The applied multi-criteria methodological framework, based on the integration of groundwater regime analysis, systematic water quality monitoring, and the application of national and international criteria, as well as the requirements of different irrigation techniques, enables a reliable assessment of groundwater suitability and the identification of key risks (salinity, alkalization, technical limitations) and their timely management.

The results obtained for the right-bank alluvium of the Sava River in Belgrade show that groundwater exhibits varying degrees of suitability for irrigation – ranging from fully suitable to conditionally applicable, depending on its natural (hydrogeological and hydrochemical) characteristics and the influence of urban conditions. Accordingly, spatial and temporal mapping of groundwater quality is necessary in order to optimize its use and minimize risks to soil and vegetation.

The practical value of the proposed methodology lies in its ability to identify optimal micro-locations for groundwater abstraction for irrigation purposes, while simultaneously ensuring sustainable resource use and the preservation of the functionality of urban green areas. The proposed framework represents a reliable and transferable approach for assessing groundwater suitability in alluvial aquifers, with direct application in the planning and management of irrigation systems in urban environments.

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