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Assessment of Multi-Depth Water Quality Dynamics in an Artificial Lake: A Case Study of the Ribnica Reservoir in Serbia

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Abstract

High water quality in reservoirs used for drinking water supply and located within protected areas is of crucial importance for sustainable water-resource management. This study aims to evaluate the multi-depth water quality dynamics of the Ribnica Reservoir in western Serbia, combining two standardized assessment tools: the Serbian Water Quality Index (SWQI) and the Canadian Water Quality Index (CWQI). Data collected at various depths during 2021 and 2022 were analyzed to assess physico-chemical parameters and their impact on water quality, while the absence of microbiological data was noted as a limitation affecting the comprehensiveness of the assessment. The SWQI results indicated a general improvement in water quality over time, with values ranging from medium (82) to excellent (95) in 2021 and increasing from good (89) to excellent (98) in 2022. In contrast, the CWQI revealed specific risks, notably elevated concentrations of aluminum, mercury, and chromium, and reduced dissolved oxygen levels, with overall CWQI values ranging from poor (40) to good (88) depending on depth and parameter variability. The study highlights the necessity for continuous, comprehensive monitoring, including microbiological analyses and seasonal assessments, both within the reservoir and in the Crni Rzav River and its tributaries, to better understand pollutant sources and catchment influences. Strengthening microbiological and heavy metal monitoring, along with implementing proactive management strategies, is essential for preserving the Ribnica Reservoir's ecological integrity and securing its long-term role in drinking water provision.

Keywords: Ribnica Reservoir; water quality assessment; water pollution; Serbian Water Quality Index (SWQI); Canadian Water Quality Index (CWQI); multi-depth monitoring; heavy metals; dissolved oxygen

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1. Introduction

Maintaining water quality is intrinsically linked to ecosystem protection and the preservation of human health, with lakes and reservoirs serving as key resources in this effort. These bodies of water play a crucial role not only in providing drinking water and preserving biodiversity but also in supporting recreational activities and agricultural use [1]. However, global threats such as pollution from industrial, agricultural, and urban sources, along with natural factors like extreme weather events and erosion, increasingly jeopardize water quality [2–5]. Climate change further exacerbates these challenges, accelerating the degradation of aquatic ecosystems and diminishing their regenerative capacities [6–8]. In this context, monitoring water quality is essential for the early detection of potential

problems and the implementation of effective mitigation measures, thereby conserving these vital resources for future generations.

Ribnica Reservoir, created by damming the Crni Rzav River, is a significant ecological and water-resource asset in western Serbia. Originally established to supply drinking water to the settlements of Zlatibor and Čajetina, the reservoir plays a critical role in protecting local natural resources and delivering essential services to the community. In addition to its primary function as a drinking water supply, Ribnica Reservoir supports a variety of fish species, positioning it as a potential hub for sport fishing and tourism development. Situated on Zlatibor, Serbia's most visited mountain [9], the lake reservoir also contributes to the region's economic and tourism growth.

The Zlatibor mountain massif, part of the eastern Dinarides, has been designated as a Category I protected area of exceptional importance, officially named the Zlatibor Nature Park. Ribnica Reservoir, as an integral component of this protected zone, is surrounded by numerous hydrological and geomorphological features of high value. However, the Crni Rzav River, although flowing through largely pristine environments, has been partially confined in its lower course due to river regulation measures, potentially disrupting natural flow regimes and ecosystem dynamics. Therefore, the protection of Ribnica Reservoir is of both local and national importance for sustainable water-resource management.

Given the high tourist influx in the Zlatibor region, continuous monitoring of water quality in such ecologically sensitive areas is essential to maintain environmental integrity. Furthermore, the lake's inclusion within a protected nature park reinforces the need to preserve water and environmental quality, aligning with broader conservation goals. These factors underscore the ecological and socio-economic significance of Ribnica Reservoir and justify the need for focused scientific research.

Several studies have investigated water quality in Serbian artificial lakes and reservoirs: Garaši Reservoir [10–15]; Bukulja Reservoir [10,13]; Radoinjsko Lake [11,13,16]; Gruža Lake, Bovan Lake, Prvonek Lake, Ćelije Lake, Vrutci Lake [11,13,14]; Sava Lake, Srebrno Lake [14]; Grlište Lake [11,14]; Vlasina Lake [11,14,17]; Zlatar Reservoir [11,12]; Pridvorica Reservoir, Bojnik Reservoir, Bresnica Reservoir, Nova Grošnica Reservoir; Barje Reservoir, Uvac Reservoir [11,13]; Potpeć Rezervoir, Ovčar Banja Reservoir, Međuvršje Reservoir, Bajina Bašta Reservoir, Zvornik Reservoir, Bor Reservoir, Krajkovac Reservoir, Divčibare Reservoir, Zavoj Reservoir, Bačka Topola Reservoir, Bela Crkva Reservoir [11]. However, Ribnica Reservoir has received little scientific attention. The chemical properties of Ribnica Reservoir were studied by Milivojević et al. [16].

Marković et al. [14] studied 10 reservoirs and found elevated levels of iron (~84 µg/L) and manganese (~80 µg/L), as well as critical values of calcium (50.7 mg/L in Lake Grlište) and residual sodium carbonate (3.08 mg/L in Srebrno Lake), indicating potential risks for irrigation and ecosystem health. Devic et al. [11] assessed 28 lakes and reported ammonium levels up to 0.28 mg/L, total phosphorus at 0.15 mg/L, and total nitrogen exceeding 1.2 mg/L in some reservoirs, surpassing drinking water guidelines and raising concerns over eutrophication. Jakovljević et al. [15] examined the Garaši Reservoir using SWQI and CWQI. SWQI values ranged from good (85) to excellent (97) in surface layers and declined from bad (59) to medium (67) at greater depths, indicating a strong vertical stratification in water quality. CWQI values varied more widely, ranging from marginal (50) to excellent (100), with the lowest scores observed at depths exceeding 1000 cm, highlighting the need for depth-specific monitoring when assessing overall reservoir condition. Milanović Pešić et al. [17] analyzed long-term trends in Vlasina Lake, where SWQI ranged from 78 to 100, but CWQI dropped to 46 in 2022, pointing to tourism-related seasonal degradation in this protected area.

These findings underscore the variability and complexity of water quality across Serbian reservoirs and highlight the need for site-specific, long-term monitoring frameworks. Despite Ribnica Reservoir's ecological importance and protected status, it remains largely unexamined in this regard, particularly in terms of depth-related dynamics and cumulative anthropogenic impacts. This study addresses the identified gap by providing a comprehensive evaluation of spatial and temporal variations in Ribnica Reservoir, with the aim of supporting sustainable management and conservation in protected areas.

Specifically, this research applies two standardized water quality indices—the Serbian Water Quality Index (SWQI) and the Canadian Water Quality Index (CWQI)—to evaluate the lake's condition. The combined use of these indices provides a comprehensive framework by incorporating a broad range of physical and chemical parameters. This approach enables an in-depth analysis of water quality dynamics across different depths and timeframes.

Considering the dual pressures of increased tourism and conservation responsibilities, the use of standardized water quality indices is significant for effective long-term monitoring. This study contributes to the sustainable management of Ribnica Reservoir and supports wider initiatives aimed at protecting water resources and maintaining ecological integrity in protected environments. The findings are intended to guide adaptive strategies that mitigate environmental risks and ensure the sustainable use of resources.

2. Materials and Methods

2.1. Study Area and Sampling

The study area is located in western Serbia, encompassing Zlatibor—a gently undulating plateau with an average altitude of approximately 1000 m. Hydrography is dominated by the Crni Rzav river, originating at an elevation of 1440 m, flowing through Zlatibor, and merging with Beli Rzav near Vardište to form the Rzav River, eventually draining into the Drina River (Black Sea basin). The Crni Rzav basin covers an area of 288 km^2, including significant tributaries such as Obudojevica, Skakavac, and Ribnica. Downstream from Ribnica, the river's average flow rate is 1.85 m^3/s, with pronounced seasonal variations [18]. Zlatibor's hydrography is influenced by lithology, tectonics, geomorphology, and climatic conditions [19]. Ribnica Reservoir, created in 1971 by damming the Crni Rzav, supplies drinking water to Čajetina and Zlatibor and is recognized for its clean water and biodiversity. The reservoir covers approximately 0.458 km^2, contributing significantly to the local hydrological system.

As an integral part of Zlatibor Nature Park, Ribnica Reservoir is situated within this protected landscape, contributing to both its hydrological significance and ecological diversity.

Zlatibor Nature Park spans 41,923.26 ha, characterized by plateaus, tectonic formations, deep canyons, and river valleys. Within this diverse terrain, 32 geosites of significance are documented, including geomorphological, geological, speleological, and architectonic–petrological features. The biodiversity of Zlatibor is shaped by serpentine geology, supporting rare and endangered flora. Among 1044 plant taxa, 34 are strictly protected, 112 are protected, and 76 are endemic. Native forests, predominantly black pine and mixed black–white pine, constitute essential habitats. Fauna include freshwater fish such as huchen and brown trout, 18 amphibian and reptile species, 154 bird species (127 strictly protected), and 38 mammal species. Zlatibor is also designated a Prime Butterfly Area (PBA) [20].

Management of the park involves three protection levels, with Zone II encompassing an area of 19,255.59 ha, representing 45.93% of the total park surface. The Ribnica Reservoir locality is situated within this zone, covering 283.42 ha, which includes both the lake itself and its surrounding terrestrial ecosystems. Conservation measures in Zone II prioritize habitat preservation, biodiversity management, and the sustainable use of

natural resources. Due to its role in supplying drinking water and supporting ecological diversity, Ribnica Reservoir holds critical hydrological and ecological importance within the protected area [20].

- Sampling was conducted at three profiles within Ribnica Reservoir (Figure 1):
- Profile A1: 43.68547° N, 19.66423° E.
- Profile B1: 43.68358° N, 19.67232° E.
- Profile C1: 43.68136° N, 19.68158° E.
- Sampling depths included:
- Profile A1: 50 cm, 200 cm, 350 cm, 500 cm, 800 cm, 1000 cm, 1200 cm.
- Profile B1: 50 cm, 200 cm, 350 cm, 400 cm, 450 cm.
- Profile C1: 50 cm.

Samples were collected by the Serbian Environmental Protection Agency in May and in September 2021 and May 2022 [21]. However, no data on water quality are available for the years preceding or following this period, highlighting a significant gap in monitoring efforts, which is particularly concerning regarding the reservoirs' location within a protected area.

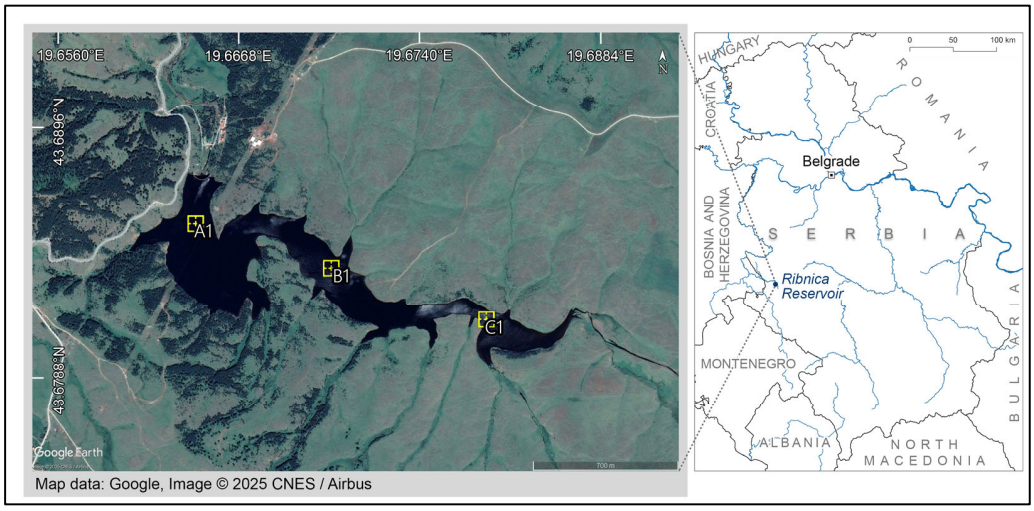


Figure 1. Locations of sampling profiles (A1, B1, C1) and geographic position of Ribnica Reservoir. Source of satellite imagery: [22].

2.2. Water Quality Indices (WQI) Analysis

Water Quality Indices (WQI) serve as a fundamental framework for the evaluation and reporting of water quality conditions across diverse aquatic environments [23–28]. Over time, various adaptations of WQI have been developed to address specific regional and methodological needs, with CWQI and SWQI emerging as widely utilized frameworks [29–36]. Their adaptability across different geographical conditions underscores their significance in scientific research.

This study employs a systematic approach to evaluating reservoir water quality, utilizing data from the Serbian Environmental Protection Agency (2021–2022). To ensure a standardized and comprehensive assessment, the Serbian Water Quality Index and the Canadian Water Quality Index were applied, providing an objective framework for analyzing key water quality parameters.

The selection of the Serbian Water Quality Index (SWQI) and the Canadian Water Quality Index (CWQI) in this study is based on their complementary strengths in water quality assessment. The SWQI, developed by the Serbian Environmental Protection Agency, is designed to reflect local environmental conditions and regulatory standards, incorporating key parameters for assessment of organic and nutrient pollution ensuring alignment

with Serbia's water protection policies and long-term monitoring practices [37]. In contrast, the CWQI, established by the Canadian Council of Ministers of the Environment, provides a broader, internationally recognized framework for evaluation. It integrates factors such as heavy metal concentrations and deviations from established objectives to assess suitability for various uses (e.g., drinking, aquatic life, irrigation, and livestock) [38]. By combining both indices, this study enhances the depth and reliability of water quality assessments, enabling a more comprehensive understanding of ecological conditions and potential risks in the reservoir.

2.3. Data Processing and Analysis

A comprehensive assessment of water quality was achieved by integrating measurements from 27 parameters, with temperature and pH representing the common variables between the Serbian and Canadian indices. Table 1 provides a summary of the methods and standards employed by the Serbian Environmental Protection Agency (SEPA) in the water quality assessment of the Ribnica Reservoir.

Table 1. Summary of methods and standards used for water quality analysis in the Ribnica Reservoir.

Parameter	Method/Standard
pH	SRPS H.Z1.111:1987
Electrical Conductivity	US EPA 120.1:1982
Oxygen Saturation	SEV:1977
Biochemical Oxygen Demand	SRPS ISO 5815:1994
Ammonium Ion	HACH Method 8155
Total Nitrogen	UP 1.27/PC 12, Chemiluminescence detector CLD
Suspended Solids	SRPS H.Z1.160:1987
Orthophosphate	HACH Method 8048
Total Coliforms	SRPS EN ISO 9308-1:2010
Turbidity	UP 1.88/PC 12
Dissolved Oxygen	SRPS ISO 5813:1994
Calcium	ISO 6058:1984
Sulphate	HACH Method 8051
Chloride, Nitrate, Nitrite	SRPS ISO 9297:1997
Arsenic, Cadmium, Chromium, Copper, Iron, Nickel, Zinc, Manganese	EP A 6020A:2014
Mercury	EPA Method 245.7
Lead	EPA 6020 A: 2007

Source of data: [21].

The Serbian Water Quality Index (SWQI) originates from the internationally recognized Water Quality Index (WQI) methodology but has been adapted by the Serbian Environmental Protection Agency (SEPA) to address regional environmental conditions and regulatory requirements. It aggregates ten key physico-chemical and microbiological parameters—including oxygen saturation, biochemical oxygen demand (BOD), ammonium ion (NH_4^+), pH, total nitrogen (TN), orthophosphates (PO_4^{3-}), suspended solids (SS), temperature (T), electrical conductivity (EC), and total coliforms (TC)—into a composite indicator for surface water quality assessment. Each parameter is weighted according to

its impact on environmental stability, ensuring a standardized and reliable framework for monitoring water resources in Serbia [37].

Complementing this localized index, the Canadian Water Quality Index (CWQI) incorporates a broader array of 19 parameters, encompassing both physico-chemical properties and heavy metal concentrations. In this study, CWQI assessment included turbidity, dissolved oxygen (DO), pH, calcium (Ca), sulphate (SO_4^{2-}), chloride (Cl^-), nitrate + nitrite (NO_3^- + NO_2^-), aluminum (Al), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn) [38]. This comprehensive set of parameters allows for a multidimensional evaluation of water quality conditions, addressing both conventional indicators and potential ecological risks. Metal thresholds are defined by experts from the Canadian Council of Ministers of the Environment (Table 2).

Table 2. Metal thresholds in water quality assessment by CWQI.

		Overall		Drinking		Aquatic		Recreation		Irrigation	Livestock
Variables	**Units**	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**	**Upper**	**Upper**	**Upper**
Al	mg/L		0.005				0.005			5	5
As	mg/L		0.005		0.025		0.005			0.1	0.025
Cd	mg/L		0.005		0.005					0.0051	0.08
Cr	mg/L		0.001		0.05		0.001			0.0049	0.05
Cu	mg/L		0.002		1		0.002			0.2	0.5
Fe	mg/L		0.3		0.3		0.3			5	
Hg	µ/L		0.003		1		0.1				0.003
Mn	mg/L		0.05		0.05					0.2	
Ni	mg/L		0.025		0.025					0.2	1
Pb	mg/L		0.001		0.01		0.001			0.02	0.05
Zn	mg/L		0.03		5		0.03			1	50

Source of data: Canadian Council of Ministers of the Environment [38].

For the Serbian Water Quality Index (SWQI), individual parameter measurements were converted into sub-indices using pre-defined national thresholds. Each sub-index was then weighted according to its environmental significance. The SWQI was calculated as the weighted sum of the following sub-indices:

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

where q_i is water quality of the ith parameter, and w_i is weight unit of the ith parameter. Weight unit is defined for each parameter by the Scottish Development Department in 1976, who developed the original version of the WQI (Table 3). This approach enables a clear categorization of water quality in accordance with Serbian national standards [37].

In parallel, the Canadian Water Quality Index (CWQI) was determined by evaluating deviations from set objectives through three components: Scope (F_1), Frequency (F_2), and Amplitude (F_3). F_3 scales the normalized sum of excursions (*nse*) from the objective; *nse* is a ratio between excursions (variables which are greater or lower than the objective) of individual tests and the total number of tests. These components quantify the proportion of

parameters not meeting objectives, how often such deviations occur, and the magnitude of the deviations. The final CWQI score was computed according to the following expression:

$$CWQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right) \quad (2)$$

with water quality objectives further contextualized by assessing the index's applicability for specific uses (e.g., drinking, aquatic life, recreation, irrigation, and livestock). The use of dedicated software tools, including the Canadian Water Quality Index Calculator, streamlined this calculation [38].

Table 3. Weighting criteria for SWQI parameter assessment.

T (°C)	pH		EC (µS/cm)	OS (%)		BOD (mg/L)	NH_4^+ (mg/L)	TN (mg/L)	SS (mg/L)	PO_4^{3-} (mg/L)	TC Coli/ 100 mg	$q_i \times w_i$
				93–109								18
				88–92	110–119							17
				85–87	120–129							16
				81–84	130–134	0–0.9						15
				78–80	135–139	1–1.9						14
				75–77	140–144	2–2.4						13
				72–74	145–154	2.5–2.9	0–0.09				0–249	12
				69–71	155–164	3–3.4	0.1–0.14				250–999	11
				66–68	165–179	3.5–3.9	0.15–0.19				1000–3999	10
	6.5–7.9			63–65	180+	4–4.4	0.2–0.24				4000–7999	9
	6–6.4	8–8.4		59–62		4.5–4.9	0.25–0.29	0–0.49		0–0.029	8000–14,999	8
	5.8–5.9	8.5–8.7		55–58		5–5.4	0.3–0.39	0.5–1.49	0–9	0.03–0.059	15,000–24,999	7
	5.6–5.7	8.8–8.9	0–188	50–54		5.5–6.1	0.4–0.49	1.5–2.49	10–14	0.06–0.099	25,000–44,999	6
0–17.4	5.4–5.5	9–9.1	189–239	45–49		6.2–6.9	0.5–0.59	2.5–3.49	15–19	0.1–0.129	45,000–79,999	5
17.5–19.4	5.2–5.3	9.2–9.4	240–289	40–44		7–7.9	0.6–0.99	3.5–4.49	20–29	0.13–0.179	80,000–139,999	4
19.5–21.4	5–5.1	9.5–9.9	290–379	35–39		8–8.9	1–1.99	4.5–5.49	30–44	0.18–0.219	140,000–249,999	3
21.5–22.9	4.5–4.9	10–10.4	380–539	25–34		9–9.9	2–3.99	5.5–6.99	45–64	0.22–0.279	250,000–429,999	2
23–24.9	3.5–4.4	10.5–11.4	540–839	10–24		10–14.9	4–9.99	7–9.99	65–119	0.28–0.369	430,000–749,999	1
25+	0–3.4	11.5–14	840+	0–9		15+	10+	10+	120+	0.37	750,000+	0

Source of data: Scottish Development Department [39].

The classification systems for SWQI and CWQI follow distinct threshold ranges, reflecting differences in methodological approaches and evaluation criteria (Table 4). The SWQI categorizes water quality into five levels, with an emphasis on compliance with Serbian regulatory frameworks and long-term monitoring practices. In contrast, the CWQI employs a separate five-level classification, incorporating a broader range of parameters and evaluating deviations from established environmental objectives. This differentiation allows for a dual-perspective assessment, ensuring both localized relevance and interna-

tional comparability in water quality evaluation. A detailed description of SWQI and CWQI methodologies was presented in our previous study [15].

Table 4. Threshold ranges for water quality classification in SWQI and CWQI.

Index	Category	Score Range
SWQI	Excellent	90–100
SWQI	Good	84–89
SWQI	Medium	72–83
SWQI	Bad	39–71
SWQI	Very Bad	0–38
CWQI	Excellent	95–100
CWQI	Good	80–94
CWQI	Fair	65–79
CWQI	Marginal	45–64
CWQI	Poor	0–44

Source of data: [37,38].

Given the limited number of sampling events (three measurements over two years) and the inconsistency in parameter coverage across different depths and profiles, it was not feasible to apply inferential statistical methods to assess trends or correlations with high confidence. Instead, the analysis focuses on descriptive evaluation, comparing water quality indices and observed parameter variations within the available dataset. A small number of samples does not allow statistical validation of trends, emphasizing the need for more frequent and systematic long-term monitoring in future assessments.

3. Results

3.1. Serbian Water Quality Index (SWQI)

Water quality assessment for Ribnica Reservoir across 2021 and 2022 indicates notable variations in several key parameters, offering insights into potential ecological changes. pH values remained relatively stable, with surface waters generally exhibiting higher readings. In 2021, the pH fluctuated between 7.5 and 8.3, while in 2022, values ranged from 7.5 to 8.0. This consistency suggests minor seasonal and biological influences but no drastic deviations that might indicate significant acidification or alkalization trends.

Electrical conductivity measurements show a slight decrease over time. In 2021, values varied between 158 and 201 µS/cm, with deeper layers maintaining lower conductivity levels. A mild reduction was observed in 2022, where conductivity ranged from 68 to 188 µS/cm. These changes could result from variations in dissolved ion concentrations, potentially influenced by hydrological inputs or precipitation patterns.

Oxygen saturation levels demonstrated improvements between the two years, reflecting possible enhancements in aeration or reduced organic loading. In 2021, saturation spanned from 62.5% in deeper waters to a maximum of 95% in surface layers. By 2022, values rose to between 78% and 100%, indicating enhanced mixing conditions or a decrease in biochemical oxygen demand. The drop in biological oxygen demand (BOD) further supports this observation—values in 2021 ranged between 4.2 and 5.3 mg/L, whereas in 2022, they declined significantly, with recorded levels as low as 1.23 mg/L. This reduction suggests improved decomposition processes and reduced organic pollution.

Suspended solids remained consistently measured at 4 mg/L throughout both years, indicating stable sedimentation rates and particulate matter distribution. However, nitro-

gen oxides present a slight increasing trend, particularly in 2022. While 2021 values ranged from 0.185 to 0.715 mg/L, concentrations in 2022 reached up to 0.800 mg/L, with higher readings observed in surface layers. This shift could suggest a rise in nutrient availability, warranting further observation to assess potential eutrophication risks.

Orthophosphate concentrations varied slightly across years, with values in 2021 fluctuating between 0.023 and 0.034 mg/L. In 2022, levels increased, reaching up to 0.054 mg/L in some instances. Elevated phosphorus concentrations may point to increased biological activity or external nutrient inputs that could influence productivity within the lake ecosystem [40].

Ammonium concentrations displayed moderate fluctuations. In 2021, values remained within 0.035–0.085 mg/L, while 2022 recorded a slightly wider range, peaking at 0.120 mg/L. This minor increase may be linked to microbial processes, sediment interactions, or shifts in nutrient cycling [41].

One notable limitation in this assessment is the absence of data on total coliforms, an essential component of Serbian Water Quality Index (SWQI) calculations. The lack of coliform measurements prevents a comprehensive evaluation of microbiological contamination, which is critical for assessing overall water quality from a public health perspective [42,43]. Additionally, missing data for biochemical indicators such as detailed seasonal variations or organic pollutant concentrations could restrict a full interpretation of ecological trends. While existing parameters provide valuable insights into nutrient dynamics, oxygen conditions, and mineralization processes, the omission of coliform data and other microbiological indicators means that potential impacts on aquatic health and water usability remain uncertain.

Overall, the available dataset suggests improvements in oxygen conditions and reductions in organic pollution over time; yet, increases in nitrogen and phosphorus concentrations highlight the need for continued monitoring to assess potential eutrophication risks. Incorporating microbiological analyses in future studies would ensure a more comprehensive evaluation of Ribnica Reservoir's water quality and its ecological integrity.

Table 5 presents the average values of the measured water quality parameters based on two sampling events conducted in 2021, providing a more comprehensive representation of the annual conditions. In contrast, Table 6 displays the parameters obtained from a single sampling conducted in 2022, reflecting a snapshot of water quality for that year. All listed parameters have been incorporated into the calculation of the Serbian Water Quality Index (SWQI).

Table 5. SWQI parameters by sampling depths—Ribnica Reservoir (annual averages, 2021).

Profile	A1	A1	A1	A1	A1	A1	A1	B1	B1	B1	B1	B1	C1
Depth (cm)	50	200	350	500	800	1000	1200	50	200	350	400	450	50
Temperature (°C)	18.5	17.3	15.4	13	9.2	5.7	5.4	19.1	16.8	15.5	14.9	13.8	19.0
pH	8.15	8.21	8.21	7.65	7.48	7.50	7.46	8.19	8.26	8.18	7.73	7.81	8.22
Electrical Conductivity (µS/cm)	190.0	189.5	188.5	167.5	158.0	158.5	159.5	196.0	194.0	194.0	182.5	179.0	201.0
Oxygen Saturation (%)	90.0	89.0	86.5	71.0	64.5	66.5	62.5	92.0	91.0	88.5	79.5	68.0	95.0
Biochemical Oxygen Demand (mg/L)	4.8	-	-	5.1	-	-	-	4.7	-	4.2	-	4.8	5.3
Suspended Solids (mg/L)	4	-	-	4	-	-	-	4	-	4	-	4	4
Total Nitrogen Oxides (mg/L)	0.295	0.185	0.205	0.375	0.515	0.530	0.480	0.315	0.320	0.310	0.320	0.65	0.715
Orthophosphates (mg/L)	0.030	0.028	0.033	0.033	0.028	0.029	0.034	0.027	0.029	0.027	0.023	0.025	0.029
Ammonium (mg/L)	0.035	0.045	0.045	0.070	0.070	0.080	0.085	0.045	0.045	0.055	0.055	0.055	0.045

Note: Missing data ('-') denotes parameters that were not measured during the specified period.

Table 6. SWQI parameters by sampling depths—Ribnica Reservoir (2022).

Profile	A1	A1	A1	A1	A1	A1	A1	B1	B1	B1	B1	B1	C1
Depth (cm)	50	200	350	500	800	1000	1200	50	200	350	400	450	50
Temperature (°C)	19.4	16.9	11.9	9.1	6.8	6.0	5.8	19.5	16.3	12.5	11.4	10.4	19.5
pH	7.93	8.05	7.91	7.65	7.5	7.47	7.46	7.89	7.98	7.93	7.86	7.78	7.92
Electrical Conductivity (μS/cm)	181	172	68	163	158	157	157	179	172	181	179	171	188
Oxygen Saturation (%)	95	100	94	86	80	79	78	94	95	94	91	88	96
Biochemical Oxygen Demand (mg/L)	3.49	-	-	-	-	-	-	1.23	-	-	-	1.41	1.34
Suspended Solids (mg/L)	4	-	-	-	-	-	-	4	-	-	-	4	4
Total Nitrogen Oxides (mg/L)	0.400	0.400	0.500	0.700	0.800	0.600	0.600	0.600	0.600	0.300	0.300	0.300	0.400
Orthophosphates (mg/L)	0.032	0.026	0.032	0.031	0.032	0.035	0.038	0.048	0.054	0.039	0.038	0.048	0.013
Ammonium (mg/L)	0.060	0.060	0.100	0.040	0.050	0.050	0.120	0.040	0.030	0.030	0.030	0.020	0.030

Note: Missing data ('-') denotes parameters that were not measured during the specified period.

The analysis of the Serbian Water Quality Index (SWQI) for the Ribnica Reservoir reveals a general improvement in water quality from 2021 to 2022. In the first year, values fluctuated between medium (82) and excellent (95) across different depths and profiles, with some variability indicating localized influences on water composition. The lowest SWQI recorded in 2021 was medium (82) at a depth of 450 cm in Profile B1, while the highest value of excellent (95) was observed at multiple depths, suggesting favorable conditions in specific zones. In contrast, the 2022 dataset shows an overall increase in SWQI values, ranging from good (89) to excellent (98), with notably higher readings across profiles and depths, demonstrating improved water quality parameters. The increase in SWQI scores between 2021 and 2022 suggests enhanced conditions in oxygen saturation, reduced biochemical oxygen demand, and more stable pH levels, contributing to an overall healthier aquatic environment. Oxygen saturation levels were notably higher in 2022, which aligns with the observed increase in SWQI across all profiles. Additionally, improvements in electroconductivity and nutrient concentrations may have reduced stress on the water system, contributing to the rise in water quality index values. The relatively consistent SWQI values across depths in 2022 indicate stronger water stability and potentially better mixing within the lake. While these trends suggest overall improvements, differences in scores at certain depths highlight the potential impact of external factors such as seasonal variations, anthropogenic influences, or shifts in nutrient dynamics. The profiles with consistently high SWQI values, such as those exceeding 95 (excellent) in 2022, could indicate areas with better circulation or lower contamination levels. However, deeper zones displaying slightly lower SWQI values—such as good (89) at 1000 cm and 1200 cm—suggest that some localized effects may still be influencing water quality at greater depths. The SWQI results emphasize the importance of continuous monitoring to assess long-term trends and potential ecological shifts.

The observed SWQI values indicate that water quality in the Ribnica Reservoir was predominantly in the good category in 2021, with some profiles briefly reaching medium levels. In contrast, 2022 results show a clear improvement, with all recorded values falling within the excellent and upper good range, reinforcing the trend of enhanced water conditions (Table 7).

Table 7. Comparison of SWQI scores across sampling depths in the Ribnica Reservoir (2021–2022).

Profile	A1	A1	A1	A1	A1	A1	A1	B1	B1	B1	B1	B1	C1
Depth (cm)	50	200	350	500	800	1000	1200	50	200	350	400	450	50
2021	88	95	95	83	85	86	85	88	95	90	94	82	86
2022	93	98	95	95	92	89	89	94	95	97	97	97	95

3.2. Canadian Water Quality Index (CWQI)

3.2.1. Overall Water Quality

CWQI values at Profile A1 for the three samples ranged from poor (40) at a depth of 50 cm to good (88) at depths of 800 cm, 1000 cm, and 1200 cm. Overall water quality was also good at depths of 200 cm and 350 cm (86), while marginal water quality (47) was recorded at a depth of 500 cm. These results were attributed to increased Al concentrations with the highest *nse* at depths of 50 cm and 500 cm and decreased dissolved oxygen with the highest *nse* at all other depths. Overall water quality decline was further influenced by increased Hg values at a depth of 50 cm and decreased dissolved oxygen at a depth of 500 cm (Figure 2).

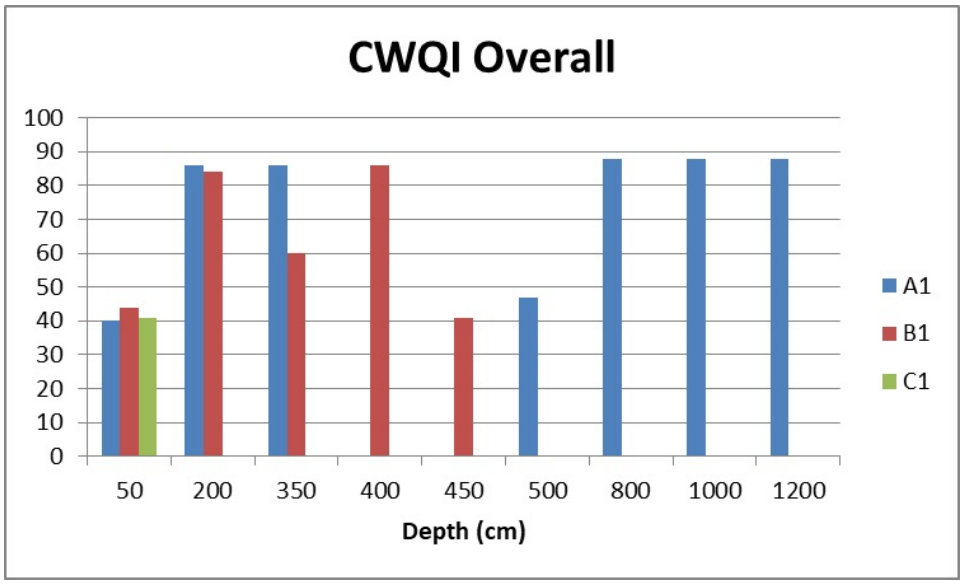


Figure 2. Overall water quality.

The results of CWQI at Profile B1 for the three samples were as follows: poor (41) at a depth of 450 cm and (44) at a depth of 50 cm, marginal (60) at a depth of 350 cm and good (84) at a depth of 200 cm and (86) at a depth of 400 cm. Poor water quality was the consequence of increased Al concentrations with the highest *nse*, marginal water quality was associated with increased Hg values with the highest *nse*, while decreased dissolved oxygen values with the highest *nse* were recorded even under good water quality. Overall water quality impairment was also further affected by decreased dissolved oxygen values at depths of 50 cm, 350 cm, and 450 cm, increased Hg values at depths of 50 cm and 450 cm, and increased Cr and Cu values at a depth of 450 cm (Figure 2).

CWQI value was poor (41) at Profile C1 for the three samples at a depth of 50 cm. This result was attributed to increased Al concentrations with the highest *nse*, further influenced by decreased dissolved oxygen and increased Hg concentrations (Figure 2).

Table 8 indicates better water quality in 2022 at all depths, except for 50 cm at all profiles and 450 cm at Profile B1.

Table 8. Comparison of CWQI scores across sampling depths in the Ribnica Reservoir (2021–2022).

Profile	A1	A1	A1	A1	A1	A1	A1	B1	B1	B1	B1	B1	C1
Depth (cm)	50	200	350	500	800	1000	1200	50	200	350	400	450	50
2021	41	84	84	44	87	87	87	47	84	57	84	46	45
2022	40	100	100	100	100	100	100	41	84	100	100	42	36

3.2.2. Drinking Water Quality

CWQI values were good at a depth of 50 cm (90) at Profile A1 and (91) at profiles B1 and C1, excellent (95) at a depth of 450 cm at Profile B1 and 500 cm at Profile A1, and (100) at all other depths. A slight decline of CWQI was attributed to increased Mn values with the highest *nse* at a depth of 50 cm at Profile A1 and increased Fe values with the highest *nse* at all other depths and profiles where a decline in CWQI was observed (Figure 3).

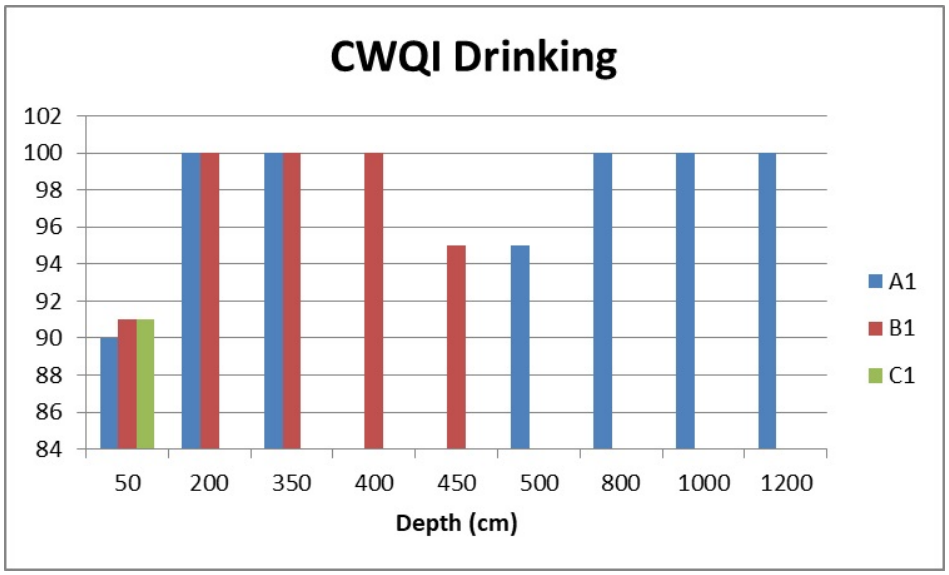


Figure 3. Water quality for drinking.

3.2.3. Water Quality for Aquatic Life

CWQI values ranged from poor (28) at Profile B1 at a depth of 450 cm to fair (69) at Profile A1 at depths of 800 cm, 1000 cm, and 1200 cm. Poor water quality was also recorded at a depth of 50 cm at all profiles: (29) at Profile A1, (30) at Profile C1, and (35) at Profile B1, as well as at a depth of 500 cm at Profile A1 (35). Marginal water quality was recorded at Profile B1 at a depth of 200 cm (59) and 350 cm (56). Fair CWQI values (65) were also recorded at Profile A1 at a depth of 350 cm and Profile B1 at a depth of 400 cm. (Figure 4). Poor and marginal CWQI values at Profile B1 at a depth of 350 cm were caused by increased Al values with the highest *nse*. Fair CWQI values and marginal CWQI values at Profile B1 at a depth of 200 cm were the result of decreased dissolved oxygen with the highest *nse*. Dissolved oxygen decline was observed at all depths and profiles. In addition, increased Cr and Cu values at Profile B1 at a depth of 450 cm also contributed to water quality impairment.

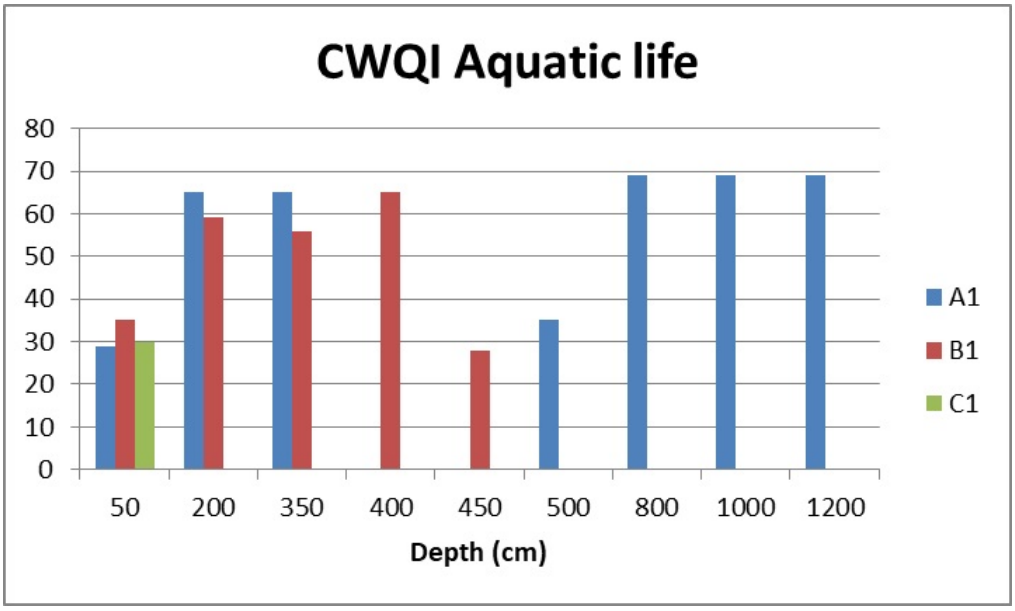


Figure 4. Water quality for aquatic life.

Table 9 presents average values of CWQI parameters in 2021 from two samples, while Table 10 presents CWQI values in 2022 from one sample.

Table 9. CWQI parameters by sampling depths—Ribnica Reservoir (annual averages, 2021).

Profile	A1	A1	A1	A1	A1	A1	A1	B1	B1	B1	B1	B1	C1
Depth (cm)	50	200	350	500	800	1000	1200	50	200	350	400	450	50
Dissolved Oxygen (mg/L)	8.335	8.585	8.785	8.120	8.135	8.350	7.905	8.470	8.745	8.780	7.970	6.995	8.735
Al (mg/L)	0.218	-	-	0.438	-	-	-	0.186	-	0.094	-	0.426	0.180
Hg (µg/L)	0.07	-	-	0.07	-	-	-	0.07	-	0.07	-	0.07	0.07
Cr (mg/L)	0.0031	-	-	0.0005	-	-	-	0.0022	-	0.0037	-	0.0017	0.0028
Cu (mg/L)	0.0024	-	-	0.0039	-	-	-	0.0021	-	0.0019	-	0.0067	0.002
Mn (mg/L)	0.059	-	-	0.049	-	-	-	0.037	-	0.010	-	0.048	0.004
Fe (mg/L)	0.304	-	-	0.389	-	-	-	0.318	-	0.287	-	0.249	0.306

Note: Missing data ('-') denotes parameters that were not measured during the specified period.

Table 10. CWQI parameters by sampling depths—Ribnica Reservoir (2022).

Profile	A1	A1	A1	A1	A1	A1	A1	B1	B1	B1	B1	B1	C1
Depth (cm)	50	200	350	500	800	1000	1200	50	200	350	400	450	50
Dissolved Oxygen (mg/L)	8.71	9.65	10.14	9.90	9.79	9.87	9.81	8.55	9.24	9.98	9.87	9.80	8.77
Al (mg/L)	0.288	-	-	-	-	-	-	0.235		-	-	0.292	0.233
Hg (µg/L)	0.07	-	-	-	-	-	-	0.07		-	-	0.07	0.07
Cr (mg/L)	0.0084	-	-	-	-	-	-	0.0054		-	-	0.0074	0.0196
Cu (mg/L)	0.0064	-	-	-	-	-	-	0.0052		-	-	0.0086	0.0179
Mn (mg/L)	0.011	-	-	-	-	-	-	0.010		-	-	0.013	0.022
Fe (mg/L)	0.504	-	-	-	-	-	-	0.390		-	-	0.634	0.374

Note: Missing data ('-') denotes parameters that were not measured during the specified period.

3.2.4. Water Quality for Agriculture

CWQI values for irrigation were good (93) at Profile C1 at a depth 50 cm, (94) at profiles A1 and B1 at a depth of 50 cm and Profile B1 at a depth of 450 cm, and excellent

(100) at profile B1 at a depth of 350 cm and Profile A1 at a depth of 500 cm. There were no data for other depths. A slight decline in CWQI values was caused by increased Cr concentrations with the highest *nse* (Figure 5).

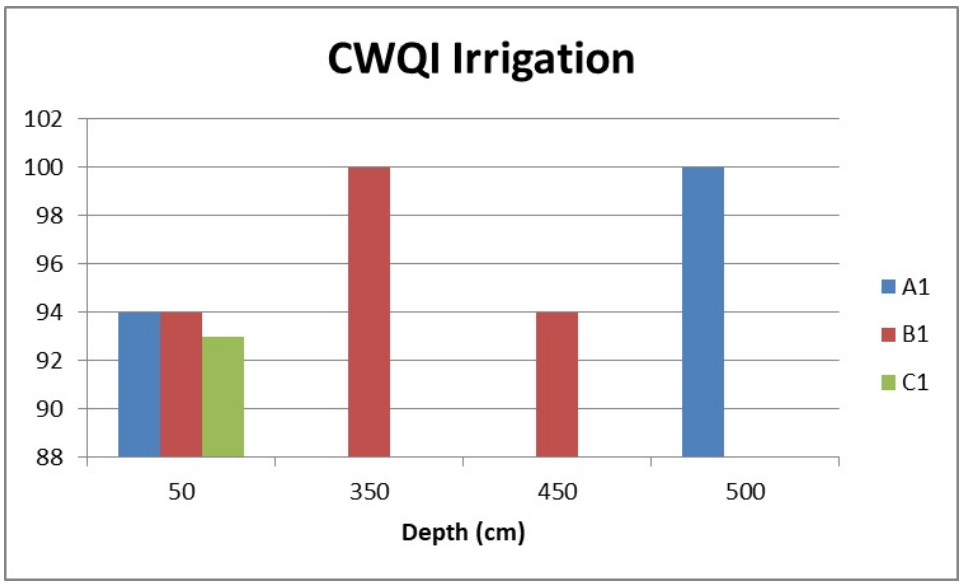


Figure 5. Water quality for irrigation.

CWQI values for livestock were marginal (62) at a depth of 50 cm at all profiles, (63) at Profile B1 at a depth of 450 cm, fair (66) at Profile B1 at a depth of 350 cm and Profile A1 at a depth of 500 cm, and excellent (100) at all other depths. Marginal and fair water quality was the result of increased Hg concentrations with the highest *nse* (Figure 6).

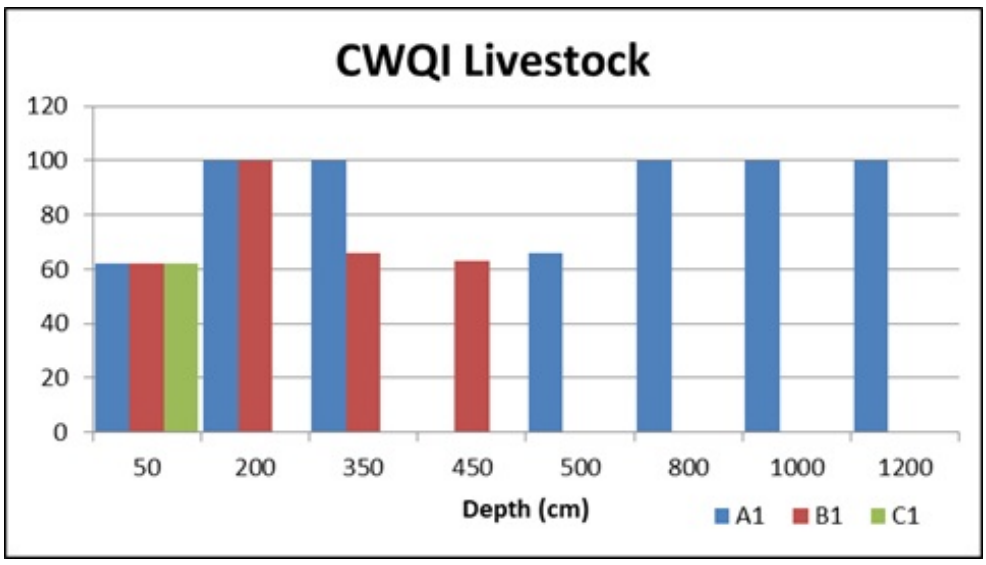


Figure 6. Water quality for livestock.

4. Discussion

A decrease in dissolved oxygen was recorded at all profiles regardless of depth (Figure 7). These conditions are very unfavorable for overall water quality and particularly harmful to aquatic organisms.

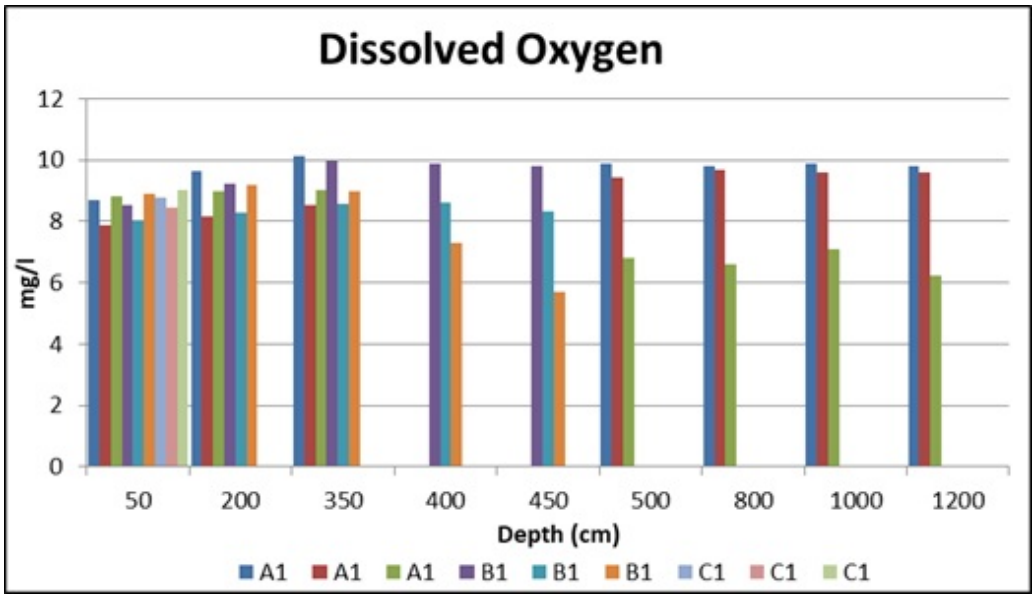


Figure 7. Dissolved oxygen concentrations.

Increased Al concentrations that affected overall water quality and water quality for aquatic life have both natural and anthropogenic origin (Figure 8). Natural factors are linked to lithological composition: mineral harzburgite contains Al-Cr spinel [44]. Anthropogenic inputs originate from water treatment: Al-sulphate, among other chemicals, is used in these technological processes [45–47].

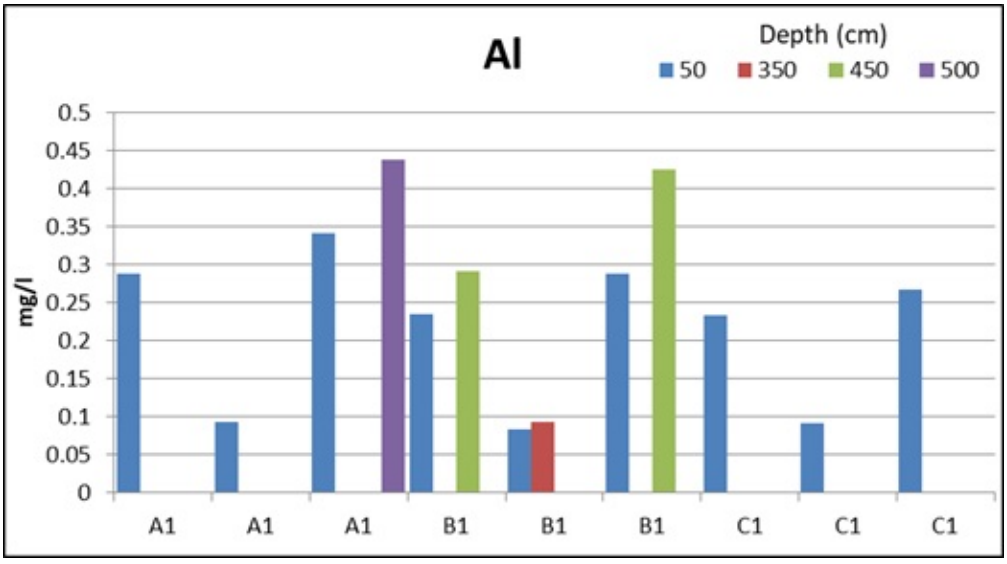


Figure 8. Al concentrations.

Monitoring of drinking water quality should be improved, especially because the Ribnica Reservoir is used for drinking water supply. Despite this fact, Fe values were not measured at greater depths, from 800 cm to 1000 cm (Figure 9). Increased Fe concentrations originate from mineral lherzolite, which contains iron oxide in its composition [44].

These results are consistent with the study of Radibratović et al. [47], who found an Fe concentration of 0.41 mg/L in 2016.

Previous investigations showed increased concentrations of toxic elements (Ni, Cr, Zn, Cd, and Hg) in reservoir sediment, caused by the geological structure and interaction of ultramaphite with surface and groundwater [45]. These results are in line with our study, which also recorded increased Cr (Figure 10) and Hg concentrations in water. Taking into

account that Hg, Cd, and Pb are considered the most toxic metals in water bodies [3], these findings indicate the need to introduce heavy metal monitoring at greater depths.

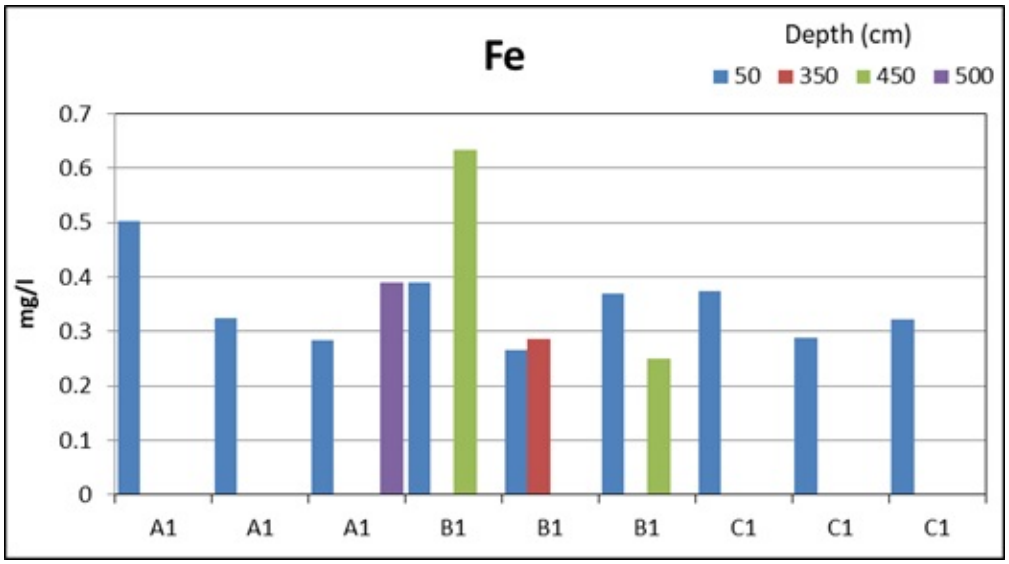


Figure 9. Fe concentrations.

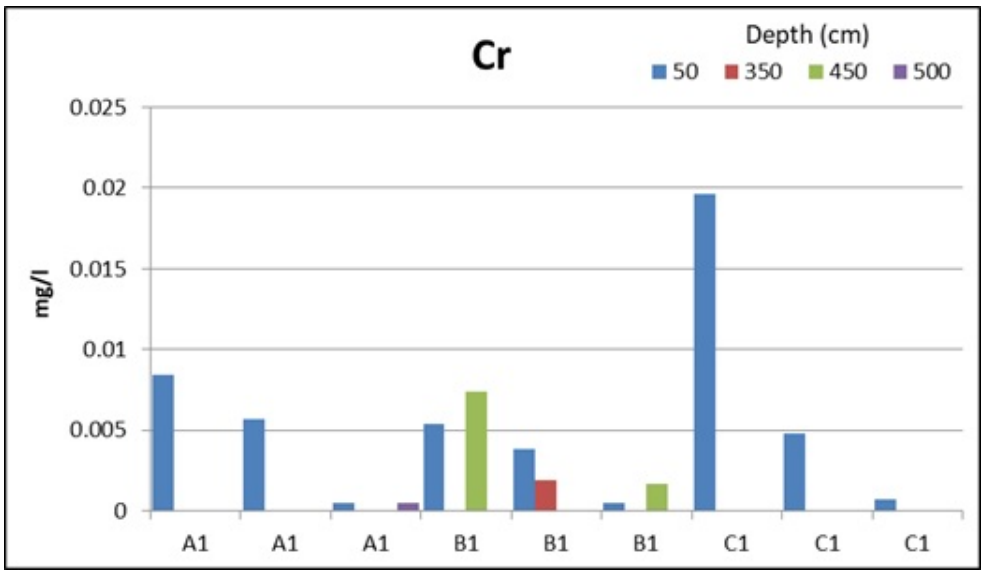


Figure 10. Cr concentrations.

4.1. Cumulative Ecological Impacts

While individual heavy metal concentrations may remain within regulated limits, their simultaneous presence in the aquatic environment can lead to additive or synergistic effects. Recent studies have demonstrated that co-exposure to multiple metals can amplify oxidative stress, disrupt enzymatic activity, and impair physiological responses in aquatic organisms. For instance, combined exposure to mercury (Hg) and chromium (Cr) has been shown to increase reactive oxygen species production and reduce antioxidant defenses in fish [48]. Similarly, El-Sharkawy et al. [49] reported that mixtures of metals such as Al, Cu, and Hg led to enhanced DNA damage and bioaccumulation potential in aquatic biota.

In the case of the Ribnica Reservoir, the concurrent detection of Al, Cr, Cu, and Hg raises concern regarding their possible cumulative ecological impact, particularly in a sensitive and protected ecosystem. Although each metal may appear in moderate

concentrations when considered individually, their combined presence could pose a more significant threat to aquatic life and water quality.

These findings emphasize the importance of implementing integrated ecological risk assessments that account for interactions among multiple contaminants. Accordingly, we recommend establishing a year-round, depth-resolved monitoring program targeting heavy metals, with a specific focus on identifying seasonal dynamics, long-term trends, and potential biological effects.

Despite the fact that this area has no registered major polluters, intensive tourism development and urbanization on Zlatibor mountain have an impact on the environment, including the deterioration of water quality [45,50,51].

4.2. Comparative Analysis of SWQI and CWQI in the Ribnica Reservoir

The comparative evaluation of the Serbian Water Quality Index (SWQI) and the Canadian Water Quality Index (CWQI) provides an in-depth understanding of water quality conditions in the Ribnica Reservoir from diverse ecological and usage perspectives. Despite their common goal of comprehensively assessing water quality, these indices differ methodologically, thus offering complementary insights.

Analysis using the SWQI indicated an overall enhancement in water quality from 2021 to 2022, characterized by increased oxygen saturation, lower biochemical oxygen demand (BOD), and improved or stable pH and electrical conductivity values. SWQI scores transitioned from primarily good and occasionally medium levels in 2021, to predominantly excellent and high-end good categories in 2022. These changes suggest favorable environmental management and positive hydrological conditions. However, depth-specific variations highlight persistent issues that may necessitate targeted interventions.

On the other hand, CWQI results revealed more nuanced water quality dynamics across different intended uses, highlighting risks not captured by the SWQI. CWQI scores varied significantly, ranging from poor to good, largely influenced by high concentrations of aluminum (Al), mercury (Hg), and reduced dissolved oxygen (DO). The assessment of water quality for drinking purposes showed mainly excellent outcomes, with slight decreases attributed to manganese (Mn) and iron (Fe). Importantly, CWQI identified substantial concerns regarding aquatic life, categorizing water quality primarily as poor to fair due to low dissolved oxygen levels and elevated concentrations of aluminum, chromium, and copper.

This comparative evaluation underscores the utility of employing both indices simultaneously. While the SWQI effectively captures general physico-chemical properties and nutrient levels aligned with regional regulatory standards, the CWQI enriches the assessment by including broader ecological threats, such as heavy metal contamination, and suitability for specific uses (drinking water, aquatic life, and agriculture). This combined methodology provides a comprehensive overview, highlighting factors potentially overlooked when relying solely on one index.

The integration of SWQI and CWQI assessments offers a robust and multifaceted approach for monitoring water quality in the Ribnica Reservoir. Continued application of both indices, supplemented by enhanced monitoring of microbiological and heavy metal parameters, is crucial for thorough water quality management and the protection of this ecologically valuable water body.

5. Conclusions

The conducted analysis clearly emphasizes the critical importance of continuous and comprehensive water quality monitoring in the Ribnica Reservoir, given its essential role in supplying drinking water and its position within the protected Zlatibor Nature Park. The

comparative evaluation using the Serbian Water Quality Index (SWQI) and the Canadian Water Quality Index (CWQI) revealed overall improvements in water quality in 2022. However, it also uncovered specific risks associated with heavy metals, reduced dissolved oxygen, and localized ecological threats, highlighting the necessity for sustained vigilance.

Heavy metals thresholds were defined by Canadian Councils of Ministers of Environment. Aluminum concentrations exceeded the threshold (0.005 mg/L) for overall and water quality for aquatic life in all samples and ranged from 0.083 mg/L to 0.438 mg/L. Taking into account that these values were many times higher than the threshold, it can be concluded that it had a detrimental effect on aquatic organisms. Iron concentrations were above the thresholds (0.3 mg/L) for overall, drinking, and water quality for aquatic life in most samples and ranged from 0.322 mg/L to 0.634 mg/L. Although these concentrations were not drastically increased, a certain level of concern is necessary, because the Ribnica Reservoir is used for drinking water supply. Chromium concentrations exceeded the threshold (0.001 mg/L) for overall and water quality for aquatic life in most samples and for irrigation water quality (0.0049 mg/L) in s few samples, and ranged from 0.0017 mg/L to 0.0196 mg/L. Increased mercury concentrations (0.007 mg/L) in all samples for overall and water quality for livestock comparing with the threshold (0.003 mg/L) were recorded in all samples. Increased chromium and mercury concentrations is also concerning, because these metals are considered as the most toxic in an aquatic environment. Their joint impact led to an increase in reactive oxygen species production and a reduction in antioxidant defenses in fish. Further, cumulative effects of aluminum, copper, and mercury cause enhanced DNA damage and bioaccumulation potential in aquatic biota.

Given these findings, several targeted measures are recommended to enhance future water-resource management efforts. Firstly, establishing a continuous, multi-depth monitoring regime is vital to capture seasonal fluctuations, anthropogenic impacts, and long-term ecological changes. Secondly, expanding the current monitoring framework to incorporate comprehensive microbiological assessments and systematic measurements of heavy metals at various depths is critical to safeguarding public health and ecological integrity. Furthermore, it is highly recommended to initiate and maintain regular water quality monitoring programs for the Crni Rzav River and other tributaries within the reservoir's catchment area, as such data is currently lacking and would greatly enhance the understanding of pollutant sources and ecological interactions.

Additionally, proactive management strategies such as regular sediment assessments, strict control of tourist and urban development activities, and mitigation of pollution sources through enhanced wastewater treatment practices are essential. Strengthening these approaches will contribute significantly to preserving the reservoir's ecological balance, maintaining high water quality standards, and ensuring its sustainable use.

Overall, this study underscores the value of integrating local and international indices, providing a nuanced understanding of water quality dynamics. Continued application and refinement of these methodologies, supported by rigorous data collection protocols, are fundamental to maintaining the Ribnica Reservoir as a reliable source of drinking water and a significant ecological asset within a protected landscape.

Furthermore, a more detailed analysis of heavy metal sources and their ecological interactions is warranted. Future research should combine geochemical and isotopic tools to distinguish between natural and anthropogenic inputs, while also assessing the cumulative impacts of co-occurring metals on aquatic ecosystems. Such integrated efforts are essential for comprehensive ecological protection and informed management of this critical water resource.

Author Contributions: Conceptualization, D.M.J., D.J. and D.D.; methodology, D.M.J. and D.J.; software, D.M.J. and D.J.; validation, D.M.J., D.J. and D.D.; formal analysis, D.M.J. and D.J.; investigation, D.M.J., D.J. and D.D.; resources, D.M.J., D.J. and D.D.; data curation, D.M.J., D.J. and D.D.; writing—original draft preparation, D.M.J. and D.J.; writing—review and editing, D.M.J., D.J. and D.D.; visualization, D.M.J., D.J. and D.D.; supervision, D.D.; project administration, D.M.J.; funding acquisition, D.M.J., D.J. and D.D. All authors have read and agreed to the published version of the manuscript.

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