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Application of water quality index for assessment of surface water, Dukagjini Region, Kosovo

Arianeta Nura[1], Rozeta Hasalliu[2], Pajtim Bytyçi[1], Berat Durmishi[1], Shkëndije Sefa Haziri[1], Flutura Ajazi[1], Veton Haziri[1*]

[1] Food Science and Biotechnology, UBT-Higher Education Institution, Kalabria, Rexhep Krasniqi Street, Nr. 56, Prishtina 10000, KOSOVO
[2] Faculty of Biotechnology and Food, Agricultural University of Tirana, 1029 Tirana, ALBANIA
*Corresponding author: veton.haziri@ ubt-uni.net

Abstract. Water quality has deteriorated considerably because of urban runoff, agricultural production, and rapid industrialization. This prosecution's objective is to assess the surface water's quality in the Gjakova location. In general, surface water quality complies with the Water Framework Directive's principles. In 2019, 2020, and 2021, three distinct sampling sites—the Lumbardh River, the Derivative Channel, and the Radoniqi Lake—were used to examine the surface water intended for consumption. According to principal corresponding analysis (PCA), there was a positive association between various physicochemical parameters and total and fecal coliforms. Based on the water quality index for each sampling site and the analyzed surface water parameters, surface water belongs to the medium category. In comparison to the Waste framework directive, most parameters fall into the first category, excluding nitrites, phosphates, and manganese. However, the water treatment for drinking should be related to parameters that exceed the upper limits. Seasonal monitoring of water quality is an effective tool to evaluate treatment processes.

Key words: Monitoring, Pollution, Water Framework Directive, Water Quality.

Introduction

Access to drinking water is a vital requirement for human health (Cabral, 2010), and the importance of water, sanitation (World Health Organization, 2014), and hygiene for health and development is emphasized in the conclusions of a series of international forums, such as the WHO (World Health Organization, 2018).

Surface and groundwater are used for domestic supply (Andreoli & Sabogal-Paz, 2020; Kruszyński & Dawidowicz, 2020), industrial water (Willet et al., 2020), and irrigation worldwide (Thorslund et al., 2021). In the last few decades, there has been a tremendous increase in the demand for freshwater due to the rapid growth of the population (Markogianni et al., 2018), socioeconomic development, and changing consumer choices and trends (Yang et al., 2021). Moreover, as a result of pollution of surface water bodies, groundwater has become an important source for ensuring the safety of the water supply (Pietrucha-Urbanik & Studziński, 2019). Population growth and increasing climate variability reduced groundwater levels (Zarzycki et al., 2020) due to an imbalance between groundwater recharge and extraction (Hssaisoune et al., 2020; Talalaj, 2013).

A Water Quality Index (WQI) (Akhtar et al., 2021; Lumb et al., 2011; Tyagi et al., 2013) is a method of summarizing water quality data for consistent public reporting. The WQI was calculated based on the suitability of groundwater for human consumption. Only 3% of the earth's surface is freshwater (Gleick, 2003), with the remaining 1% accounting for all available water resources for the survival of all living beings (Deep et al., 2020; Nace, 2021).

The Radoniqi waterworks provide water to Gjakova and Rahoveci, as well as 36 villages in these municipalities and Prizren. Radoniqi Lake has a surface area of 580 ha and is located at an altitude of 400-456 m above sea level. It is the second-largest lake in Kosovo in terms of surface area. The water catchment area for filling the lake is 120 km^2, located at an altitude of 600-2500 m above sea level, indicating that the catchment area is remote from settlements and pollution sources. Lumbardh of Deçan and the river Prroi of Ratisha are the primary sources of the Radoniqi lake. Lumbardh of Deçan collects water mainly from nearby sources and has an annual average flow of 5 m^3/s. The flow capacity of Deçan's Bistrica is 650 L/s. The lake has a volumetric capacity of 117.8 million m^3 of water, is 5.2 kilometers long, has a maximum width of 2.5 kilometers, and a depth of 52 meters.

Since drinking water must be devoid of toxic elements, living and non-living species, and minerals in excess can also be harmful to health (Yadav et al., 2012). The goal of this study is to investigate the qualitative aspects of drinking water in Radoniqi as well as the overall water quality based on surface waters. Statistical analysis, such as the water quality index (WQI) and principal component analysis (PCA), is used to support the assessment of water quality. All the data is investigated to figure out seasonal variations in surface water quality as well as the extent to which the water is safe for human consumption.

Materials and Methods

Sampling

Water samples have been taken in three locations as depicted in the map (Figure 1), in the region of Gjakova: S1 (the river of Lumbardh), S2 (the derivative channel), and S3 (the Radoniqi lake) (Table 1). 108 water samples were collected during the period 2019–2021. Samples were collected monthly in the morning between 9 a.m. and 12 p.m.

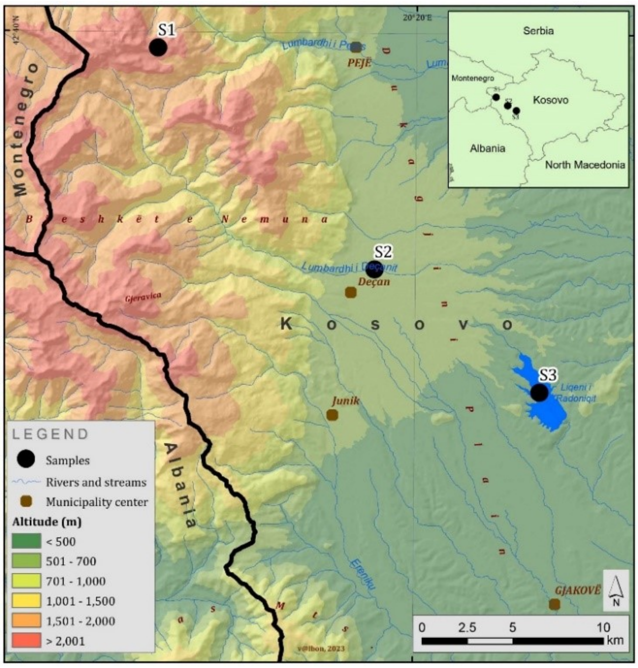

Fig. 1. Map of the location of water sampling.

Table 1. Water sampling in different locations.

Location	Samples	Latitude (N)	Longitude (E)
River of Lumbardh	S1	42°39'32"N	20°9'34"E
Derivative Channel	S2	42°32'59"N	20°18'22"E
Radoniqi Lake	S3	42.4893° N	20.4173° E

Physico-chemical analysis

A multi-parameter meter (HANNA HI 98199) is used to measure physico-chemical parameters *in situ*. Some of parameters include temperature, pH, electrical conductivity, total dissolved solids (TDS), dissolved oxygen, percentage of oxygen saturation, and turbidity (model WTW Turb 430IR). Many of the chemical parameters were determined using the spectrophotometer photo-lab 7600 UV-vis digital spectrophotometer.

Microbiological analysis

Total coliforms were quantified using a 0.45 µm pore size filter and Violet Bile Agar and Chromogenic Coliform Agar, incubated for 213 hours at 36°C, with colonies that gave a positive ß-D galactosidase reaction assumed to be coliform bacteria rather than *E. coli.* M-Endo Agar Less and Chromogenic Coliform Agar were used to identify fecal coliforms, which resulted in a positive -D-galactosidase and -D-glucuronidase reaction. For *E. coli* colonies, the oxidase test yields a negative result. Aerobic mesophilic bacteria are identified using membrane filtration, incubation with Violet Red Bile Agar and m-Endo Agar-less, and nutrient agar (NA). The number of colonies formed on each plate was counted at the end of incubation to determine the colony-forming unit (CFU) per ml of sample (Table 2).

Table 2. ISO standards for microbiological analysis.

Analyses type	ISO standard
Total coliform bacteria	ISO 9308-1:2014
Fecal coliform bacteria	ISO 9308-1:2004
Aerobic mesophilic bacteria	ISO 6222:1999

Statistical analysis

PCA is a multivariate statistical method that can be used to reduce the complexity of input variables when there is a large volume of data, with the goal of improving the interpretation of the variables (Fan et al., 2010; Mishra et al., 2017).

Statistical principal corresponding analysis (PCA) is used to process the study results using Origin software. Positive correlation is represented by a relatively long vector pointing roughly in the same direction, while negative correlation is represented by an arrow pointing in the opposite direction (Linting et al., 2007).

WQI is a number that expresses water quality by aggregating measurements of water quality parameters (Table 3) (Adelagun et al., 2021). The indexes have been modeled and developed mainly for surface waters, espe-cially drinking water (dos Santos Simoes et al., 2008). The most common parameters inclu-ded in the calculation of the indices are Dis-solved oxygen (DO), Biochemical oxygen demand (BOD), pH, total dissolved solids, and fecal coliforms, or *Escherichia coli* (Lumb et al., 2011).

Since many models calculate WQI, we have focused on the calculation model based on the formula (Patel, 2011):

$$\boldsymbol{WQI} = \sum \boldsymbol{q_i w_i}$$

qi - is the sub-index of water quality, which indicates the quality of water in reference to 100 for each parameter.

w_i - is the relative weight of each parameter in the overall water quality.

Table 3. Water quality categorization based on WQI.

WQI values	90-100	70-90	50-70	25-50	0-25
Quality	Excellent	Good	Medium	Bad	Very bad

Results and Discussion

The physicochemical parameters of water quality are presented in Tables 4, 5, and 6. Water temperature varied from a minimum of 3.2ºC during winter to a maximum of 13.4ºC during summer. Water's pH indicates its acidity or alkalinity. The pH values ranged from 6.6 to 9.9, and most results were within acceptable limits. Turbidity is a significant physicochemical parameter. The turbidity ranged from 0.1 to 7.1, and, as with pH, most of the measurements of water turbidity were within acceptable limits. Ammonium concentration levels in the examined samples ranged from 0.030 to 0.118 mg/l.

Permanganate index (CODMn) is related to water quality. The CODMn starts from 0.78 mg/l at the lake of Radoniqi to 19.7 mg/l at channel derivatives. The idea of water mineralization comes from electrical conductivity. The values recorded during the study period varied from 115.6 to 481 µs/cm, which are in line with the surface water quality standards.

The amount of dissolved oxygen was lowest in Radoniqi Lake during the fall of 2021, at 7.2 mg/l, and highest in Lumbardh during the summer, at 18.8 mg/l in 2020. The chloride ion concentrations were mostly within the allowed limits, with only minor variations between site-sampling, according to the results. Calcium and nitrite concentrations ranged from 30.8-50.1 mg/l and 0.008-0.09 mg/l, respectively. The iron and manganese concentrations in the tested samples were also within acceptable limits, ranging from 0.03-0.24 mg/l and 0.02-0.03 mg/l, respectively. Phosphate levels in the Lumbardh River ranged from 0.025 mg/l in the autumn of 2020 to 1.8 mg/l in the summer of 2019.

Table 7 displays the results of microbiological analyses. In the S1 point during the summer season in 2020 were found 301 CFU/100 mL of total coliform bacteria. Bacteria levels are significantly lower in the winter. The bare minimum of individuals discovered at the S2 point in 2019 during the winter season is 101 CFU/100 mL.

Fecal coliform bacteria were found in higher amounts at the S1 point during the summer season in 2020, with a maximum of 284 CFU/100 mL, than at the S3 point during the spring season in 2021. Meanwhile, anaerobic mesophilic bacteria in the S1 point of 2019 reached a maximum of 127 CFU/100 mL on average during the summer season, but only 15 CFU/100 mL in the S3 point during the winter season of 2020.

Table 4. Physico-chemical analyses of water samples in a different location in 2019.

Location	Season	pH	Temp.	NTU	NH_3	CODMn	Cond.	Diss. O_2	Cl^-	Ca^{2+}	NO_2^-	Fe	Mn	PO_4^{3-}
Lumbardh	Spring	8.53	5.7	2.86	0.084	6.0	357.8	13.1	5.6	39.3	0.035	0.24	0.109(I)	0.978
	Summer	8.73	8.6	1.98	0.084	6.4	406.8	13.4	5.4	40.3	0.068	0.16	0.208(I)	1.800
	Autumn	8.80	7.7	2.73	0.079	5.5	295.5	11.8	3.7	35.8	0.090	0.07	0.170(I)	0.578
	Winter	9.08	5.0	2.69	0.076	5.8	258.0	12.5	4.7	38.0	0.073	0.11	0.100(I)	0.188
Channel derivatives	Spring	8.43	5.7	2.73	0.062	5.5	115.6	10.7	5.5	36.5	0.035	0.15	0.096(I)	0.943
	Summer	8.64	8.6	2.28	0.066	19.4	255.3	10.9	6.0	40.0	0.048	0.13	0.188(I)	1.700
	Autumn	9.43	7.7	2.80	0.030	19.7	254.8	9.9	4.9	35.8	0.068	0.06	0.120(I)	0.545
	Winter	8.31	5.1	2.68	0.039	5.7	177.0	10.8	5.0	32.5	0.060	0.11	0.083(I)	0.175
Radoniq Lake	Spring	9.86	9.2	2.71	0.045	5.9	234.3	12.5	5.3	50.1	0.034	0.07	0.090(I)	0.093
	Summer	9.88	13.4	2.15	0.031	17.7	241.4	12.6	5.6	50.1	0.082	0.06	0.130(I)	0.070
	Autumn	7.84	10.4	1.64	0.031	6.5	234.5	9.6	4.2	39.5	0.080	0.04	0.093(I)	0.058
	Winter	7.74	6.4	1.68	0.031	4.8	201.3	10.0	3.9	39.1	0.053	0.04	0.058(I)	0.080

Table 5. Physico-chemical analyses of water samples in a different location in 2020.

Location	Season	pH	Temp.	NTU	NH_3	CODMn	Cond.	Diss. O_2	Cl^-	Ca^{2+}	NO_2^-	Fe	Mn	PO_4^{3-}
Lumbardh	Spring	8.4	6.9	3.7	0.084	6.9	481	18.2	3.26	39.12	0.017	0.125	0.098	0.148
	Summer	8.9	8.4	3.7	0.085	7.3	449.75	18.8	3.62	41.85	0.036	0.103	0.101	0.085
	Autumn	6.6	3.2	0.1	0.070	3.5	164.5	13.7	3.23	20.92	0.068	0.037	0.068	0.025
	Winter	8.4	4.7	3.4	0.068	5.6	421.75	16.0	4.09	30.84	0.015	0.078	0.068	0.120
Channel derivatives	Spring	8.4	7.4	2.2	0.112	5.5	404.75	16.1	3.82	39.58	0.013	0.063	0.083	0.088
	Summer	9.0	10.0	2.2	0.113	6.0	425	17.0	3.36	41.64	0.069	0.063	0.068	0.078
	Autumn	8.1	8.8	2.4	0.065	5.1	322	15.8	3.53	36.99	0.075	0.055	0.037	0.055
	Winter	8.1	4.1	1.9	0.118	4.8	349.5	14.9	3.79	31.57	0.024	0.060	0.065	0.350
Radoniq Lake	Spring	7.9	5.3	2.5	0.057	3.8	237	10.6	4.25	39.07	0.013	0.085	0.077	0.348
	Summer	8.0	10.4	0.7	0.099	3.8	239	11.0	3.98	40.32	0.058	0.039	0.108	0.050
	Autumn	7.8	9.6	1.9	0.034	3.8	240.5	10.6	4.25	39.31	0.058	0.039	0.093	0.053
	Winter	7.9	5.3	2.5	0.057	3.8	237	10.6	4.25	39.07	0.013	0.085	0.077	0.348

Table 6. Physico-chemical analyses of water samples in a different location in 2021.

Location	Season	pH	Temp.	NTU	NH_3	CODMn	Cond.	Diss. O_2	Cl^-	Ca^{2+}	NO_2^-	Fe	Mn	PO_4^{3-}
Lumbardh	Spring	8.1	6.8	2.6	0.087	1.53	175.0	12.9	4.88	40.58	0.013	0.153	0.132	0.073
	Summer	8.2	9.1	2.4	0.097	1.54	182.5	11.8	4.52	41.65	0.012	0.100	0.270	0.068
	Autumn	8.4	9.5	7.1	0.087	0.97	172.0	9.0	4.35	40.96	0.027	0.060	0.150	0.053
	Winter	8.2	6.1	3.3	0.093	2.08	168.6	11.4	4.81	38.06	0.010	0.100	0.128	0.078
Channel derivatives	Spring	8.1	7.1	2.4	0.079	1.27	162.5	12.8	4.85	41.05	0.010	0.063	0.091	0.063
	Summer	8.3	9.4	2.1	0.095	1.20	176.8	11.6	4.46	40.36	0.016	0.073	0.017	0.065
	Autumn	8.2	10.4	7.1	0.080	0.92	175.3	8.1	4.29	42.30	0.013	0.053	0.013	0.053
	Winter	8.0	6.4	3.2	0.086	1.94	155.0	11.3	4.63	37.27	0.009	0.085	0.093	0.083
Radoniq Lake	Spring	8.0	7.3	1.8	0.073	1.00	148.2	11.4	4.87	39.33	0.027	0.031	0.065	0.048
	Summer	7.8	9.6	1.6	0.085	0.78	161.8	9.9	4.44	38.82	0.016	0.035	0.042	0.053
	Autumn	7.9	10.7	2.1	0.058	0.81	160.7	7.2	4.52	38.78	0.011	0.050	0.010	0.058
	Winter	8.0	6.6	3.0	0.069	1.72	143.6	10.4	4.60	38.82	0.008	0.073	0.068	0.083

Table 7. Microbiological analyses of water samples in a different location in 2019, 2020 and 2021.

Location	Season	2019			2020			2021		
		Total Col.	Fecal Col.	Aerob Mez.	Total Col.	Fecal Col.	Aerob Mez.	Total Col.	Fecal Col.	Aerob Mez.
Lumbardh	Spring	218	183	127	240	212	64	162	133	56
	Summer	260	203	120	301	284	77	235	195	63
	Autumn	190	179	79	265	251	53	219	196	56
	Winter	162	146	108	178	165	33	141	118	59
Channel derivatives	Spring	206	173	111	152	127	54	154	127	52
	Summer	257	197	105	253	208	71	203	166	64
	Autumn	187	170	75	208	167	51	198	156	62
	Winter	149	134	96	146	112	28	133	107	64
Radoniq Lake	Spring	121	111	59	112	116	29	116	68	37
	Summer	156	148	64	187	176	44	174	114	55
	Autumn	132	120	51	178	146	25	180	129	46
	Winter	101	82	29	117	102	15	106	91	51

Principal component analysis (PCA)

The principal component analysis (PCA) reveals a relationship between the studied physicochemical and bacteriological parameters (Fig. 2).

During the spring (Fig. 2a), the highest correlation was found among several physical and chemical variables that have an impact on the increasing aerobe mesophile, total coliforms, and fecal coliforms, such as NO^{2-}, Mn, turbidity, PO_4^{3-}, and Fe, while NH_3 had a low correlation. Figure 1b depicts the results of the summer experiment. In the summer is found that aerobes and mesophiles respond favorably to CODMn, Cl^-, NO^{2-}, pH, Mn, PO_4^{3-}, Fe, and NTU. While dissolved O_2, conductivity, and NH_3 positively correlated with fecal and total coliforms. The results in the autumn season (Fig. 2c) are like those in the summer. In contrast to the summer, mesophilic aerobics correlated positively with Mn, PO_4^{3-}, Fe, and pH. The positive correlation between conductivity and dissolved oxygen persists in the autumn. Fecal coliforms had a positive correlation with CODMn, NH_3, and Cl^-.

When the results from the winter and spring seasons are compared, Figure 2d shows more similarity. Aerobic mesophiles, fecal coliforms, and total coliforms correlate positively with Mn, Fe, NTU, NO^{2-}, and pH and negatively with PO_4^{3-}.

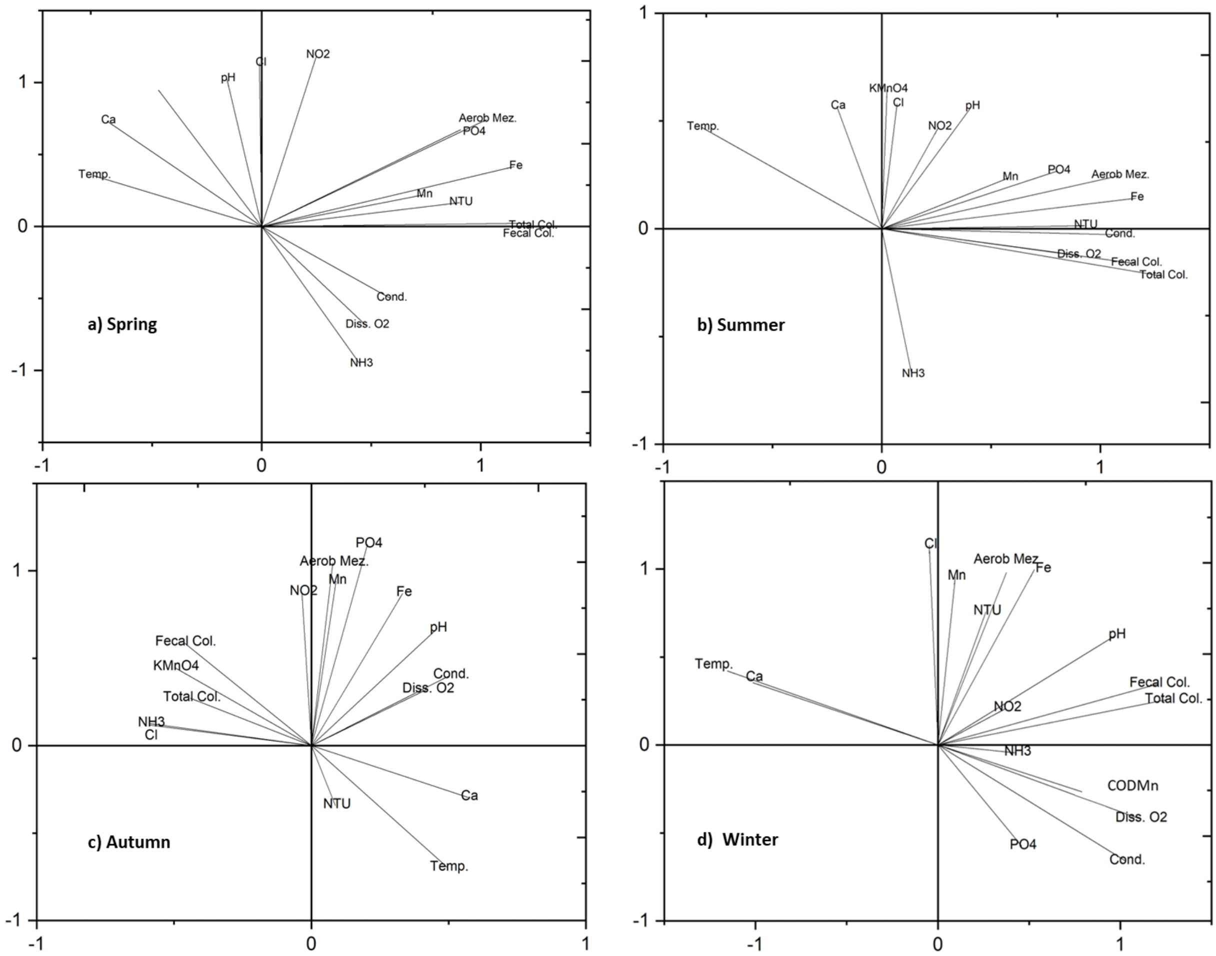

Fig. 2. PCA biplot distribution analysis based on the dominant biological species concerning physicochemical data over 36 months separated by seasons. a) Spring; b) Summer; c) Autumn; d) Winter.

The results show the highest positive correlation among many physicochemical variables, such as pH, Mn, Cl^-, NO_2^-, PO_4^{3-}, and Fe, that play a role in the increasing fecal coli, total coli, and aerobe mesophiles.

Water Quality Index (WQI)

Based on the water quality index for each site-sampling, suggest that the water quality is medium, as shown in Table 8. Similar WQI values for water quality are presented in Bytyçi et al. (2018) research in the Lepenc river basin.

According to the Water Framework Directive (European Commision, 2000), total coliforms and fecal coliforms are in the first category in all site-sampling, comparable levels of fecal coliforms have been found in surface waters intended for drinking in Bardovci Lake (Kashtanjeva et al., 2023). Water falls into the first category based on the average values of dissolved oxygen, chloride, and ammonium ions in all points measured according to the GD 161 standard. The presence of NO_2 in the S1 point in 2019 belongs to the third category, while in 2020 it belongs to the second category and in 2021 it belongs to the first category. In the S2 and S3 points in 2019 and 2020, it belongs to the second category, and in 2021 it belongs to the first category of water quality, the first quality category and the similar values of NO_2 are also found in the river Klina (Bytyçi et al., 2022).

According to the Water Framework Directive (European Commision, 2000), manganese values found in the S1 point in 2019 and 2021 classify the water in the second category, while in 2020 they classify it in the first category; likewise, the S3 point is classified as monitors and the second point in 2020 and 2021. The values of iron and $KMnO_4$ at all points during the three years of water fall into the first category. Based on the GD 161 water standard, phosphates at the S1 point during 2019 belong to the third category, while during 2020 and 2021 they belong to the second category. During the years 2019 and 2021, the water belongs to the third category in the S2 point, while during the year 2021, the water belongs to the second category. At the S3 point during the year 2019, the water belongs to the first category, 2020 to the third category, and 2021 to the second category.

Based on the total value of the water quality index according to this research, where the water belongs to the medium category, such a problem in the medium category has also been presented in other research in Kosovo (Bytyçi et al., 2018; Luzha et al., 2023).

Table 8. Water quality classification by WQI.

Years/Sample	S1	S2	S3
2019	51	52	56
2020	53	54	55
2021	50	50	55
Average	**51.3**	**52**	**55.3**

Conclusions

The water quality index has helped to classify and characterize the waters in our study area. According to the findings, the samples analyzed for three years in a row are safe for drinking purposes based on the European Standard Directive 2014/101/EU for surface water (Commission, 2014). Apart from a few parameters, most detected parameters did not exceed the values set by the Ministry of Environment and Spatial Planning; however, appropriate treatments are required to deal with the disturbing parameters.

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