Spatial-temporal investigation of water quality and pollution of Sirvan River (Sanandaj-Kurdistan)

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Abstract

Gaveh-rood and Gheshlagh Rivers are the main branches of the Sirvan River. Zhaveh dam was built on this river, with the purpose of use in agriculture and industry. Determine the water quality and water pollution in the Sirvan River and predicting the trophic conditions of the Zhaveh Dam reservoir are important goals of this study before the operation phase of the dam. Sampling was done at 5 selected stations of surface water in the branches of the Gheshlagh and Gaveh-rood Rivers, as well as the reservoir of Zhaveh Dam location. In this study, 27 water quality parameters (such as physical variables, hardness, alkalinity, nutrient, and sulfate) were investigated. Comparing the data of the current research with different standards showed that only the nitrate was within the permissible limit, but other parameters from one to several times (especially organic nitrogen) exceeded the permissible limit, which indicates that the water is polluted and has bad quality in different stations (especially in stations 2 and 3 in Gheshlagh branch). Based on the classification of the Iran water quality index (IRWQI) and the Comprehensive Water Pollution Index (CPI), all sampling stations (except the upstream of Gheshlagh River, Station 1) were classified in the "very bad" group (class V) and severely polluted (CPI=2.01) classes, respectively. Based on the values of TN and TP, the area was classified as a hypertrophic condition. Therefore, it is recommended to improve the water quality of the river to reduce adverse effects and promote sustainable use of water sources.

Keywords: Water quality index, Pollution index, Trophic state, Sirvan River, Kurdistan

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Introduction

Rivers are essential natural resource that support economic and social development. Rivers and streams have been exploited to a large extent to provide water for human consumption, livestock drinking, aquaculture, irrigation, industries, transportation, recreation and many other purposes (Barakat *et al.*, 2016). Despite these crucial ecology services provided, rivers and streams are continuously exposed to pollution from various anthropogenic and natural sources, which include rural, urban, industrial, agricultural, sewage, municipal and domestic waste (Mustapha *et al.*, 2013; Oketola *et al.*, 2013). As a result, organic matter, nutrients, trace metals and potentially hazardous substances are introduced into the river systems, causing deterioration of river water quality.

Zhaveh Dam is located 15 km from Sanandaj city in Kurdistan province (Mashanir, 2018). The water of this dam is supplied from the two main branches of Gheshlagh and Gaven-rood Rivers, which feed into the Sirvan River. Gheshlagh and Gaveh-rood rivers and its tributaries pass through the city of Sanandaj and agricultural lands, respectively. For the purposes of dam dewatering in the future, the water quality and trophic state of the dam are important for sustainable and optimum use. Studies on the quality of water and sediments play important roles in the evaluation of the amount and the history of chemical pollution in aquatic ecosystems. The introduction of additional load of nutrients, especially phosphorus, leads to increase in algal growth and eutrophication. Based on two water quality indices, Jafari Salim *et al.* (2009) reported that the effluent of the Sanandaj sewage treatment plant has the worst quality for agricultural uses, which also impacted the downstream stations. Besides this, Minoei *et al.* (2009) observed an increase of nitrogen elements in the form of NO_3 and chlorine in the Sirvan River under the influence of agricultural activities and sewage discharge. On the other hand, in the studies of Amani *et al.* (2011) and Karimian *et al.* (2020), the water quality of Garan River (another tributary in the Sirvan River basin) was reported in medium to good condition in different months of the year. These findings subsequently led to the evaluation of Garan River water as suitable for agricultural and industrial activities, even as drinking water after proper water treatment.

In view of the important roles play by the Sirvan River in the area, this study aimed to investigate the spatial-temporal changes in water environmental parameters, which led to the formation of indices of water quality (WQIIR) and water pollution (CPI). The project subsequently compared the obtained water environmental parameters with national and global standards and made prediction on the phenomenon of eutrophication in the reservoir of the Zhaveh Dam.

Material and methods

The map of the geographic location of the sampling stations of Zhaveh Dam tributaries (in Sanandaj –Kurdistan province) is shown in Fig. 1. The seasonal sampling was done from the fall of 2020 to the summer of 2021 at 5 selected sampling stations. The methods of sampling and laboratory analysis of parameters are given in Table 1.

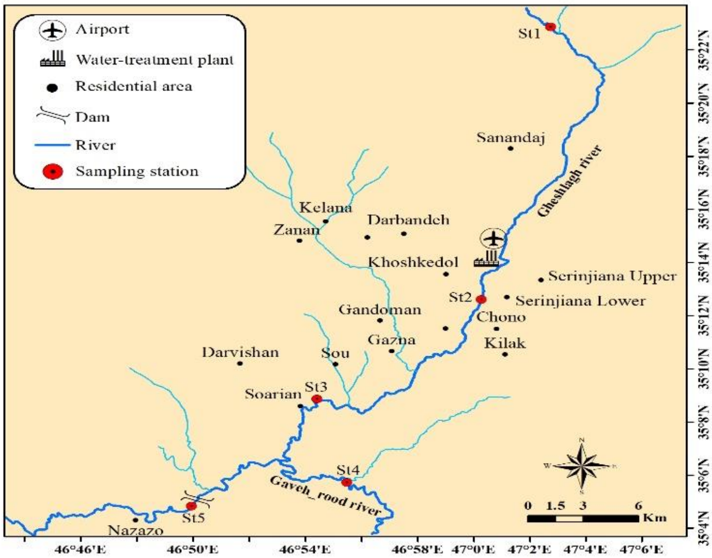


Figure 1: The location of sampling stations in the Sirvan River from fall of 2020 to summer 2021 (Sanandaj-Kurdistan).

Table 1: Equipment and methods of sampling and laboratory analysis of parameters, in the Sirvan River.

Environmental Parameters	Equipment	Methodology (References)
Water and Weather Temp.	Thermometers	-
pH	WTW 320(pH meter)	-
Dissolved Oxygen (DO)	Winkler Bottle	APHA, 2017
Biological Oxygen Demand (BOD5)	Winkler Bottle, Incubator	5-Day BOD Test; 5210D (APHA, 2017)
Chemical Oxygen Demand (COD)	Spectrophotometry (Cecil 1010)	5220D (APHA, 2017)
Turbidity (NTU)	Turbidity meter (AQUALYTIC, AL450T)	Optical beam refraction method
Total Suspended Solid (TSS)	TE313S Sartorius	2540D (APHA, 2017)
Electoconductivity (EC)	EC meter, (WTW3110)	4500E (APHA, 2017
Total Hardness (TH)	Titration	2340C (APHA, 2017)
Calcium Hardness (Ca^{2+})	Titration	2340C (APHA, 2017)
Magnesium Hardness (Mg^{2+})	Calculated	-
Chloride (Cl^-)	Titration	4000,4500B (APHA, 2017)
Sulfate (SO_4^{2-})	Titration	4500E (APHA, 2017)
NH_4+/N	Spectrophotometry (Cecil 1010)	(Indophenol) (APHA, 2017 ; Sapozhnikov *et al*., 1988)
NH_3	Calculated	Walker Method
NO_2-/N	Spectrophotometry (Cecil 1010)	APHA, 2017 (4500B)
NO_3-/N	Spectrophotometry (Cecil 1010)	APHA, 2017(4500E)

Table 1 (continued):

Environmental Parameters	Equipment	Methodology (References)
DIN/N	Calculated	(Yurkovskis, 2004), DIN = (NH_{4+})+ (NO_{2-})+ (NO_{3-})
DON/N	Calculated	(Yurkovskis, 2004), DON=TN-DIN
TN/N	Spectrophotometry (Cecil 1010)	APHA, 2017
PO4/P	Spectrophotometry (Cecil 1010)	APHA, 2017
DOP/P	Calculated	DOP=TP-DIP (Yurkovskis, 2004)
TP/P	Spectrophotometry (Cecil 1010)	APHA, 2017

Iran Surface Water Quality Index (WQIIR) and Single Factor Evaluation Index (SFEI), Comprehensive Pollution Index (CPI)

WQIIR: The calculation of this index was performed by equation 1 (DEI, 2016):

WQI=ΣwiQi   Equation 1

Wi, The weight of each factor (0-1); Qi, The number obtained from the quality index curves (0-100)

The obtained result of equation 1 is used to classify the water quality based on the definition in Table 2.

Table 2: Values of WQIIR, CPI, and classification and description of river water quality.

Quality condition	CPI	Quality status	WQIIR
Clean	0.0-0.20	Very bad	<15
Sub clean	0.20-0.40	Bad	15.0-29.9
Slightly polluted	0.41-1.00	Slightly Bad	30.0-44.9
Medium polluted	1.01-2.00	Moderate	45.0-55.0
Heavily polluted	2.01≥	Slightly Good	55.1-70.0
		Good	70.1-85.0
		Very Good	>85

SFEI: The index was calculated with equation 2:

SFEI= Mi/Si   Equation 2

Where "PI" stands for a single evaluation factor for each water quality parameter; "Mi" represents the measured concentration of each parameter, and "Si" stands for the corresponding max. permissible standards for surface water. The result is interpreted as follows: when the value of PI<1, the water quality meets the surface water quality standards. On the other hand, If the value of PI>1, it indicates that the water quality exceeded the standards; hence, the water is polluted (Yan *et al.*, 2015).

CPI: Equation number 3, was used for the determination of the CPI:

$$1/n \sum_{i=1}^{n} Mi/Si$$ Equation 3

Where; "CPI" is a comprehensive water pollution index, "Mi" represents the measured concentration of each parameter; "Si" is environmental quality standards for surface water; "n" denotes the total number of parameters. Based on the computed value of CPI, the water quality can be classified into five categories (Yan *et al.*, 2015) as shown in Table 2.

Data analysis was done in SPSS statistical programs version 11.5. The data was transferred based on the ranking process and then its normality was confirmed by the Shapiro-Wilk test and Q-Q graph drawing (Nasiri, 2009). The normalized data were used in the parametric tests (Pearson correlation, ANOVA).

Results

The changes in weather and air temperature (˚C) at different stations and seasons of the catchment area of Zhaveh Dam were recorded as 7.00-25.50 and 5.00-29.50, respectively. The minimum and maximum turbidity (NTU) and total suspended solid (g/L) were 2.85-2.6 and 0.001-0.171, respectively (Fig. 2).

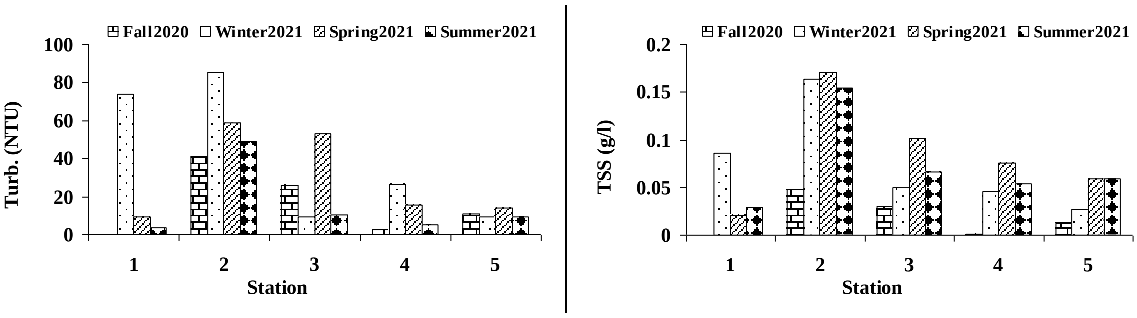


Figure 2: Spatial-temporal changes of Turbidity (NTU) and Total suspended solids (mg/L) in the Sirvan River -Sanandaj (2020-2021).

Changes in the concentration of dissolved oxygen (DO), oxygen saturation (DO%), biochemical oxygen demand (BOD5), and chemical oxygen demand (COD) (mg/L) in different stations and seasons, respectively were equal to 9.96 -3.60, 39-108, 2.76-27.35 and 15-178 (Fig. 3).

The mean concentration of SO_4^{2-} and total hardness (TH, mg $CaCO_3$/L) were recorded at 23.5±1.5mg/L, and 281±0.14mg/L respectively. The mean concentration of Ca^{2+}, $Mg^{2+,}$ and Ca/Mg were 14.5±3.5, 5.02±0.91, and 19±4 (mg/L), respectively. Changes in electrical conductivity (EC) (ms/cm), chloride (Cl^-) (mg/L), mean EC, and Cl^- respectively were equal to 638.5±27.5 and 57.4±3.2 at the station and different seasons (Fig. 4).

Mean values of TP, PO_4, and $P_{org.}$ were observed at 2.60±0.50, 2.00±0.38, and 0.37±0.07 at different stations and seasons, respectively. The maximum value of TP and PO_4 were obtained at station 2, but the maximum value of P_{org}. was recorded at station 4 (Fig. 5).

The mean of NH_4/N, NO_2/N, and NO_3/N were 12.1±5.7, 0.39±0.15, 2.79±0.44, and 1.07±0.31, respectively. The Maximum of NH_4/N, NO_2/N, and NO_3/N was recorded at stations 2, 2, and 3, respectively. The mean value of TN/N, N_{inorg}/N, and $N_{org.}$/N were 54.5±7.5, 15.5±5.8, and 39.0±3.8, respectively. Maximum TN/N and N_{org}/N were recorded at station 3 and N_{inorg}/N at station 2 (Fig. 6).

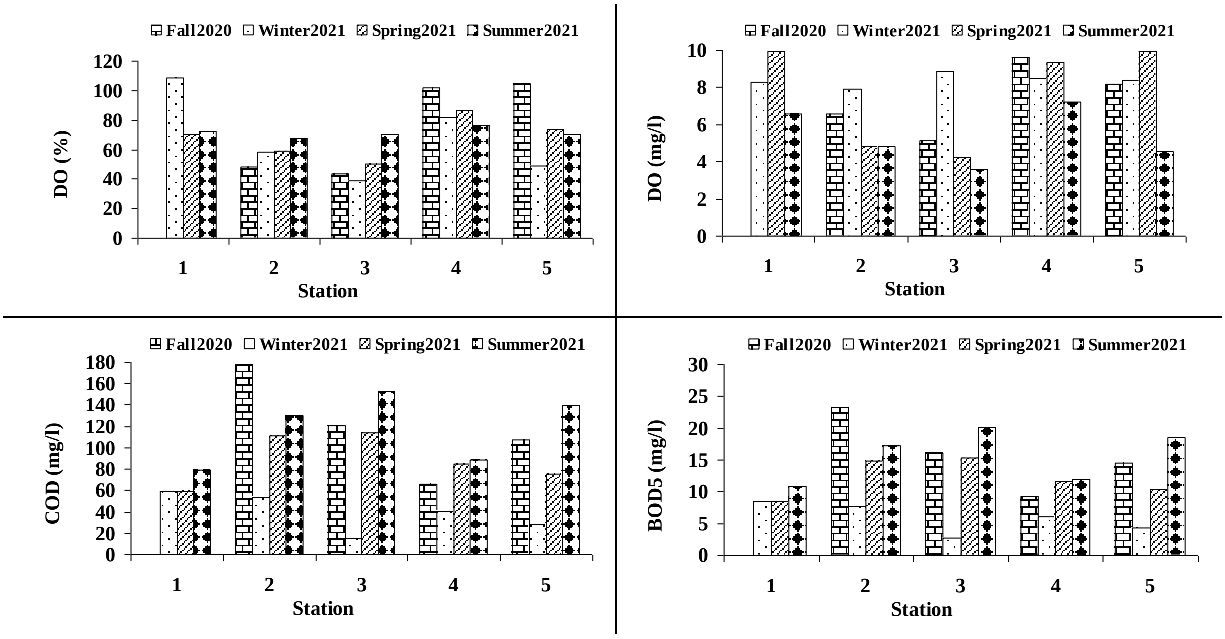
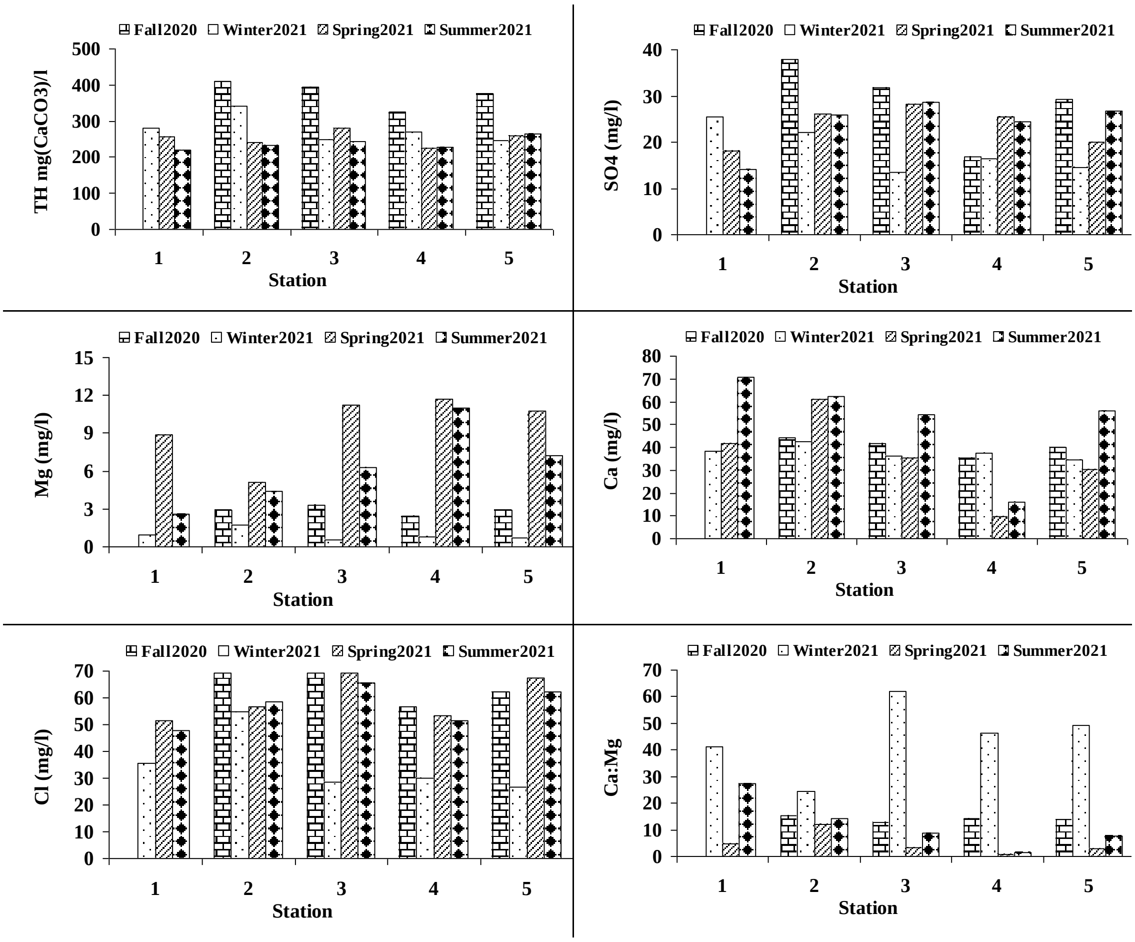


Figure 3: Spatial-temporal changes of DO (mg/L), DO%, BOD_5 and COD (mg/L) in the Sirvan River -Sanandaj (2020-2021).



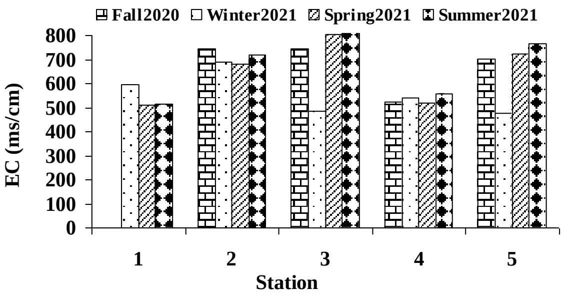


Figure 4: Spatial-temporal changes of sulfate concentration (SO_4^{2-}) (mg/L), total hardness (TH, mg $CaCO_3$/L), calcium (Ca^{2+}), magnesium (Mg^{2+}) (mg/L) and calcium and magnesium ratio (Ca:Mg), electrical conductivity (EC) and chloride (Cl^-) (mg/L) in the Sirvan River - Sanandaj (2020-2021).

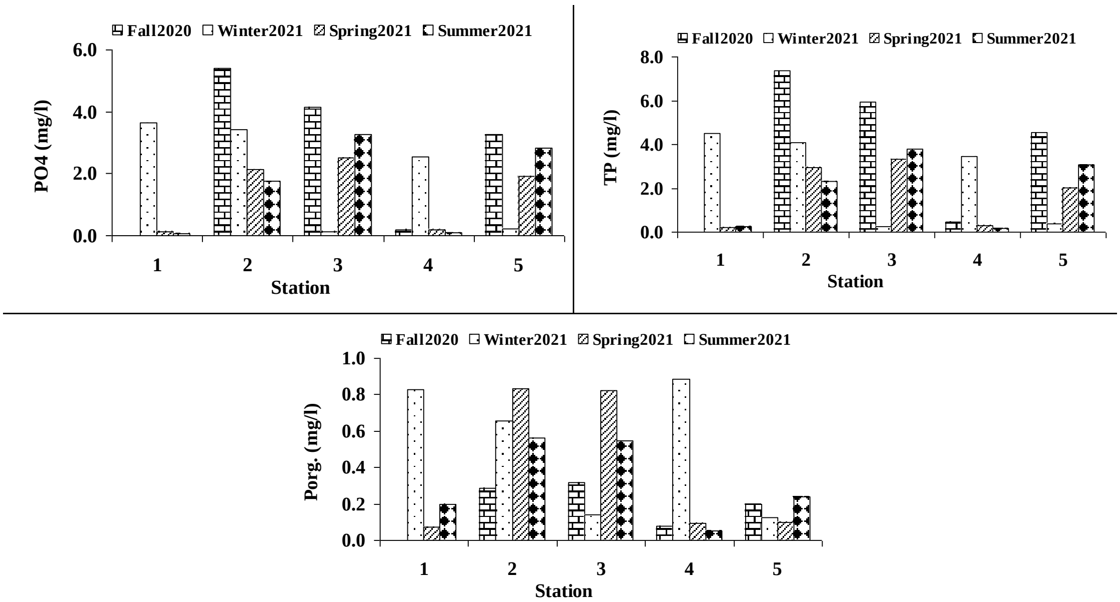
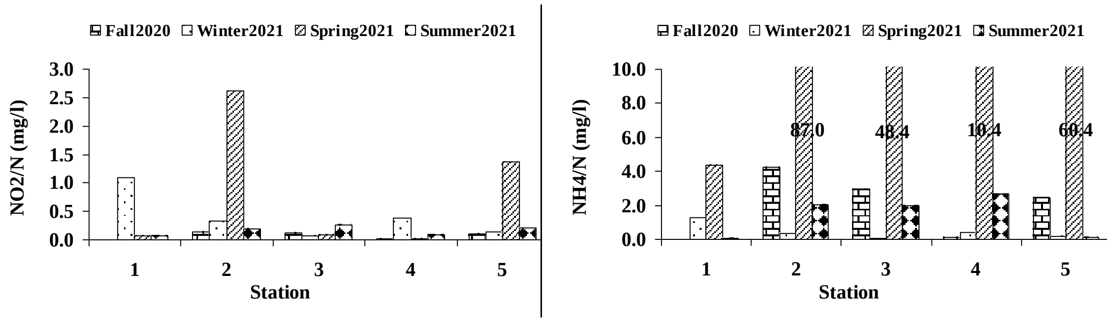


Figure 5: Spatial-temporal changes in the concentration of total phosphorus (TP), phosphate (PO_4), and organic phosphorus ($P_{org.}$) (mg/L) in the Sirvan River -Sanandaj (2020-2021).



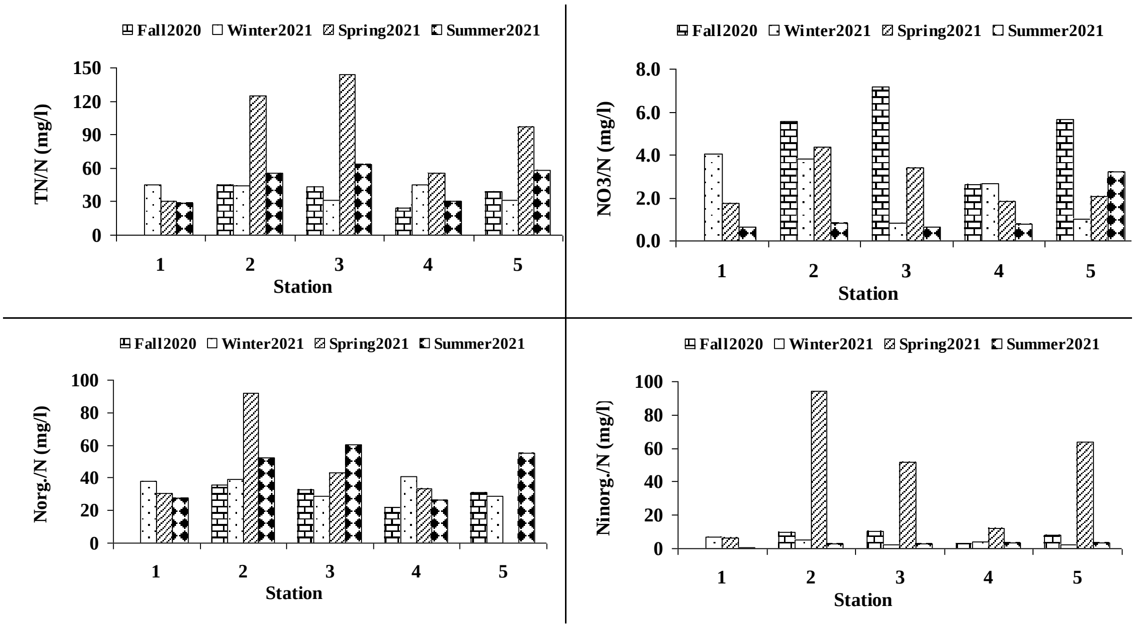


Figure 6: Spatial-temporal changes in the concentration of different forms of nitrogen (mg/L) in the Sirvan River -Sanandaj (2020-2021).

The results of WQIIR (Fig. 7) varied from 0.01-57.28 which indicated a relatively bad to slightly good classes. The lowest quality was recorded at stations 2 and 3.

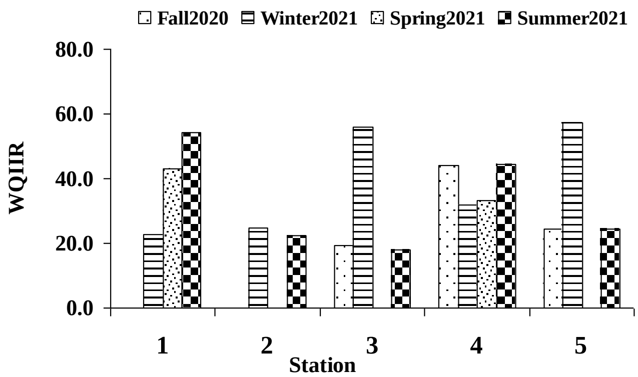


Figure 7: Spatial-temporal changes of the water quality index (WQIIR) in the Sirvan River - Sanandaj (2020-2021).

The values of the comprehensive water pollution index (CPI) and single-factor evaluation indices at different stations and seasons are shown in Tables 3 and 4. In all the sampling stations, the single-factor assessment (PI) value for most variables exceeded unity (PI>1) and the highest CPI was recorded at station 2 (CPI=32). In the fall and summer seasons, PI and CPI were lower than in winter and spring.

The Pearson correlation between parameters of WQIIR and CPI is shown in Table 5. The correlation coefficient between WQIIR, with EC parameter (0.823) and phosphate (0.726) was strong. The parameters of BOD5, COD, TSS, TP, NTU, and NH_4 showed a significant correlation with CPI, and the correlation coefficient of total phosphorus (0.801) and ammonium (0.753) parameters was strong.

Table 3: Changes in single-factor evaluation indices and comprehensive water pollution index (CPI) at different stations in the Sirvan River -Sanandaj (2020-2021).

Parameters	Mean (Median) of PI					Threshold/ Standards
	St1	St2	St3	St4	St5	
pH	8.31 (8.42)	7.91(8.00)	8.03(8.06)	8.25 (8.30)	8.27 (8.00)	6.5-9.5
TSS(mg/L)	45 (29)	134 (159)	62 (58)	44(50)	39 (43)	25
Turbidity(NTU)	30.0 (9.3)	58.6 (53.8)	24.7(18.1)	12.6 (10.3)	11.0 (10.4)	50
EC(ms/cm)	540 (530)	708 (704)	719 (774)	534 (531)	667 (712)	400
Cl^-(mg/L)	44.83(48.00)	59.73(57.50)	58.10(67.50)	47.78 52.00)	54.40(62.00)	150
DO(mg/L)	8.28 (8.28)	6.03 (5.70)	5.46 (4.68)	8.67 (8.94)	7.77 (8.28)	5
BOD_5(mg/L)	9.23 (8.42)	15.78(16.08)	13.56 (15.68)	9.73 (10.43)	11.94 (12.45)	3
COD (mg/L)	66 (59)	118 (120)	100 (117)	70 (76)	88 (92)	20
TP (mg/L)	1.65 (0.26)	4.18 (3.52)	3.34 (3.57)	1.09 (0.39)	2.49 (2.54)	0.065
$PO4^{3-}$(mg/L)	1.29 (0.14)	3.18 (2.78)	2.51 (2.88)	0.76 (0.19)	2.07 (2.38)	0.10
NH_4/N(mg/L)	1.90 (1.28)	23.41 (3.13)	13.36 (2.47)	3.41 (1.58)	15.79 (1.30)	0.78
NH_3/N(mg/L)	1.41 (0.38)	1.71 (1.55)	0.50 (0.47)	0.89 (0.49)	0.91 (0.52)	0.03
NO_2/N(mg/L)	0.41 (0.07)	0.82 (0.26)	0.13 (0.10)	0.12 (0.06)	0.45 (0.17)	0.003
NO_3/N (mg/L)	2.15 (1.77)	3.64 (4.09)	3.02 (2.12)	1.99 (2.24)	2.99 (2.65)	10.2
SO_4^{2-}(mg/L)	19.2 (18.2)	28.0 (26.0)	25.6 (28.5)	20.8 (20.6)	22.6 (23.4)	429
SUM	274 (56)	478 (295)	201 (171)	112 (60)	259 (129)	
CPI	16 (4)	32 (20)	14 (12)	7 (4)	17 (9)	
Water quality class	Heavily polluted (V)	Heavily polluted (V)	Heavily polluted (V)	Heavily polluted (V)	Heavily polluted (V)	

Table 4: Changes in single-factor evaluation indices and comprehensive water pollution index (CPI) in different seasons in the Sirvan River -Sanandaj (2020-2021).

Parameters	Mean (Median) of PI					Threshold/ Standards
	Fall2020	Winter2021	Spring2021	Summer2021	Year	
pH	8.06 (8.23)	8.41 (8.43)	8.17 (8.15)	7.92(8.00)	8.15 (8.15)	6.5-9.5
TSS (mg/L)	23 (21)	74 (50)	85 (76)	72 (59)	66 (54)	25
Turbidity (NTU)	20 (19)	41 (27)	30 (16)	15 (9)	27 (14)	50
EC (ms/cm)	678 (723)	557 (539)	648 (680)	679 (7.18)	638 (680)	400
Cl^- (mg/L)	64.3 (65.5)	35.1 (30.1)	59.4 (57.0)	57.0 (58.0)	53.4 (57.0)	150
DO (mg/L)	7.38 (7.38)	8.40 (8.40	7.65 (9.36)	5.35 (4.80)	7.18 (7.92)	5
BOD_5(mg/L)	15.8 (15.3)	5.8 (6.0)	12.1 (11.6)	15.8 (17.3)	12.2 (11.6)	3
COD (mg/L)	118 (114)	39 (41)	89 (85)	118 (130)	90 (85)	20
TP (mg/L)	4.58 (5.24)	2.52 (3.44)	1.76 (2.03)	1.91 (2.24)	2.60 (2.97)	0.065
PO_4^{3-}(mg/L)	3.26 (3.71)	2.00 (2.55)	1.38 (1.93)	1.60 (1.77)	2.00 (2.13)	0.10
NH_4/N (mg/L)	2.44 (2.71)	0.46 (0.37)	42.12(48.43)	1.37 (1.97)	12.08 (2.01)	0.78
NH_3/N (mg/L)	0.061(0.053)	2.39 (2.58)	1.58 (1.04)	0.046(0.29)	1.07(0.378)	0.03
NO_2/N (mg/L)	0.094(0.105)	0.397(0.322)	0.831(0.088)	0.164(0.198)	0.368(0.132)	0.003
NO_3/N (mg/L)	5.26(5.62)	2.48(2.68)	2.69(2.07)	1.23(0.78)	2.79(2.62)	10.2
SO_4^{2-} (mg/L)	29 (31)	18 (17)	24 (26)	24 (26)	23 (26)	429
SUM	157 (177)	300 (283)	441 (224)	110 (103)	252 (156)	
CPI	12 (10)	20 (18)	29 (15)	7.4 (7.0)	17 (10)	
Water quality class	Heavily polluted (V)	Heavily polluted (V)	Heavily polluted (V)	Heavily polluted (V)	Heavily polluted (V)	

Table 5: Pearson correlation between WQIIR, CPI, and water quality parameters.

CPI			WQIIR		
Parameter	**Pearson Correlation (r)**	***p*-value**	**Parameter**	**Pearson Correlation (r)**	***p*-value**
pH	-0.132	0.591	**pH**	0.514	**0.024**
Turbidity	0.510	**0.026**	**Turbidity**	-0.528	**0.020**
TSS	0.390	**0.099**	**BOD5**	-0.652	**0.020**
EC	0.017	0.944	**COD**	-0.653	**0.002**
Cl-	0.009	0.970	**DO%**	0.369	0.120
DO	0.143	0.560	**TH**	-0.348	0.144
BOD5	0.364	0.125	**EC**	-0.823	**0.001**
COD	0.365	0.126	**DIP**	-0.726	**0.001**
TP	0.801	**0.001**	**NH_4**	-0.630	**0.004**
NH_4	0.753	**0.001**	**NO_3**	-0.552	**0.014**
NH_3	0.150	0.541	**Fecal Coli.**	-0.455	**0.050**
NO_2	0.166	0.498			
NO_3	0.194	0.426			
SO_4	0.644	**0.003**			

Discussion

Bogart *et al.* (2018), reported that water hardness and calcium-magnesium ratio for organisms (algae, macrobenthic, warm-water fishes) are 125 (mg $CaCO_3$/L) and 2.4-6.7, respectively according to the water quality standard (WQG). But based on British Colombia standard, these values are considered as 292 and 4.7-1.2, respectively. In this study, the mean total hardness and the mean ratio of calcium to magnesium in water were 281±60 and 19±16 respectively, which values were higher than the WQG and British Colombia standards. The high values of these parameters were probably due to the result of human activities. Calcium and magnesium toxicity are related to each other. The organisms in waters with low ions content are very sensitive to small increases in magnesium even without additional calcium (Bogart *et al.*, 2018).

The comparison of the mean and median of some environmental parameters in the Sirvan River with the standard values of (WQG) for the survival of freshwater organisms (BCMECCS, 2021) are shown in Table 6. The values of pH, Cl^-, NO_3/N, and SO_4 were lower than the toxicity range defined in WQG. Also, the highest pH value in this study was within the threshold range (6.5<pH<9.5) of the World Health Organization (WHO, 2017), which is acceptable for most aquatic species. However, the other parameters (especially total phosphorus) were higher than the standard values with regards to long-term and acute toxicity, which indicates unsuitable water quality.

Dissolved oxygen (DO) is often considered as a key factor for aquatic survival (Bakan *et al.*, 2010). The mean DO concentration at some sampling locations (stations 2 and 3) were lower than the standard value of the European Union (5 mg/L) (EU, 1998). It may be due to the aerobic decomposition of organic matter and respiration of aquatic organisms and chemical oxidation.

Normally, both BOD5 (biochemical oxygen demand) and COD (chemical oxygen demand) are the main parameters investigated to indicate the level of river pollution (Sawyer and McCarty, 1988) and organic pollution (Su *et al.*, 2011). The highest concentration of BOD5 and COD were recorded at stations 2 and 3, which indicated a high organic matter load to the river. The main input for organic pollutants into stations 2 and 3 includes the input of surface water of Sanandaj city, household waste, and sewage treatment line connected to the river. The high loading of organic pollutants into the river (especially at station 2) had a strong impact on the river water quality, with the water color turned black, foul-smell emission and reduced the overall aesthetic value of the river.

Table 6: Standard values of water quality (WQG) for the survival of freshwater organisms (BCMECCS, 2021).

Parameters	Chronic long-term toxicity	Short-term acute toxicity	Present study (median, mean ± SD)
pH	5.0-6.9		8.15, 8.15±0.29
Cl^-(mg/L)	150	600	57.0, 53.3±14.0
Turb.(NTU)	2-8		13.9, 27.5±25.1
TSS(mg/L)	5-25		54, 66±50
NO_3/N(mg/L)	3.0	32.8	2.62, 2.79±1.93
NO_2/N(mg/L)	0.20	0.60	0.13, 0.39±0.65
TP/P(µg/l)	5-15		2.96, 2.60±2.16
SO_4(mg/L)	429	-	25.5, 23.5±6.6

Excessive concentration of nutrients such as nitrate, ammonia, and phosphate can affect surface water quality in many ways. For example, ammonia is toxic to aquatic organisms when its concentration exceeds the permissible value. A high concentration of nitrate and phosphate in water causes eutrophication (Tanjung *et al.*, 2019). Excess phosphate in surface water causes algal blooms and eventually decreases DO in the water, which may kill fish and aquatic life (Bakan *et al.*, 2010). The maximum concentration of NO_3-N and NH_3-N was recorded at stations 2 and 3, and the lowest was recorded at upstream and downstream stations in different seasons (except winter). The highest concentrations of nitrates and ammonia can be attributed to nitrogen inputs from point sources pollution (sewage and sewage treatment plant of Sanandaj city connected to the river) and non-point sources pollution (chemical fertilizers and domestic sewage). The lowest concentration of nitrates and ammonia at stations 1, 4, and 5 in different seasons were due to low human inputs of nitrogen from non-point sources (chemical fertilizers and domestic sewage). The highest concentration of PO_4^{3-} was recorded at station 2 as well. In general, the sources of all NO_3-N and PO_4^{3-} in the river were agricultural, industrial, and domestic effluents.

Table 7 shows the threshold of permitted quality for surface water by

“The Department of Environment of Iran". Comparing the data of the present research with the standards of Table 7, showed that only the nitrate parameter was within the permissible limit, but other parameters exceeded the permissible limit (from one to several times), especially organic nitrogen. The comparison of results to the standard values indicates the water pollution of different stations.

Table 7: Standard values of parameters for surface water quality (Department of Environment of Iran, 2014).

Parameter	Standard values	Present Study
TSS (mg/L)	25	66±55, 1-171
BOD5(mg/L)	3	12.2±5.4, 2.76-23.35
COD(mg/L)	20	90±43, 15-178
TP(mg/L)	0.065	2.59±2.16, 0.15-7.35
NH_4/N(mg/L)	0.78	12.08±24.5, 0.07-87.02
NO_2/N(mg/L)	0.003	0.37±0.64, 0.01-2.62
NO_3/N(mg/L)	10.17	2.79±1.94, 0.62-7.18
DON/N(mg/L)	0.50	39±17, 22-92

A comprehensive water pollution index (CPI) and single-factor evaluation indices were used to understand the general state of river pollution and to identify the main parameters affecting pollution. The results in Table 3 show that the single-factor assessment (PI) value for most variables (9 variables) exceeded unity (PI>1) in all stations. It is indicating that the measured values far exceeded the surface water quality standards. The nutrients and organic pollution related to anthropogenic activities were believe leading to the pollution of all stations (Mishra *et al.*, 2015).

However, the PI values were less than 1 for some measured parameters such as pH, Cl^-, DO, NO_3/N and SO_4^{2-}. This indicated that the measured values were within the standards threshold of surface water (Yan *et al*., 2015) and they did not contribute to water pollution. The mean values of CPI of the water samples in the study area were between 7-32 with a mean value of 17. The CPI values in Table 3 show that the stations experienced varying levels of pollution. However, the highest CPI (32) was recorded at station 2, which indicates that the overall/accumulated water pollution was the worst at this station. Based on the classification of water quality, the obtained CPI values showed that all sampling stations were in class V.

The seasonal results of the single-factor evaluation index (PI) of nutrients have become the main cause of river pollution, and as a result, the comprehensive water pollution index (CPI) has increased. In the fall and winter seasons (wet seasons, CPI=21) compare to the dry season (spring and summer, CPI=13), the more rainfall in the region had caused the pollution load of the river to be diluted, which led to a decrease in the pollution load as expected. On the contrary, the CPI of wet seasons was more than dry seasons which was due to the flushing of the river in the raining event. The concentration of some variables, especially ammonium ions increased as a result.

A comparison of the CPI value in this study (7-29) with similar studies in Ganges River- India (Matta *et al*, 2018), and Henwal River- India (Matta *et al.*, 2020) showed that the CPI value obtained for the Sirvan River was higher than the Ganges River (CPI- 0.54-2.47) and the Henwal River (CPI =1.25-8.52). Son *et al*. (2020) reported a CPI value ranging from 0.50 to 1.57 with a mean value of 1.08 for the Cau River, which is lower than the value obtained in this study. In general, CPI index is a useful tool for water basin managers to recognize the general state of river water quality.

The changes of (WQIIR) and (CPI) indices in different seasons and stations are compared in Figure 8. In Figure 8, it was decided on whether the increase/decrease of the WQIIR was confirmed by the decrease /increase of the CPI. Figure 8 is indicating that the highest WQIIR in station 4 (Gaveh-rood branch) was accompanied by the lowest value of CPI. The lowest WQIIR and the highest CPI were recorded in station 2 (near the sewage treatment plant, at the Gheshlagh branch). Also, in the seasonal survey, the minimum WQIIR was seen along with the maximum CPI in spring. Most of the data showed that the increase in pollution index was associated with the values of physicochemical parameters out of the defined standard limits. The significant and direct correlation between CPI and physicochemical parameters (BOD_5, COD, TSS, TP, NTU, and NH_4) in Table 5 further elucidated on this point.

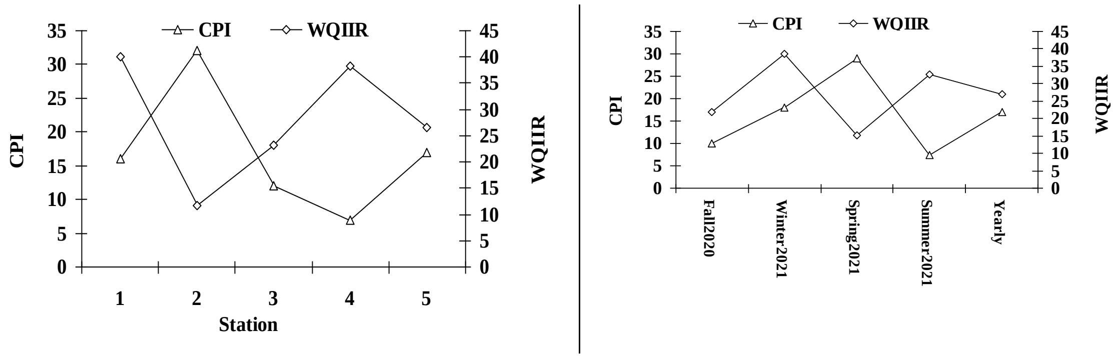


Figure 8: Spatial-temporal Changes in WQIIR and CPI of the catchment area of Zhaveh dam - Sanandaj (2020-2021).

In the report of Mashanir (2018), the concentration of TP and TN in the reservoir of Zhaveh Dam was recorded at 1.83 and 10.67 mg/l, respectively. However, in the present study, the values of TP and TN were highly increased to 2.50 and 56.47 mg/l respectively in the reservoir (station 5). Yang *et al.* (2008) classified the trophic state of the environment based on the TP and TN values. They considered the values of TP and TN in oligotrophic, mesotrophic, eutrophic and hypertrophic classes as 0.01-0.005, 0.010-0.030, 0.030-0.100 0,

>0.100 and 0.25-0.60, 0.50-1.10, 1.0-2.0, >2.0, respectively. Based on the values of TN and TP in this study, the area was classified to be in the hypertrophic condition. The tributaries of the Sirvan River are exposed to point and non-point sources (rural, urban, industrial and agricultural sewage) of pollution. Since nutrient loading, especially phosphorus (P) and nitrogen (N), are considered the main factors for eutrophication and phytoplankton growth and reproduction in the reservoir, controlling nutrient loading in river tributaries is necessary to improve the water quality of the reservoir (Yang *et al.,* 2008).

In this regard, upgrading the treatment plant and transferring the leachate to the river water has an important contribution to reduce the load of pollutants. To significantly reduce the concentration of various nitrogen and total phosphorus loadings and increase the dissolved oxygen, all the sources of point and non-point pollutants from the main tributaries (Gheshlagh and Gaveh-rood rivers) as well as the sub-tributaries receiving sewage needed to be properly managed and organized.

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