Evaluation of Water Quality and Sustainability of Treated Wastewater for Irrigation and the Municipal Uses in Karbala Province

Haneen Hussain Abbas and Saad Wali Alwan
College of Environmental Sciences/ Al-Qasim Green University/ Republic of Iraq
Corresponding author Email: saadwali.eco@environ.uoqasim.edu.iq

DOI: https://doi.org/10.36077/kjas/2024/v16i2.11405

Received date: 2 / 3 /2023
Accepted date: 29 / 4 /2023

Abstract

This study was conducted to assess the quality of treated wastewater from the wastewater treatment project in Karbala. and its reuse for irrigation and municipal by Canadian Water Quality Index (CWQI). Samples were collected periodically with three replications from (Dec. 2021 –Jul.2022). The results showed that the water was characterized by high salinity, TDS, TSS, total hardness, EC, and turbidity, which were recorded at 2039 -3739 mg/l; 1030-2640; 30-48 mg.L^{-1}. 3740 -2040 µs/cm and 3.17 -8.5 NTU respectively, major cations and anions (Cl$^-$, PO$_4^{-3}$, NO$_3^-$, S$_2$O$_4^{-2}$ and K$^+$) exceed significantly to (57-380; 0.003-4.99; 8.63-44.25; 453-1340; 4.537) mg. L^{-1}, sodicity index (SAR, Na$^+$ and Sodium percentage ratio) and magnesium hazard, were detected 0.59 – 4.89; 138-447.5 12.98-43.76), Water can be classed depending on that as a permit to good. However, it's categorized as marginal-fair according to the CCME Water quality index, especially in the far station from the plant water. Principal Component Analysis (PCA) showed depending on its effect on the value of the index, where the first group PCA1 recorded the largest proportion (35.26%) and includes dissolved solids, EC, salinity, Na, SAR, Na%, alkalinity, SO$_4$, pH, DO, BOD$_5$ Mg risk of magnesium. The second group, PCA2, with the lowest percentage (18.78%), was represented by temperature, Ca^{+2}, total hardness, K, Cl, PO$_4$, NO$_3$, TSS, and turbidity. This water is a wealth that can be exploited in the cultivation of the desert adjacent to Karbala governorate, and by adopting different methods to reduce the effect of salinity.

Keywords: CCME Water quality index, physical-chemical properties, treated wastewater.

Introduction

Sustainable water resource management and exploitation of all available resources are required to deal with water scarcity. Treated wastewater (TWW) reuse is an important solution that has been employed in a wide range of agricultural, industrial, and recreational purposes around the world, especially in arid and semiarid regions. In the United Arab Emirates TWW is used for landscaping and watering public parks, green areas, and forests (9). Moreover, it can be used in private gardens, roadsides ,and sports facilities; street cleaning; fire protection systems; car wash; toilet cleaning; air conditioners; dust control. Commercially unprocessed food crops; commercially processed food crops; pasture for milking animals. Lining. Orchard ornamental flowers. Hydroponics; greenhouses. Industrial applications such as water treatment; cooling water; recycled concrete cooling towers. Environmental uses include groundwater recharge; wetlands; swamps. Over stream and wildlife habitat (19).

The different uses of TWW led to positive and negative impacts on the environment. The soil gets important macronutrients and micronutrients when irrigating with wastewater (30). Preventing wastewater discharge into water bodies and avoiding water pollution with fertilizers by reducing the use of mineral fertilizers in agriculture decreases water pollution and preserves the quality of freshwater resources (36). However, the presence of salts (cations and anions) in irrigated wastewater can lead to temporary and permanent salinization the soil. High soil salinity reduces agricultural productivity by reducing plant water consumption and

Modifying plant physiology and morphology (25).

Water quality assessment includes several characteristics that can cause varying strains on overall water quality, over the last 40 years, various water quality indexes have been established (22). Water quality indices are tools for determining water quality conditions and, like any other tool, need an understanding of water principles and basic concepts (28). The Water Quality Index (WQI) was proposed by the Canadian Council of Ministers of the Environment (CCME) to simplify the reporting of water quality data (14). The CCME WQI provides a mathematical framework for comparing ambient water quality to water quality objectives, Consequently, WQI is a beneficial and useful approach for researchers and decision-makers to monitor and evaluate the quality of treated wastewater for any purpose (27).

In Iraq, treated wastewater has not been widely investigated and evaluated. Therefore, the current study aims to analyze the treated wastewater produced by the Karbala wastewater treatment plant and assess its suitability as a non-conventional water resource for irrigation and other purposes by determination of water physicochemical quality parameters, such as (Temperature, pH, EC, Salinity, DO, BOD_5, Turbidity, TDS, water TSS Total Alkalinity, Total Hardness, Calcium, Magnesium, Magnesium Hazard, Sodium, SAR, Na %, Potassium, Phosphate, Nitrate, Sulfates, and Chlorides), and the classification of treated wastewater quality based on the Canadian model CCME-WQI.

Materials and Methods

Description of the Study Area

The Karbala wastewater treatment plant was established on an area of 400 acres on 2019, it is located on the Karbala-Najaf Road, 32.539° N, 44.08237° E, St.1: 32°33'46.6"N 44°05'57.5"E, St.2: 32°32'45.6"N 44°06'44.6"E, St.3: 32°32'11.5"N 44°07'13.8" E). This project consists of four units of treatment plants with a capacity of $400{,}000\ \mathrm{m}^3/\mathrm{day}$, the treated effluent is released on a discharge channel of 20 km long. Three stations were chosen to carry out this study along the effluent drainage canal. The first St.1 was positioned at the beginning of the drainage, St.2 was located in the middle of the waterway, and St.3 was located at the end of the drainage. Figure 1.

Sampling and Methodology

Samples were collected monthly from the three stations from (December 2021 to July 2022) using clean five-liter polyethylene containers (11). Temperature, pH, EC, DO, and total dissolved solids were measured in the field with a multifunction water quality tester (EZ-9908 YINMIK), and salinity was measured in terms of electrical conductivity (17). Magnesium hazard, SAR, and Sodium percentage ratio Na% were calculated according to Szabolcs (35); Wilcox, (39); Sadashivaiah *et al.*, (32). Other parameters were total hardness, BOD_5, chloride, Turbidity, Nitrate, TSS, calcium, and magnesium ion, alkalinity, sulfate, nitrate, sodium, potassium, and phosphate determined according to the standard protocols (11). The Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) depends three measures of variation, scope (F1) represents the proportion of variables that have values do not match with

The criteria set for the model (failed variables) are calculated according to the following equation:

$$\mathrm{F1} = \frac{\text{No.of failed variables}}{\text{Total No.of variables!}} x100 \qquad (1)$$

Frequency (F2) is the percentage of failed tests to the total data of the variables studied.

$$\mathrm{F2} = \frac{\text{No.of failed testes}}{\text{Total No.of tests!}} x100 \qquad (2)$$

Amplitude (F3) is the ratio of the collective number of failed tests whose values do not meet standards quality, F3 is calculated by a formula that scales the (nse) to yield a range between 0 and 100. (nse) is the ratio of the sum of excursions for individual tests to the total number of tests

The excursion is the relative deviation of a failed test from the water quality standard. It is calculated in three steps:

When the test must exceed the water quality standard, it is calculated using Eq. (3).

When the test is not below the standards, it is calculated using Eq. (4).

$$Excursion = \frac{Failed\ tests\ value}{Objective} - 1 \qquad (3)$$

$$Excursion = \frac{Objective}{Failed\ tests\ value} - 1 \qquad (4)$$

$$nse = \frac{\sum_{n=1}^{n} \text{Excrusion}}{Number\ of\ testes} \qquad (5)$$

$$\mathrm{F3} = \frac{\mathrm{nse}}{0.01\mathrm{nse}+0.01} x1 \quad (6)$$

$$\mathrm{CCME\ WQI} = 100 - \left(\frac{\sqrt{\mathrm{F1}^2+\mathrm{F2}^2+\mathrm{F3}^2}}{1.732}\right) \quad (7)$$

The sum of these three variance values yields a number between 0 and 100 that represents the overall quality of the water. The index classification schema shown in Table (1) is then used to convert the CCME WQI values into classes (14).

Statistical Analysis

The blocked design was used to evaluate current data by finding significant variations in LSD values between stations and months at a significance level of P = 0.05 in order to compare the results obtained from different samples. In statistical analysis, both SPSS.Version.16 statistical analysis software and Microsoft Excel software were utilized.

The program (XLSTATE 2015) was also utilized, as it was adopted to conduct a Principal Component Analysis (PCA Analysis) for the purpose of identifying the physical, and chemical variables (which were applied in the calculation of the water quality index (WQI)) that had the greatest impact on the values of the water quality index (2).

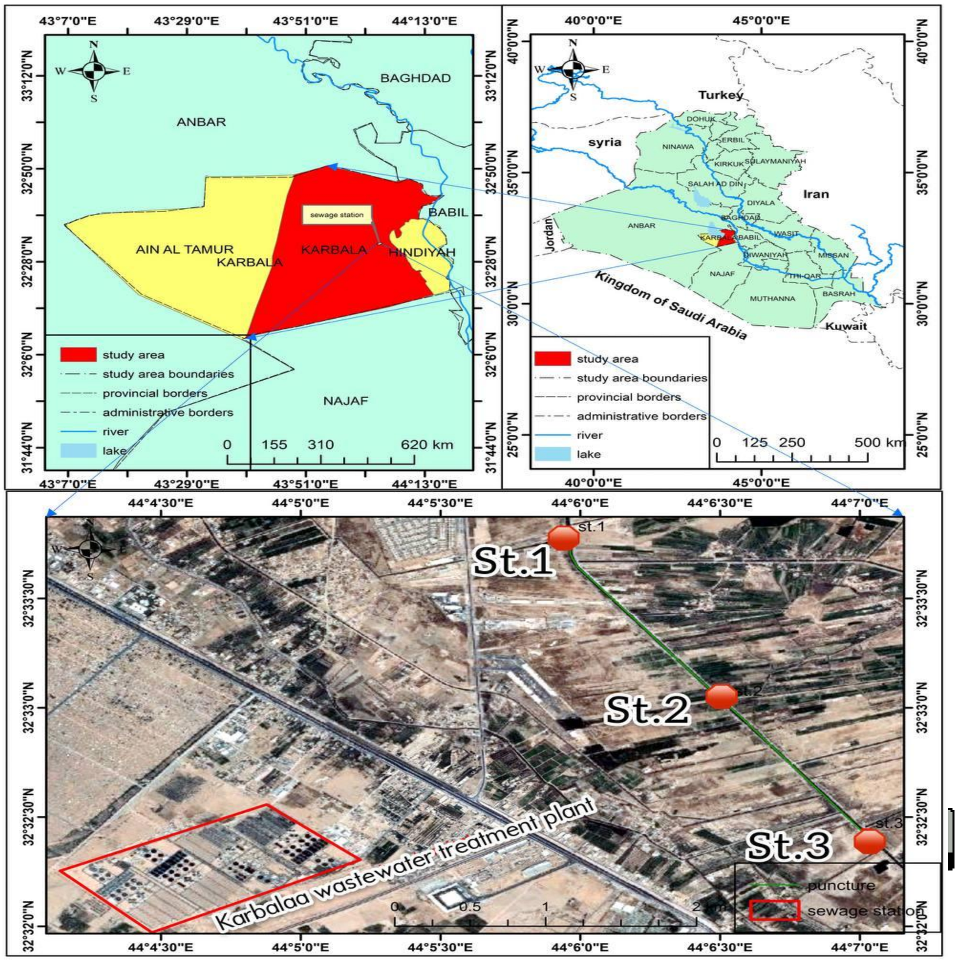

Figure 1. Map of study stations (Karbala wastewater treatment

Class	WQI	Nots
Excellent	95-100	Almost all measurements are within the acceptable level all of the time.
Good	80-94	Measurements rarely deviate from acceptable levels.
Fair	65-79	Measurements sometimes deviate from acceptable levels.
Marginal	45-64	Measurements often deviate from acceptable levels.
Poor	0-44	Usually, measurements deviate from their acceptable levels.

Results and Discussion

Water Quality Parameters

The temperature value ranged from 10 °C in January at St.3 to 28 °C in July at St.1. The statistical analysis revealed that there are monthly variations in the temperature caused by climatic conditions (10), while no significant difference was found among Stations, this could be related to the nearby location of the stations and the water's high heat capacity (33).

The results of salinity measurement in the three sites showed that the highest concentration was 3739mg/l at the beginning of the drainage channel in the first site, while the lowest concentration 2039 mg/l was recorded in the third site. So, this data differed statistically among stations and the months, which indicates that the effluent water content is very high from the salts that were not treated inside the plant and the source of these salts is soap and detergents (24).

The EC values ranged from 2040 µs/cm in January at St.3 to 3740 µs/cm in May at St.1. EC exceeds the Iraqi standard limit of 2250; this is because wastewater effluent includes significant levels of dissolved salts due to poor treatment or due to the disposal of other sewage in the discharge channel. In the current study, turbidity levels were evaluated from 3.17 NTU in December 2021 at St.3 to 8.5 NTU in July 2022

At St.1. Sediments are transported together with the water flow because of the high-water velocity, and the high concentrations of organic and inorganic debris, dust particles, sand, and microorganisms in the wastewater effluent, both of which contribute to the turbidity of the water (21).

TSS value ranged between 30 mg/L at St.3 in December 2021 to 84 mg/L at St.1 in July 2022. The TSS value exceeds the Iraqi standard limit at all study stations, This may be either due to the inefficiency of sedimentation basins in removing suspended matter or to increase the activity of organisms, or it may be due to the overgrowth of zooplankton and phytoplankton (6).

TDS concentrations measured ranged between 1030 $mg.L^{-1}$ in December 2021 at St.1, and 2640 $mg.L^{-1}$ in May 2022 at St.1. The majority of the total dissolved solids readings surpassed the allowed threshold of 1500 mg/L set by Iraqi and Canadian model standards. An increase in dissolved solids values was observed during the winter season due to the dredging of large quantities of salts from agricultural lands with rainwater to the drainage channel, the data also indicated an increase during the summer months, which could be related to the higher solubility of salts and evaporation rates caused by the elevated temperature (3).

Total hardness varied from 900 mg/L in January at St.3 to 1353 mg/L in June at St.1, hardness is one of the natural properties of water and is a measure of calcium and magnesium ions in water, and sometimes iron, manganese, and aluminum ions are the ones that increase total hardness, the concentration of Calcium and magnesium ions changes in the water due to the composition of the soil and rocks that the water flows through (26). Calcium levels ranged between 185 mg/L in December 2021 at St.3 to 409 mg/L in July 2022 at St.1, while Magnesium levels ranged from 32.72 mg/L in January at St.3 to 136 mg/L in July at St.1.

There is no significant difference of pH data across stations, while seasonal variations reveal significant differences. The readings varied from 7 at St.1 in July to 7.76 at St.3 in February. The minor increase in pH could be the result of an increase in the photosynthetic activities of aquatic plants and algae, which results in a reduction of carbon dioxide and, thus, an increase in pH (20), While the rise in carbon dioxide concentration in wastewater caused by the biodegradation of organic matter results in an increase in acidity and a corresponding decrease in pH value (4).

Alkalinity values differ from 160 mg/L in July 2022 at St.3 to 250 mg/L in December 2021 at St.1, Natural waters generally tend to be alkaline due to the abundance of carbonate and bicarbonate ions (26). The wastewater also contains bicarbonates and large quantities of phosphates that increase the alkalinity (11).

Chloride concentration increased from 57 mg/L in December 2021 at St.3 to 380 mg/L in July 2022 at St.1. Chloride salts are more available in water than other salts due to their easy solubility and the difficulties of chloride adsorption on the surfaces of natural minerals, industrial waste, cleaning products, and organic waste are key sources of chloride ions in surface water (38).

The lowest PO4 $^{-3}$ value (0.003) was recorded in January at St.3 and the highest was recorded in July at St.1 (4.99 mg/L). Wastewater includes a high concentration of phosphates due to the presence of phosphate-rich detergents, which enhance the concentration of phosphates in the drainage channel, in addition to the decomposition of waste and organic materials containing phosphorus (23).

NO^{3-} levels varied from 8.63 mg/L in May 2022 at St.3 to 44.25 mg/L in December 2021 at St.1, when the concentration of nitrates and phosphates increases, it leads to eutrophication, which has severe consequences on aquatic habitats and the creatures that inhabit them (7).

SO_4^{-2} values ranged from 453 mg/L in December 2021 at St.3 to 1340 mg/L in July 2022 at St.1, Sulfates are among the components that produce salinity and permanent hardness (34). Increased sulfate ion concentration could contribute to the erosion of rocks, soils, and agriculture activities, in addition to the role of liquid waste including detergents and washing powders that are rich with sulfur ions (37).

The maximum value of magnesium hazard was recorded at St.1 in June (35.68), and the lowest value was recorded at St.3 in February (15.65). The concentration of Magnesium Ions Hazards is calculated to determine the water's suitability for irrigation. When the magnesium hazard value exceeds 50, water becomes harmful and unsuitable (35).

K^+ concentrations vary from 4.9 mg/L at St.3 to 37 mg/L at St.1, from Dec. 2021 to May 2022, Potassium is relatively harmless, with the exception that it raises the value of dissolved solids (38).

Na^+ levels were from 33.4 $mg.L^{-1}$ at St.3 in December 2021 to 447.5 $mg.L^{-1}$ at St.1 in July 2022. Sodium is one of the micronutrients plants and algae require in trace concentrations (18), and sodium has the ability to affect the soil's permeability so affecting the free movement of water through the soil (1). The results of the current study indicated a considerable increase in sodium levels in all stations and seasons. Soluble Sodium Percentage (SPP) or Sodium Percentage (Na%) is essential in classifying water for irrigation because it interacts with the soil, leading to molecular blockage, and reducing soil permeability (15). Water can be classed as "excellent" (< 2%), "good" (2- 40%), "permit" (40-60%), "doubtful" (60-80%), or "inappropriate" (> 80%) based on the stadium percentage (39). Throughout this study, the SPP varies from (12.98 to 43.76).

The sodium adsorption ratio (SAR) is one of the most important hydrochemical parameters of irrigation water for evaluating the soil filtration problem that occurs when the sodium concentration in irrigation water exceeds the calcium plus magnesium concentration (3:1), which caused soil dispersion (13), the SAR in the study area about (0.59 – 4.89) According to the established standards, all of the sample results belong within the excellent category for irrigation purposes.

The majority of the dissolved oxygen concentrations were greater than 5 $mg.L^{-1}$, where the highest value (9.5 $mg.L^{-1}$) was recorded at St.3 in December 2021 and the lowest (5.3 mg/l) at St.1 in July 2022. Oxygen enters the aquatic systems in two main ways; dissolving oxygen from the air into the water directly (waves, turbulence, currents, etc.) or through photosynthesis in aquatic plants, movement of water flows, lower temperature, and lower salinity all increase the amount of dissolved oxygen available (31). The BOD_5 values ranged from 1.2 mg/l at St. 3 in December 2021 to 5.32 mg/l at St.1 in June 2022, Results indicated a rise in the value of BOD_5 that exceeded permitted limits during the summer season, this is due to the high concentration of organic matter in the wastewater effluent, which may be the result of inadequate treatment processes, as well as the increased activity of biodegrading microorganisms which rise oxygen demand (12).On the other hand, Abdullah *et al*., (2) found that the Euphrates River at Southeast Al-Nasiriya city is characterized as poor where (EC, TDS, TH, and Cl^-) recorded (4.27 dS m-1, 2555, 1610, 925 mg/l). However, it is for different uses such as cooling water for the Nasiriyah power station used, Municipal uses, feeding the central marshes of southern Iraq, and other uses. Finally, in order to improve the effluent water quality of the Karbala plant, it needs tertiary treatment to remove at least cationic salts, especially when used in irrigation because they contain high concentrations of macronutrients (PO_4, NO^3, SO_4 and, K^+). Furthermore, reduction of soil deterioration due to sodality effects and magnesium hazard.

Table 2. The mean and standard deviation (±) of physical and chemical parameters of water samples collected from the effluent of the Karbala wastewater treatment plan during the study period at the study stations

Parameter		December	January	February	March	April	May	June	July	LSD (0.05)
		Mean ± Standard Deviation								
Temp.	S1	14±1.2	14±2.2	12±2.2	17.2±3.2	21.3±0.7	23±0.6	26.5±1.3	28.1±2.2	LSD$_{(S)}$ =1.687 LSD$_{(M)}$=1.122 LSD$_{(S*M)}$ =1.944
	S2	11±2.2	10±0.6	10±0.6	16.9±2.2	21.8±0.6	22±0.5	26.4±1.2	27.2±3.6	
	S3	11±0.9	10±0.6	10±0.6	17.4±0.8	21.1±1.1	22±0.5	25.9±1.7	27.3±1.9	
pH	S1	7.4±0.3	7.29±0.2	7.5±0.8	7.32±0.2	7.2±0.6	7.1±0.9	7.1±0.9	7±0.4	LSD $_{(S)}$=1.518 LSD$_{(M)}$=0.845 LSD$_{(S*M)}$ =1.464
	S2	7.46±0.2	7.57±0.3	7.56±0.2	7.43±0.1	7.07±0.2	7.15±0.2	7.2±0.6	7.1±0.9	
	S3	7.56±1.1	7.65±0.5	7.76±0.2	7.55±0.6	7.5±0.3	7.3±0.3	7.3±1.1	7.35±0.9	
EC	S1	2760±7.3	2770 ±12.6	3540 ±14.2	3250±10.1	3510±22.3	3740±12.3	3470±6.6	3720±5.5	LSD $_{(S)}$=4.753 LSD$_{(M)}$=7.761 LSD$_{(S*M)}$ =13.44
	S2	2470±10.2	2600 ±15.4	2660 ±5.7	3100±9.3	3120±7.7	2770±11.4	2600±4.2	2870±3.9	
	S3	2122±11.7	2040 ±11.7	2060 ±9.3	2230±8.4	2610±5.5	2450±9.3	2420±3.3	2600±11.4	
Salinity	S1	2759±9.7	2769 ±9.8	3539 ±15.2	3249±6.4	3509 ± 8.2	3739±14.2	3469±20.3	3719±12.2	LSD $_{(S)}$=1.349 LSD$_{(M)}$=2.203 LSD$_{(S*M)}$ =3.815
	S2	2469±5.4	2599 ±11.4	2659 ±13.3	3099±3.6	3119 ±3.6	2769±17.3	2599±19.6	2869±10.7	
	S3	2121±4.4	2039±20.6	2059 ±9.2	2229±4.8	2609±16.8	2449±22.1	2419±18.7	2599±9.5	
Turb.	S1	4.62±1	5.3±1.1	5.92±0.3	6.59±0.1	6.67±0.7	6.43±0.2	7.88±0.6	8.5±0.1	LSD$_{(S)}$=0.515 LSD$_{(M)}$=0.841 LSD $_{(S*M)}$ =1.457
	S2	4.22±0.1	4.99±0.5	4.5±0.6	5.1±0.2	5.1±0.1	5.3±0.3	5.2±0.3	5.68±0.9	
	S3	3.17±0.6	4.23±0.3	4.2±0.8	4.6±0.3	4.8±0.1	4.54±0.4	4.5±0.2	5.18±0.4	
TDS	S1	1770±8.8	1980±22.1	2380±17.3	2360±22.3	2440±14.3	2640±12.6	2500±11.4	2570±7.2	LSD $_{(S)}$=2.959 LSD $_{(M)}$=4.832 LSD $_{(S*M)}$=8.370
	S2	1596±12.3	1715±16.4	1720±9.2	1890±25.4	1967±10.6	2170±7.7	2102±10.3	2370±6.8	
	S3	1030±8.9	1098±11.1	1490±8.4	1702±17.8	1770±9.9	1740±8.5	1780±9.2	1842±13.4	
TSS	S1	45±4.2	43±4.2	49±2.6	60±2.2	71±2.6	74±3.4	66±2.1	84±1.8	LSD$_{((S)}$=1.247 LSD $_{(M)}$=2.036 LSD $_{(S*M)}$ =3.527
	S2	39±2.2	38±3.3	47±8.4	45±1.8	46±3.3	44±1.0	47±3.9	46±1.5	
	S3	30±1.7	35±2.2	36±3.3	37±2.2	37±1.2	35±4.1	36±4.2	32±0.8	
Alk.	S1	250±5.8	249±12.7	229±17.6	230±12.2	224±5.6	219±5.1	208±3.7	199±7.2	LSD $_{(S)}$=2.232

	S2	244±10.6	232±5.6	214±15.2	220±9.9	201±3.9	209±6.4	192±4.3	180±6.3	LSD$_{(M)}$=3.644 LSD$_{(S*M)}$ =6.312
	S3	220±7.7	223±4.3	208±8.9	199±7.8	189±4.4	180±5.3	177±5.1	160±4.7	
T.H	**S1**	1030±11.4	1080±15.4	1099±18.4	1190±11.4	1350±7.7	1260±18.7	1353±19.7	1290±15.4	LSD $_{(S)}$=1.821 LSD $_{(M)}$=2.973 LSD$_{(S*M)}$ =5.150
	S2	980±6.9	920±20.3	998±16.4	1070±20.3	1210±8.1	1166±5.6	1145±22.3	1180±11.2	
	S3	903±15.3	900±30.4	916±12.9	970±23.9	1190±4.4	1041±9.8	1103±20.4	1100±10.4	
Ca^{+2}	**S1**	300±14.4	316±9.8	358±30.1	352±4.7	361±3.6	374±7.4	386±10.6	409±22.9	LSD$_{(S)}$=2.161 LSD$_{(M)}$=3.529 LSD $_{(S*M)}$ =6.112
	S2	199±7.9	280±7.4	318±25.4	316±2.2	337±4.2	330±6.6	380±9.7	388±17.4	
	S3	185±20.1	208±3.3	291±15.2	298±19.7	295±5.3	289±5.2	320±8.2	340±12.3	
Mg^{+2}	**S1**	49±6.6	58±2.2	56±6.2	110±4.4	109±2.6	102±12.3	130.1±4.6	136.1±7.8	LSD$_{(S)}$=2.132 LSD$_{(M)}$=3.172 LSD $_{(S*M)}$ =6.031
	S2	37±4.2	54±4.4	50±6.7	69.3±5.8	95±3.9	99.7±7.7	114.3±5.8	122±2.9	
	S3	34±3.9	32.72±3.7	32.8±2.5	46±3.9	77.8±3.3	74±2.5	71.7±8.4	90±7.4	
Cl^{-}	**S1**	98±20.1	135±6.9	150±8.8	164±6.4	254±1.8	294±1.7	370±11.4	380±7.7	LSD$_{(S)}$=1.971 LSD$_{(M)}$=3.219 LSD $_{(S*M)}$ =5.576
	S2	75±9.2	100±10.1	110±5.6	126±3.3	160±2.1	236±1.6	235±10.6	340±4.6	
	S3	57±6.1	80±4.2	104±4.7	122±2.7	142±3.4	199±1.3	198±9.5	200±5.5	
SO$_4$	**S1**	639±3.9	741±2.6	785±22.1	772±5.6	816±2.4	843±12.4	1004±12.6	1340±12.4	LSD$_{(S)}$=5.347 LSD $_{(M)}$=8.732 LSD $_{(S*M)}$ =15.125
	S2	547±17.3	662±13.3	704±14.5	740±8.7	772±10.3	805±11.6	868±7.8	1039±9.6	
	S3	453±12.8	621±14.6	583±3.4	691±9.1	755±9.4	760±30.8	823±5.9	890±8.2	
NO$_3$	**S1**	44.25±5.6	43.61±4.4	35.9±2.2	39.6±2.2	31.87±4.2	38.92±2.7	41.09±1.4	44.2±5.9	LSD$_{(S)}$=1.069 LSD $_{(M)}$=1.746 LSD $_{(S*M)}$=3.025
	S2	35.97±2.3	33.19±2.3	20.62±1.2	30.52±1.0	22.24±3.4	31.66±3.4	32.88±1.9	36.1±4.6	
	S3	12.28±1.6	10.02±1.7	9.38±1.8	11.15±0.6	12.12±1.5	8.63±1.9	14.57±2.2	13.2±2.3	
Na	**S1**	170.9±5.5	189±2.8	178.8 ±17.4	191.9 ±6.8	200.5±2.2	288±3.9	333.4±3.9	447.5±3.6	LSD$_{(S)}$=5.347 LSD$_{(M)}$=8.740 LSD $_{(S*M)}$ =15.171
	S2	138.2±3.4	163±6.4	160±11.2	180.5±2.7	180.3±3.9	200.7±2.8	260.5±5.5	324±2.4	
	S3	33.4±2.6	77±17.4	110.3±5.6	133.1±7.4	150.5±4.2	180.1±1.7	160.7±2.8	200.6±1.7	
K	**S1**	22±1.2	20±2.2	16.4±0.7	23±3.4	25.5±1.4	37±2.3	32±1.2	30±0.6	LSD $_{(S)}$=1.458 LSD$_{(M)}$= 2.117 LSD$_{(S*M)}$ =4.125
	S2	6.9±0.9	6.7±1.4	10.1±0.8	12.2±2.7	18±0.8	21±1.8	24±1.1	23±0.5	
	S3	4.9±0.2	5±0.3	6±0.8	9±1.7	10±0.8	11±0.9	12±1.6	11.9±0.2	
PO$_4$	**S1**	2.59±0.1	1.61±0.2	2.98±0.13	3.007±0.12	4.177±0.17	4.38±0.12	4.89±0.12	4.99±0.44	LSD$_{(S)}$=0.009 LSD$_{(M)}$=0.015
	S2	1.99±0.01	1.022±0.002	1.04±0.002	1.03±0.001	2.05±0.001	2.79±0.07	2.82±0.11	3.39±0.22	

	S3	0.81±0.02	0.003±0.001	0.03±0.001	0.02±0.001	0.02±0.001	0.27±0.04	0.32±0.07	0.29±0.15	LSD$_{(S*M)}$ =0.026
DO	**S1**	8.2±0.6	8.1±0.6	7.2±1.3	6.1±0.4	6±0.2	5.45±0.2	5.41±0.4	5.3±0.1	LSD(S)=0.972 LSD(M)=1.588 LSD(S*M) =2.750
	S2	9±1.1	8.5±0.4	8.27±2.2	8.3±0.2	6.8±0.7	6.8±0.3	6.5±0.2	5.9±0.4	
	S3	9.5±0.6	9.3±0.3	9.3±1.4	8.9±0.1	8.2±0.3	8.75±0.1	7.5±0.7	6.5±0.2	
BOD_5	**S1**	3.1±0.3	3.5±0.1	3.9±0.2	4.58±0.2	5±0.4	5.19±0.1	5.32±0.6	5.27±0.3	LSD $_{(S)=}$0.095 LSD $_{(M)}$=0.155 LSD$_{(S*M)}$ =0.269
	S2	2.2±0.1	3.2±0.3	3.3±0.1	4.11±0.1	4.5±0.3	4.8±0.3	5.2±0.2	4.88±0.1	
	S3	1.2±0.1	1.5±0.02	2.3±0.3	2.6±0.5	3.6±0.6	4.1±0.2	4.5±0.1	4.2±0.2	
SAR	**S1**	2.41±0.3	2.56±0.4	2.32±0.3	2.29±0.6	2.37±0.3	3.40±0.2	3.74±0.2	4.89±0.6	LSD$_{(S)=}$0.292 LSD$_{(M)}$=0.476 LSD$_{(S*M)}$ =0.825
	S2	2.36±0.2	2.33±0.2	2.20±0.1	2.39±0.4	2.23±0.2	2.48±0.6	3.01±0.3	3.67±0.4	
	S3	0.59±0.1	1.31±0.1	1.63±0.2	1.89±0.1	2.01±0.1	2.44±0.4	2.11±0.4	2.50±0.2	
Na%	**S1**	31.54±0.7	32.42±3.6	29.35±2.6	28.35±2.2	28.81±2.2	35.96±2.2	37.82±1.7	43.76±2.2	LSD$_{(S)=}$2.188 LSD$_{(M)}$=3.572 LSD$_{(S*M)}$ =6.187
	S2	36.26±1.4	32.36±2.2	29.73±3.1	31.23±1.3	28.61±1.4	30.81±1.5	33.45±1.9	37.81±1.7	
	S3	12.98±1.3	23.86±1.4	25.06±2.8	27.58±3.5	28.22±1.6	32.51±1.2	28.47±2.2	31.22±1.3	
M.H	**S1**	23..19±3.2	23.20±2.5	20.48±0.6	33.97±2.7	33.20±2.7	33.21±1.6	35.68±2.9	35.39±0.9	LSD$_{(S)=}$1.604 LSD$_{(M)}$=2.620 LSD$_{(S*M)}$ =4.537
	S2	23.43±2.2	24.10±1.3	20.56 ±1.1	26.52±3.2	31.70±3.3	30.98±1.7	33.12±3.1	34.11±0.7	
	S3	21.23±0.9	20.57±1.6	15.65±1.3	20.26±1.4	30.27±2.4	29.65±1.1	26.94±2.4	30.35±1.5	

CCME Water Quality Index Canadian model

The WQI ranged between its lowest value of 46.17 (Marginal) in St.1 during June and the highest value of 70.91 (Fair) in St.3 during January, table 4, the water quality at St.1 is lower than St.2 and St.3, this could be because the treated sewage water includes a high concentration of TDS, TSS, Turbidity, EC, TH, Ca, Mg, Cl^-, K, SO_4, PO_4, NO_3, BOD_5, table 2, at the same time these ionic salts gradually decrease in the second and third station, resulting in an improvement of water quality due to the self-purification processes of water (29), including the biodegradation activity of microorganisms which reduce organic matter in wastewater effluent (12), the lower water level in St.3 increase in sedimentation processes, which lowers turbidity and TSS (6), algae and aquatic plants activity contributed to consuming sulfate, phosphate, and nitrate as a macronutrient as well as micronutrient may be consumed by producers activity (1). Chemical precipitation and adsorption on clay particles also reduce PO_4 concentration (16), all above-mentioned caused improvement in water quality in St.3.

The PCA method was used to isolate significant variables for each factor. Retracted were the components having Eigenvalues greater than 1. PCA yielded six Factors (Figure 2) that explained 86.39 percent of the total variance. Nearly 68.83% of the total variation was explained by the first three factors (35.26 %, 18.78 %, and 14.73 % for F1, F2, and F3, respectively).

F1 expressed the most positive correlations with EC, salinity, TDS, Na, SAR, Na%, and Alkalinity (0.78, 0.80, 0.81, 0.80, 0.85, 0.83, and 0.55, respectively), and the negative correlations with NO_3 (-0.75), PO_4 (-0.82), K (-0.79), Cl (-0.55), and Turbidity (-0.50). F2 was associated positively with temperature, alkalinity, magnesium, and manganese Hazard, and negatively with pH and DO. The third component was positively correlated with TSS, Hardness, and Ca, but negatively correlated with MH. F4, F5, and F6 had a positive correlation with BOD_5, Cl, and SO_4, sequentially (Table 3).

The results of the principal components analysis (PCA), Figure 3, showed the arrangement of the water quality variables according to the strength of their influence on the WQI, whereby the variables were divided into two groups depending on their influence on the index value, as the first group was F1 with the largest percentage (35.26%) and included TDS, EC, Salinity, Na, SAR, Na%, alkalinity, SO_4, pH, DO, BOD_5, Mg, Magnesium hazard. The second group with F2 with the lowest percentage (18.78%) was represented by Temperature, Ca, Total hardness, K, Cl, PO_4, NO_3, TSS, and Turbidity.

Table 3. Correlations between variables and factors.

Parameters	Factors					
	F1	F2	F3	F4	F5	F6
Temperature	-0.47	0.81	-0.12	0.03	-0.04	-0.07
pH	0.50	-0.72	0.10	0.17	0.24	-0.03
EC	0.78	0.32	0.39	-0.13	0.01	0.24
Salinity	0.80	0.20	0.36	-0.09	-0.13	0.25
Turbidity	-0.50	-0.50	0.45	0.13	-0.32	0.27
TDS	0.81	0.34	0.32	-0.17	-0.01	0.21
TSS	-0.41	-0.42	0.57	0.23	-0.34	0.31
Alkalinity	0.55	0.61	0.29	-0.11	0.15	-0.05
Hardness	-0.05	0.38	0.58	-0.39	-0.10	-0.09
Ca	-0.30	0.19	0.79	-0.31	0.11	-0.24
Mg	0.09	0.84	-0.28	0.28	-0.08	0.25
Cl	-0.59	0.09	-0.21	-0.02	0.56	-0.10
SO_4	0.14	-0.14	-0.19	-0.31	0.66	0.55
NO_3	-0.75	-0.13	0.35	0.15	0.30	0.19
Na	0.80	0.13	0.43	0.24	0.17	-0.12
K	-0.79	0.24	0.34	0.19	-0.02	0.08
PO_4	-0.82	0.19	0.24	0.11	0.30	-0.10
DO	0.39	-0.66	0.01	0.22	0.10	0.10
BOD_5	0.12	0.35	0.28	0.64	0.12	-0.23
SAR	0.85	-0.03	0.32	0.25	0.19	-0.13
Na %	0.83	-0.23	0.09	0.28	0.14	-0.13
MH	0.21	0.61	-0.56	0.37	-0.09	0.29

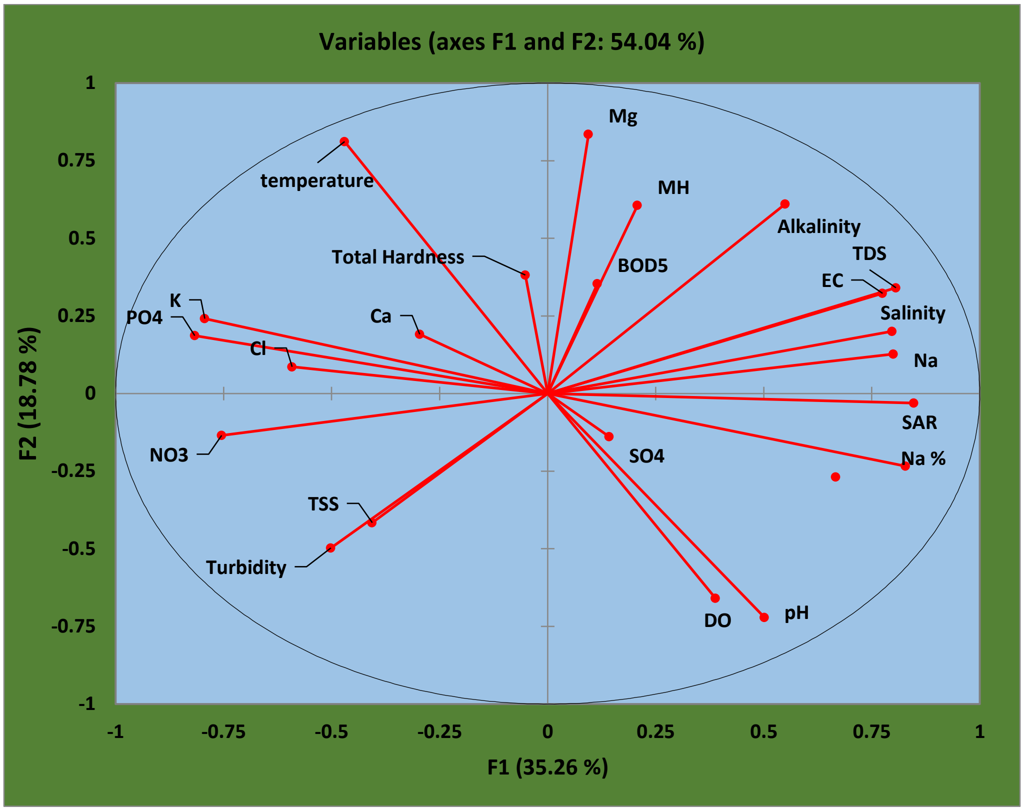

Figure 3. Scheme of principal component analysis (PCA) for water quality properties.

Table 4. Water Quality Index (WQI CCME) Canadian Model at Study Stations. From (December 2021-July 2022).

Stations	Months	WQI	Classification
St.1	December	48.78	Marginal
	January	52.89	Marginal
	February	57.04	Marginal
	March	53.93	Marginal
	April	51.82	Marginal
	May	52.78	Marginal
	June	46.17	Marginal
	July	48.87	Marginal
	Overall	49.12	Marginal
St.2	December	69.55	Fair
	January	68.00	Fair
	February	63.39	Marginal
	March	61.12	Marginal
	April	57.20	Marginal
	May	60.14	Marginal
	June	52.72	Marginal

	July	53.02	Marginal
	Overall	56.12	Marginal
St.3	December	70.53	Fair
	January	70.91	Fair
	February	65.59	Fair
	March	66.57	Fair
	April	65.04	Fair
	May	65.01	Fair
	June	69.87	Fair
	July	68.71	Fair
	Overall	65.03	Fair

Conclusion

The Canadian water quality index might be a highly efficient and effective method for summarizing and reporting monitoring data in order to evaluate the status of treated wastewater quality and present the possibility for future improvement. The Water Quality Index of treated effluent from the Karbala wastewater treatment plant ranges between Marginal and Fair. TDS, Na, and EC are factors that decrease treated wastewater quality. The marginal water quality in the first and second stations indicates a defect in the treatment of wastewater at this plant. While the water quality in St. 3 is fair, making it suitable for irrigation and other uses.

Conflict of interest

The authors have no conflict of interest.

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