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ORIGINAL ARTICLE

Assessing surface water uses by water quality index: application of Qalyubia Governorate, Southeast Nile Delta, Egypt

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Abstract

In this study, water quality index (WQI) was applied at one of the most crowded Nile reaches surroundings in Egypt to investigate its impacts on different water uses. Twelve sites are selected for monitoring (S1–S12) within the irrigation system network of the Qalyubia Governorate, and water samples from these locations in 2021 were collected, analyzed, assessed, and compared to analyze water quality data collected in 2014 in light of the Egyptian permissible water quality limits regarding the drinking and irrigation uses. These two main sets of data were chosen to emphasize the change in WQI within this period, denoting the time before the epidemic COVID19 and after the lockdown of the epidemic in 2021 in the study area. Fifteen physicochemical water parameters were measured. The results show that the WQI for the surface water monitoring sites is classified as good quality except for S8, which showed a poor water quality type. In addition, S2 has recorded a BOD concentration of 6.4 mg/L, which is slightly above the Egyptian limit (6 mg/L). Also, S8 recorded a slight increase in Fe, Mn, and F compared to permissible concentrations. TDS varies between 258.08, 318, and (249 ± 18.2) mg/L for minimum, maximum, and average ± standard deviation, respectively, indicating suitable irrigation water. The study suggests that surface water can be used to irrigate crops, but it should be purified before being used for drinking purposes. A comparison of the water quality parameters for the years 2014 and 2021 for the sites S1, S4, S5, S7, S9, and S10 reveals an increase in water quality from poor (2014) to good (2021). Therefore, the poor water quality in 2014 can be referred the effect of inadequate sewage treatment, industrial wastewater flows, and urban runoff discharge, which had been decreased with the decrease in different activities during the epidemic period and lockdown.

Keyword Water resources · Water quality indices · Heavy metals · Qalyubia-Egypt · Sustainable drinking and irrigation water use

Introduction

The Sustainable Development Goals (SDGs) are endangered due to the increasing scarcity in water and its impacts on food production (SDGs 2014). In particular, the SDGs related to hunger, poverty, and environmental sustainability are threatened by population increase, urban sprawl, climate change, in addition to a series of connected and cascading international crises and wars, as the aggravating COVID-19 epidemic and the food, energy, humanitarian, and refugee crises. The wars in Ukraine and recently in Sudan are also fueling recognized emergency situations. The Sustainable Development Goals Report 2022 presents evidence of the negative effects of those crises in achieving the SDGs 2022. As a consequence, the management of water resources has become an increasingly challenging job from a technological, economic, social, and political perspective. Monitoring water quality is an important tool for long-term assessment that provides valuable information for water stakeholders. Many countries with arid or semiarid climates that are sensitive to climate change (Mohammed et al. 2022; Abdel-Fatteh et al. 2020) face a delicate and crucial issue with surface water quality. Public awareness is needed to ensure water quality preservation. Surface and groundwater

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pollution has a direct effect on the human health, economy, and water resources availability (Brkic et al. 2019). About 80% of infections in low-income and developing countries are directly linked to contaminated drinking water and unhygienic settings (Das and Nag 2015). The quantity and kind of anthropogenic activity in an area's basins, including agricultural, industrial, and other activities, greatly influences the quality of that area's surface water (Atta et al. 2022). In Egypt, the limited water supply must balance a range of expanding needs. The complex and unpredictably interwoven components of the Egyptian water resources system interact with other complex and unrelated systems, such as the economic, social, and environmental systems. The Nile River, rainfall-runoff, and groundwater for both renewable and non-renewable aquifers are all examples of freshwater resources in Egypt (Gabr 2020). Point and non-point sources of pollution such as untreated wastewater, nutrients coming from agricultural runoff, and industrial wastewater are degraded surfaces and groundwater sources (Nouhaila et al. 2022; Gabr 2022). In order to decrease pollution and enhance water quality, researchers must examine and control the fluctuations in the amounts of heavy metals and other substances in both surface and groundwater. In contrary to organic pollutants, heavy metals tend to accumulate in living organs and are not biodegradable. Additionally recognized to be harmful or carcinogenic are certain heavy metal ions (El-Amier et al. 2021). Heavy metal separation and purification have come under a lot of strain due to their bioaccumulation in food chains and toxicity to biological systems as concentrations increase over time. Heavy metals are changing into one of the most significant environmental problems due to their negative impacts on ecosystem. For irrigation waters, salinity, sodicity, and ion toxicity are the most significant quality problems. Continuous soil and water river monitoring is necessary to detect any changes in salt concentration (Gabr 2018). The threshold concentration at which certain salts, such as HCO_3^{-1}, CO_3^{2+}, Na^+, Cl^-, Mg^{2+}, and other trace elements, have a detrimental effect on plant growth (Zaman et al. 2018). In order to evaluate the water quality status of irrigation water, water quality index (WQI) is used. WQI is a single unitless value deduced through mathematical method based on various hydro-chemical properties (El-Amier et al. 2021). Many WQI exist like Kelley index (KI), permeability index (PI), potential salinity (PS), etc. (Shil et al. 2019) based on used parameters group. In general, water quality indices are categorized into four main groups: (1) public indices used for general water quality (e.g., NSFWQI), (2) specific consumption indices based on the kind of consumption and application, whether it is drinking, industrial, ecosystem preservation, etc. (e.g., BCWQI), (3) designing or planning indices aiding decision-making and planning in water quality management projects (Agriculture, desalination, and remediation projects), and (4) statistical indices used based on personal opinions considerations. On reclaimed land, an understanding of water quality is taken into consideration while planning and managing the water supply and irrigation system. In order to gain a comprehensive understanding of surface water appropriateness for drinking and irrigation applications in Egypt's Qalyubia governorate, this research work uses hydro-chemical WQI technique. To achieve this objective, twelve monitoring sites (S1 through S12) were selected for water sampling. In 2021, water samples from these sites were taken, examined, evaluated, and compared to examine water quality data from 2014. These two major sets of data were chosen to reflect the WQI changes before and after the COVID-19 pandemic, and the impacts of the lockdown on the WQI in the same investigated regions. Fifteen water quality parameters were analyzed for each sample (i.e., total dissolved solids (TDS), pH, dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total nitrogen (TN), total phosphorous (TP), organic nitrogen (ON), ammonia (NH_3), sulfates (SO_4), nitrate (NO_3), iron (Fe), manganese (Mn), fluoride (F), and oil and greases (O&G). Water quality index was deduced and compared to the Egyptian water quality criteria and the World Health Organization (WHO) for the years 2014 and 2022, to determine the water quality suitability for different water uses.

Materials and methods

Study area

The research area is located in the Egyptian delta province of Qalyubia governorate. Banha City is the capital, as shown in Fig. 1. Population, urban sprawl, and rising industrial activity are fast growing in Qalyubia. According to demographic estimations, the governorate's population was predominantly concentrated in rural areas with only 44.7% of its residents residing in urban areas. 2,825,045 of the governorate's projected 5,105,972 residents lived in rural areas, while only 2,280,927 are found in urban areas (CAPMAS 2015).

Sample collection and preparation

We selected twelve locations along the Rayah EL-Tawfiki (one of the main Nile river branches), Qalyubia, Egypt, for the collection of water samples using GPS device (eTrex series, Garmin, Romsey, UK). The proximity of drinking water purification facilities and the locations of potential pollution sources were taken into consideration while choosing these water quality monitoring sites. Table 1 summarizes the monitoring site coordinates on the irrigation network. Three surface water samples were gathered in December 2021 (winter season), at a depth of 15–30 cm at each site,

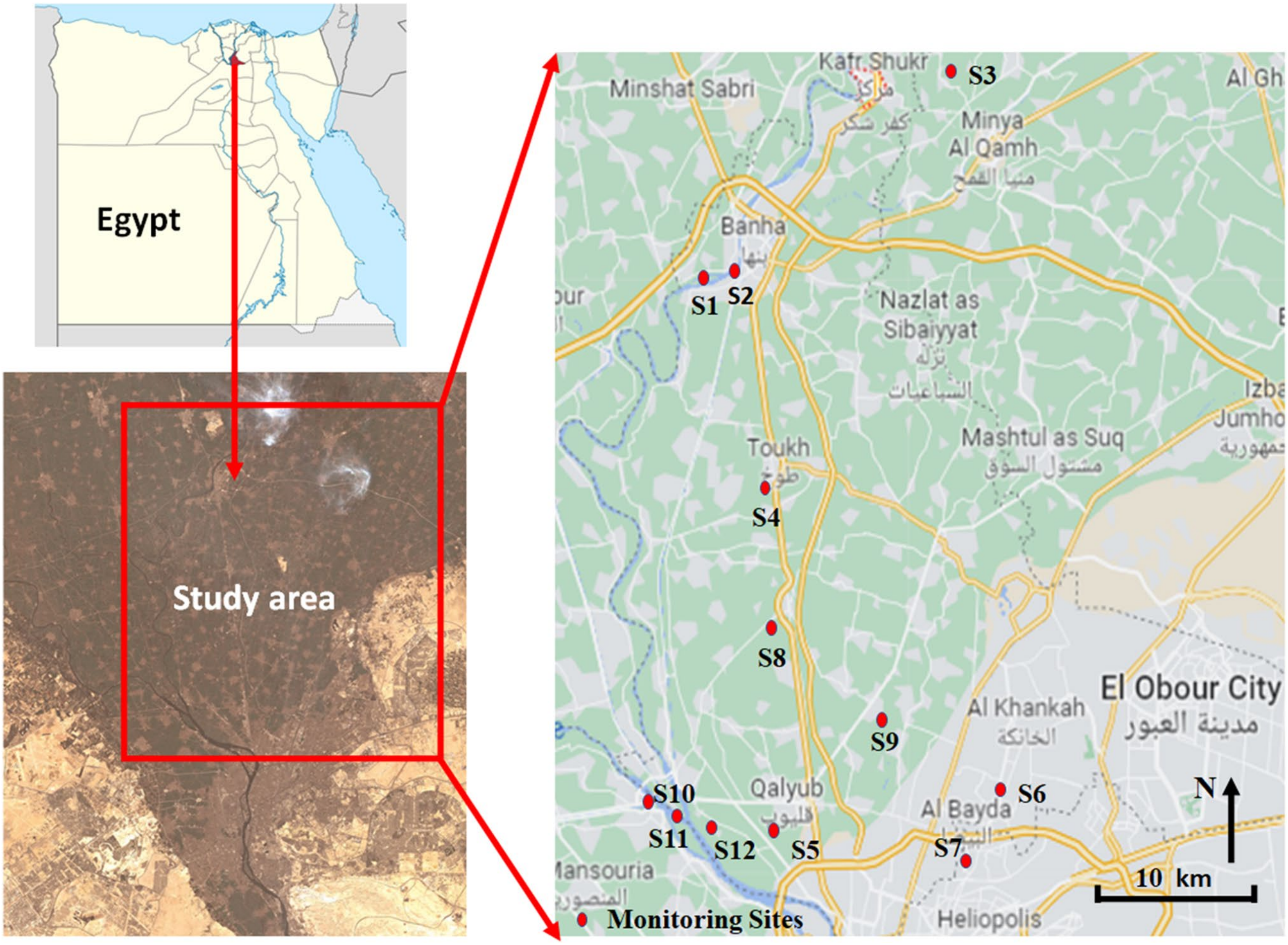

Fig. 1 Map of the study area showing water monitoring sites

Table 1 Monitoring site coordinates on the irrigation network

SR	Monitoring site	Latitude (N°)	Longitude (E°)
1	S1	30.4612	31.1692
2	S2	30.466	31.1848
3	S3	30.5677	31.304
4	S4	30.3537	31.2021
5	S5	30.1763	31.2068
6	S6	30.1952	31.3313
7	S7	30.1598	31.3127
8	S8	30.2799	31.2056
9	S9	30.2317	31.2669
10	S10	30.1902	31.1384
11	S11	30.1824	31.1546
12	S12	30.1749	31.1739

and stored in acid-washed polyethylene bottles for examination. The samples were then filtered using 0.45-m membrane filters. All necessary measures were performed to prevent sample contamination during sample collection and processing (total samples: 12 sites × 3 samples with total of 36 samples). In this study, we analyze for each sample fifteen water parameter pH, TDS, DO, BOD, COD, TN, TP, NH_3, SO_4, ON, NO_3, Fe, Mn, F, and O&G. The principal ions and trace elements were investigated by the water quality laboratory of the Faculty of Engineering at Ain Shams University, Egypt. Using the Hydrolab model Multi Set 430i WTW, pH was measured in situ. The biological oxygen demand (BOD) was calculated using a 5-day incubation procedure. The potassium permanganate method was used to conduct the chemical oxygen demand (COD) test. As soon as the water samples were taken, the alkalinity of the water was assessed using the markers methyl orange and phenolphthalein. The amounts of chlorinity and sulfate were determined using the Mohr's and turbidimetric procedures, respectively. Ion chromatography equipment (Dionex, ICS-1100, Thermo Fisher Scientific Inc., Waltham, MA, USA) was used to measure SO_4^{2-}. The electrical balance (EB%) between the cations and anions was used to evaluate the precision and dependability of the chemical analysis (Appelo and Postma 2005). Using inductively coupled plasma mass spectrometry (ICP, POEMSIII, Thermo Jarrell elemental company, Waltham, MA, USA) and standard solutions containing 1000 mg/L (Merck), trace elements (Fe, Mn, and F) were detected. A glass fiber filter (GF/C) was used to filter a volume of sample, and a known weight of the filtrate was evaporated at 105 °C to determine the total dissolved solids (TDS). TSS, or total suspended solids, is the distinction between TS and TDS. A modified Winkler technique was used to calculate the amount of dissolved oxygen (DO, mg/L). The phenate technique was used to measure ammonia. Using a colorimetric method, nitrite was found via the production of a reddish-purple azo-dye. After cadmium reduction, nitrate was found to be nitrite. The ascorbic acid-molybdate method was used to measure orthophosphate and total phosphorus (TP).

In addition, fifteen water quality parameters pH, TDS, DO, BOD, COD, TN, TP, NH_3, SO_4, ON, NO_3, Fe, Mn, F, and O&G for the sites 1, 4, 5, 7, 9, and 10 were gathered from the Egyptian Ministry of Water Resources and Irrigation during December 2014. The analyzed water quality metrics were statistically broken down using the Excel tool, and a correlation matrix between the WQI and its properties was created. The mapping of the concentration of the water quality metrics also made use of the Surfer 16 program.

Water quality index (WQI)

The presence of undesired dissolved salts or components is the primary factor used to determine water suitability for various uses (Sener et al. 2017; Megahed et al. 2022; Kamboj and Kamboj 2019). There are many methods utilized to evaluate the water quality for use in irrigation and for drinking such as the water quality index (WQI) (Oregon 2001; CCME1999) and the irrigation water quality index (IWQI) (Yıldız and Karakuş 2020; Soumaia et al. 2022).

Weighted arithmetic water quality index method

The weighted arithmetic approach, for the index of water quality, is widely used to evaluate water quality as follows:

(i) Determine the value of the constant K using the formula

$$K = \frac{1}{\sum\left(\frac{1}{s_i}\right)} \tag{1}$$

where s_i is the standard allowable for ith water parameter.

(ii) For each water parameter, the quality rating scale (Q_i) is calculated by substituting in the following equation:

$$Q_i = 100 \times \left(\frac{V_i - V_0}{V_i - V_0}\right) \tag{2}$$

where V_i is computed level of ith parameter in the analyzed water, V_0 is ideal value of this parameter's in pure water. Therefore, for disolved oxygen $V_0 = 14.6$ mg/L; for pH, $V_0 = 7$; otherwise, V_0 is equal to zero for any water parameter.

(iii) For each individual water quality parameter, the unit weight (W_i) is calculated as follows:

$$W_i = \frac{K}{S_i} \tag{3}$$

(iv) then the water quality index was calculated using the equation below:

$$WQI = \frac{\sum Q_i W_i}{\sum W_i} \tag{4}$$

In this method, the allocation of Wi is a very important issue as weights generally refer to the relative importance of each water parameter with respect to the other parameters (Megahed et al. 2022 and Kamboj and Kamboj 2019). There are five WQI classifications ranging the value of WQI from zero (excellent water quality) to more than 100% (unsuitable for drinking and irrigation purposes). Oregon 2001 classified the WQI into five categories as shown in Table 2.

Assessment of studied water quality parameters using WQI

Based on how much the surface water is suitable for human consumption, the weighted arithmetic water quality index (WQI) is calculated in this study. The WHO 2011, drinking water standards, and Egypt's drinking water standards (Egypt Decree 458/2007) have both been considered for calculating WQI. Each of the 15 water parameters DO, pH, BOD, TDS, COD, TN, TP, ON, NH_3, SO_4, NO_3, Fe, Mn,

Table 2 Water quality rating and uses

WQI value	Grading	Water quality rating	Possible usages
0–25	A	Excellent	Drinking, industrial, and irrigation
26–50	B	Good	Domestic, industrial, and irrigation
51–75	C	Poor	Industrial, and irrigation
76–100	D	Very Poor	Irrigation
Above 100	E	Unsuitable for drinking purpose	Restricted use for irrigation

F, and O&G has been given a weight (W_i) based on how it is thought to affect primary health and how that affects the overall quality of water that may be used for drinking. The parameters with the greatest impact on water quality (TN, TP, ON, NH_3, Mn, and Fe) are given a weight of 4, while the parameters with the less effects are given a weight of 2 (pH and O and G). Other variables like TDS, DO, BOD, COD, SO_4, NO_3, and NH_3 are given a weight of 3 based on how important they are to the overall quality of the water. Table 3 summarizes the allocated weight, Egypt Decree 458/2007 and WHO 2008 water standards values, and the estimated relative weight. After calculating the WQI values, the water quality is rated and categorized according to Table 1. Figure 2 shows the WQI computation methodology based on spread Excel sheet.

Results

Using the excel spreadsheets software, the statistical breakdown of the 15 water quality parameters was calculated. As indicated in Table 4, the Qalyubia irrigation network's 12 monitoring sites' pH, TDS, DO, BOD, COD, TN, TP, ON, NH_3, SO_4, NO_3, Fe, Mn, F, and O&G, as well as the WQI deduced from the selected equation. Then the Surfer 16 software was used to display the results in a graphical way. Figure 3 shows the map of the 15 water quality parameters that were examined and their concentrations for the Qalyubia irrigation network in 2021.

Table 3 Physicochemical characteristics' relative weights based on WHO and Egypt's drinking water quality requirements (Decree 458/2007) and WHO (2011)

Parameter	UNIT	Egypt Decree 458/2007	WHO (2011)	wi	Wi
PH	–	6.5–8.5	7.5	2	0.04
TDS	mg/L	1000	500	3	0.06
DO	mg/L	6	6	3	0.06
BOD	mg/L	6	6	3	0.06
COD	mg/L	10	10	3	0.06
TN	mg/L	3.5	3.5	4	0.08
TP	mg/L	2	2	4	0.08
ON	mg/L	1	250	4	0.08
NH_3	mg/L	0.5	0.5	4	0.08
SO_4	mg/L	250	250	3	0.06
NO_3	mg/L	45	45	3	0.06
Fe	mg/L	0.3	0.3	4	0.08
Mn	mg/L	0.4	0.4	4	0.08
F	mg/L	0.5	0.5	3	0.06
O&G	mg/L	0.1	0.1	2	0.04
				Σ = 49	Σ = 1.0

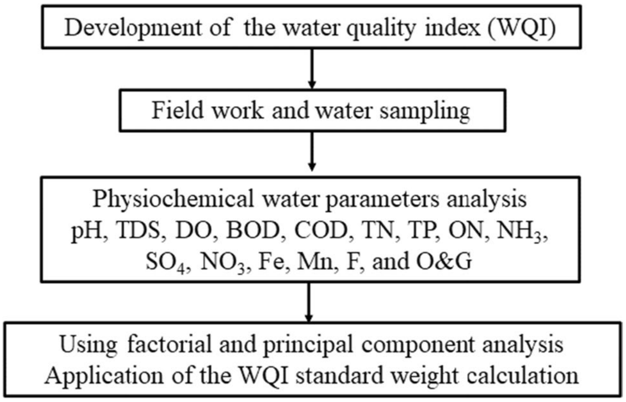

Fig. 2 WQI methodology

Physicochemical and biochemical water parameters

The measured pH values maximum, minimum, and (average ± standard deviation) were 8.12 (S7), 8.02 (S4), and (8.07 ± 0.04), respectively. All the measured pH values were confined between 6.5 and 8.5 according to permissible limits (Egypt's Law No. 458 of 2007 and Law No. 48 1998). TDS indicates excellent concentration as the TDS values maximum, minimum, and (average ± standard deviation) were 318 (S8), 249 (S10), and (258.1 ± 18.18), respectively. All the TDS values were below the allowable TDS (1000 mg/L). One of the primary and significant drinking water factors is TDS. Water's taste is significantly influenced by the overall amount of solids present. The research area's water samples are classified as having fresh water types based on the TDS classifications provided by (Batabyal et al. 2015; Brindha et al. 2015; Brown et al. 1970). For all stations, DO above 6 mg/L, a maximum of 8.2 mg/L was recorded in site 10, while the minimum was 7.1 mg/L recorded in site 1, and an average of (7.725 ± 0.327). The amount of pollution caused by organic materials is measured by the DO (Bora and Goswami 2017). Therefore, a decline in DO indicates that the surface water is contaminated with organic matter. Measured BOD and COD indicate maximum values of 6.4 and 11.6 mg/L, respectively, in S2 above the allowed Egyptian values of 6 and 10 mg/L, respectively, while the minimum BOD and COD were measured at sites 12 and 11, respectively, at 4.6 mg/L and 7.4 mg/L. The average BOD and COD were (5.5 ± 0.64) mg/L and (9.33 ± 1.53) mg/L, respectively. Except for sites 1, 2, 6, and 7, all of the sites show lower BOD and COD concentrations than the Egyptian regulation standards (Table 4 and Fig. 3). The largest source of BOD is probably domestic sewage, and it increases in the direction of the downstream contaminated canals (Chandra et al. 2017). The measured SO_4 values maximum, minimum, and (average ± standard deviation)

Table 4 The water quality metrics for samples of water collected from sites S1 through S12 during 2022 of the Qalyubia irrigation network

Location	pH	TDS	DO	BOD	COD	TN	TP	ON	NH_3	SO_4	NO_3	Fe	Mn	F	O&G	WQI
S1	8.02	254	7.1	6.2	11.3	0.11	0.019	0.0072	0.06	37.2	1.13	0.015	0.013	0.12	0.1	35
S2	8.11	251	7.9	6.4	10.8	0.13	0.021	0.0096	0.09	37.6	1.02	0.019	0.014	0.096	0.15	38
S3	8.1	255	7.7	5.8	9.9	0.14	0.014	0.0077	0.09	39.8	0.98	0.019	0.01	0.12	0.22	40
S4	8.02	251	7.9	5.5	9.2	0.12	0.012	0.0062	0.06	38.5	0.91	0.01	0.01	0.15	0.16	36
S5	8.05	256	7.8	5.4	8.6	0.096	0.0096	0.0054	0.09	38.8	0.93	0.01	0.01	0.14	0.18	37
S6	8.1	254	7.4	6.2	11.6	0.088	0.012	0.0079	0.06	34.4	0.95	0.012	0.01	0.11	0.26	41
S7	8.12	252	7.4	6.2	11.1	0.13	0.015	0.0036	0.09	34.1	0.95	0.019	0.01	0.16	0.14	38
S8	8.1	318	7.4	4.8	7.6	0.096	0.012	0.0024	0.02	68.6	1.12	0.48	0.51	0.63	0.19	65
S9	8.02	255	7.7	5.8	9.3	0.095	0.0096	0.0063	0.06	41.3	1.06	0.01	0.01	0.13	0.28	41
S10	8.02	249	8.2	4.8	7.6	0.0036	0.0003	0.0044	0.01	42.5	0.77	0.01	0.01	0.1	0.32	40
S11	8.1	251	8.1	4.7	7.4	0.0033	0.0003	0.0046	0.01	43.2	0.72	0.01	0.01	0.1	0.29	38
S12	8.1	251	8.1	4.6	7.5	0.0031	0.002	0.0047	0.01	43.6	0.71	0.01	0.01	0.1	0.36	41
Max	8.12	318	8.2	6.4	11.6	0.14	0.021	0.0096	0.09	68.6	1.13	0.48	0.51	0.63	0.36	65
Min	8.02	249	7.1	4.6	7.4	0.0031	0.0003	0.0024	0.01	34.1	0.71	0.01	0.01	0.096	0.1	35
Aver	8.071	258.1	7.725	5.5	9.33	0.084	0.011	0.006	0.05	41.6	0.9375	0.052	0.052	0.163	0.22	41
SD	0.04	18.18	0.327	0.64	1.53	0.05	0.0065	0.002	0.032	8.66	0.136	0.13	0.14	0.14	0.08	7.5
Permissible limits (Egypt's Law No. 458 of 2007 and Law No. 48 1998)																
	6.5–8.5	1000	6	6	10	3.5	2	1	0.5	250	45	0.3	0.4	0.5	0.1	

were 68.6 (S8), 34.1 (S7), and (41.6 ± 8.66) mg/L. All the measured SO_4 values were below 250 mg/L according to Egyptian regulations.

Organic matter (TN, TP, ON, NH_3, NO_3, and O&G)

The maximum values of measured TN and TP are 0.14 (S3) and 0.021 (S2) mg/L, respectively, which are lower than the permitted Egyptian levels of 3.5 and 2 mg/L, respectively. While the minimal TN and TP were measured at sites 11 and 8, respectively, at 0.003 mg/L and 0.0003 mg/L. The typical values for the two parameters were (0.08 ± 4 0.05) mg/L and (0.011 ± 0.007) mg/L, respectively. In comparison with Egyptian regulations, all sites show lower TN and TP concentrations (Table 4 and Fig. 3). The measured organic nitrogen (ON) values maximum, minimum, and (average ± standard deviation) were 0.0096 (S8), 0.0024 (S2), and (0.006 ± 0.002) mg/L. Measured NH_3 and NO_3 indicate maximum values of 0.09 (sites 2, 3, 5, and 7) and 1.13 (S1) mg/L, respectively, and all sites were below the allowed Egyptian values of 0.5 and 2 mg/L, respectively, which confirm high water quality (Table 4 and Fig. 3), whereas the minimum NH_3 and NO_3 were recorded at 0.01 mg/L (sites 10, 11, and 12) and 0.71 (S12) mg/L, respectively. All the sites indicate lower NH_3 and NO_3 concentrations compared to the Egyptian regulation values. In contrast to nitrite and nitrate, which can be harmful to human health, ammonium in drinking water is not directly related to human health (Nihalani and Meeruty 2021; WHO 2011). Ammonium values up to 0.5 mg/L are allowed if the waterworks do not include a filtration step and the distribution system does not change ammonium to nitrite. Nitrate levels in drinking water must not exceed 50 mg/L at consumer faucets, private property entrances, and waterworks exits. Drinking water standards for nitrite are 0.01 mg/L at waterworks exits, 0.1 mg/L at private property entrances, and 0.1 mg/L at consumer taps (WHO 2011; MEFD 2017; Schullehner et al. 2017). The most significant and prevalent alkaline component in the atmosphere, ammonia (NH_3), is responsible for the aerosolization of sulfate and nitrate (Zhou et al. 2016; Fu et al. 2015). Additionally, it develops into a second source of NO and N_2O (Fernández et al. 2015). A loss in biodiversity, eutrophication of water bodies, and soil acidification are further effects of NH_3 sinking into terrestrial and aquatic ecosystems. Measured O&G values maximum, minimum, and (average ± standard deviation) were 0.36 (S12), 0.1 (S1), and (0.22 ± 0.08) mg/L. Except for S1, all of the measured O&G values exceeded the permitted limits (0.1 mg/L) as per Egyptian rules.

Heavy metals (Fe, Mn, and F)

The average Fe and Mn were (0.052 ± 0.13) mg/L and (0.052 ± 0.14) mg/L. According to Egyptian regulations, all the measured F values were within allowable concentrations except for S8. Measured Fe and Mn values maximum and minimum were 0.48 mg/L (all sites except for S8) and 51 mg/L (all sites except for S8), respectively. Measured F values maximum, minimum, and (average ± standard deviation) were 0.63 (S8), 0.1 (S2), and

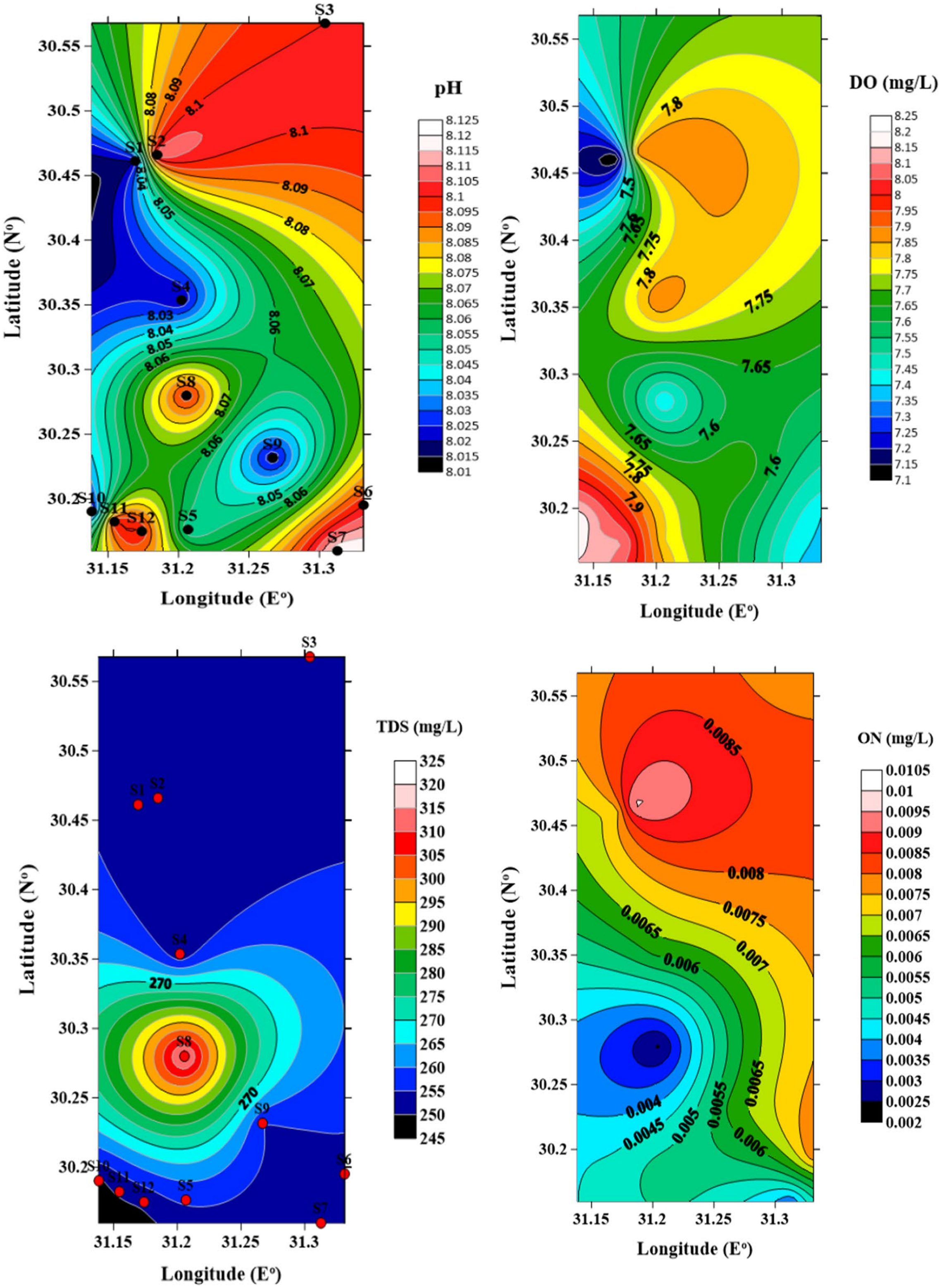

Fig. 3 Map of the studied 15 water quality parameters concentration variation for the Qalyubia irrigation network for year 2021

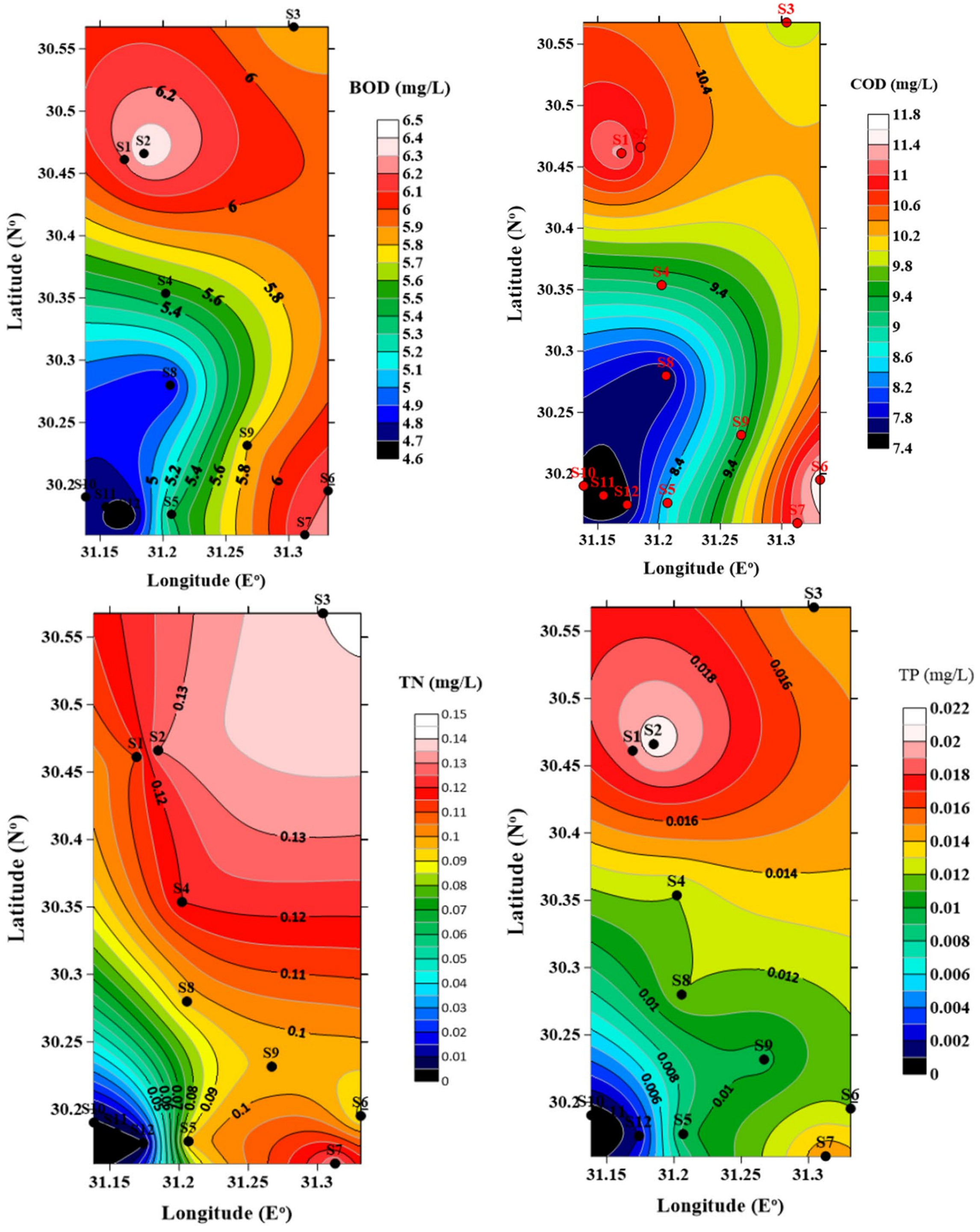

Fig. 3 (continued)

(0.16 ± 0.14) mg/L. According to Egyptian regulations, all the measured F values were within allowable concentrations (0.1 mg/L) except for S8. Water contamination from sewage irrigation is confirmed by high Mn levels (Abuzaid et al. 2022). According to the local geology and other chemical elements of the river, iron, the fourth most prevalent element in the Earth's crust, may be present in natural waters in varied concentrations (ANZECC 2000). Iron is often found in its ferric condition in surface waters, while it can occasionally be found in its ferrous form in reducing waters. In fresh water, the current analytical practical quantitation limit (PQL) for iron is 1 g/L, whereas,

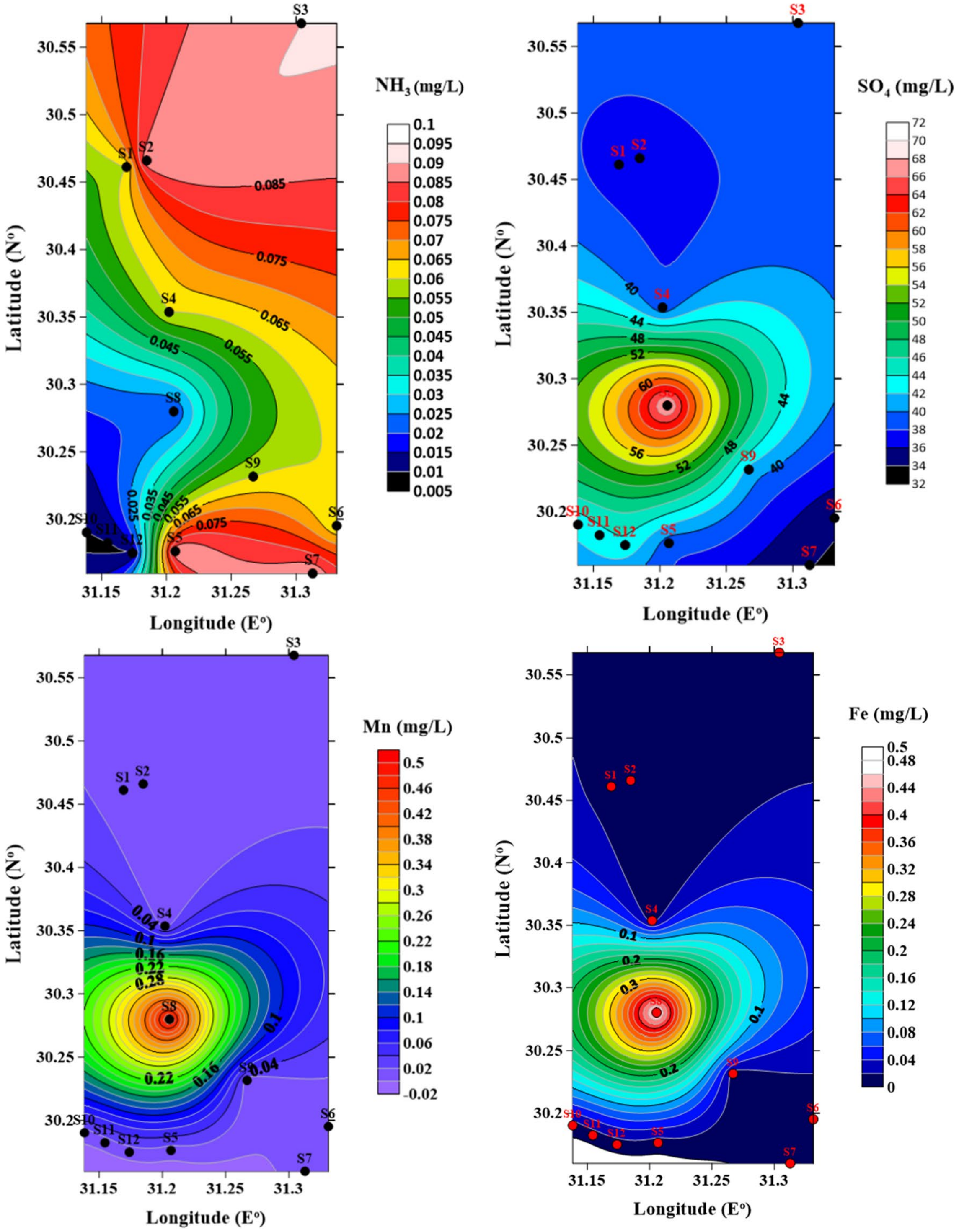

Fig. 3 (continued)

in marine water, it is 2 g/L (Wang et al. 2020). Although additional forms of iron may be present in organic and inorganic wastewater streams, ferrous (Fe^{2+}) and ferric (Fe^{3+}) states are the most frequent oxidization states of iron in the water.

Assessment of the water quality using the WQI method

Evaluations of water quality avoid complex data intervals since the quality of irrigation water is defined as a single

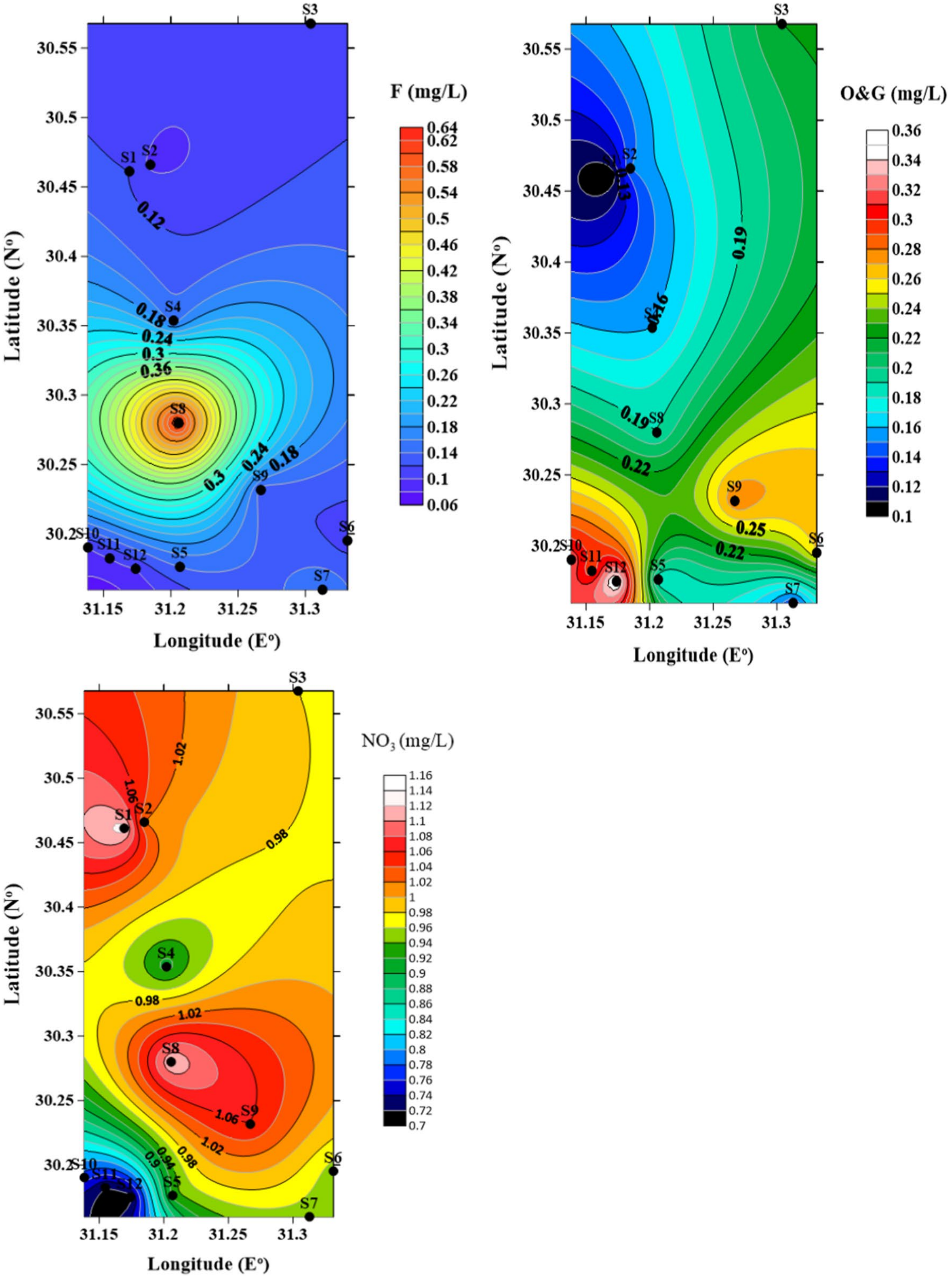

Fig. 3 (continued)

number. The notion behind comparing water quality measures to predetermined standards forms the basis of WQI evaluation. The irrigation water quality index is computed using the suggested water consumption limits for all soil types. The grading of water quality based on WQI values is displayed in Table 5. The WQI variation for the surface

Table 5 Surface water quality index for Qalyubia irrigation network

Location	WQI	Grading	Water quality rating
S1	35	B	Good
S2	38	B	Good
S3	40	B	Good
S4	36	B	Good
S5	37	B	Good
S6	41	B	Good
S7	38	B	Good
S8	65	C	Poor
S9	41	B	Good
S10	40	B	Good
S11	38	B	Good
S12	41	B	Good

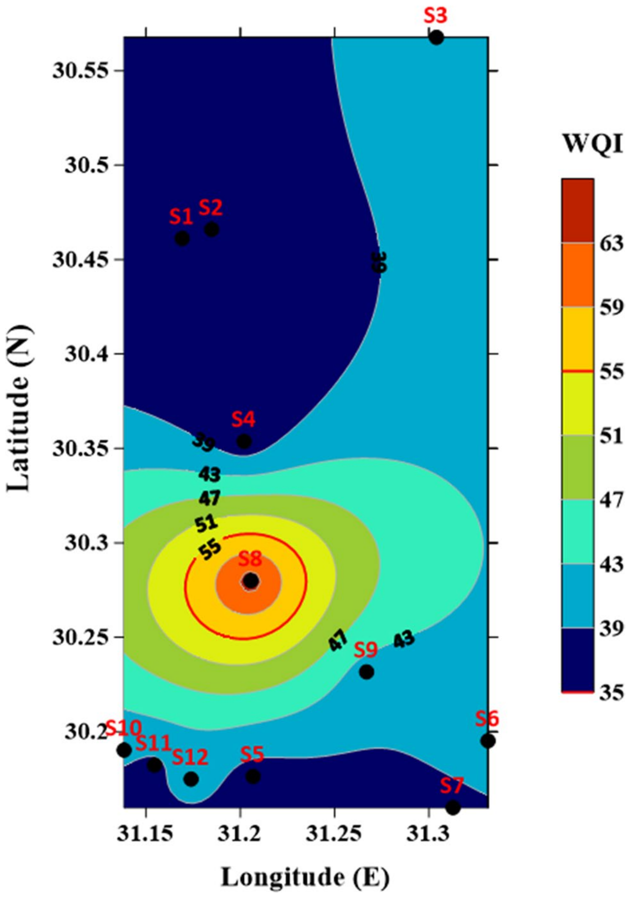

Fig. 4 WQI variation for the Qalyubia irrigation network

water in the Qalyubia irrigation network is also shown in Fig. 4. The WQI score in the study ranged from 35 (good) to 62 (poor), with a mean score of (41 ± 7.5) (good). The samples from sites 1, 2, 3, 4, 5, 6, 7, 9, 10, 11, and 12 all indicated good water quality, while samples from S8 showed poor water quality.

Discussion

Analysis of the measured water quality sites between the years 2014 and 2022

The water quality parameters for sites 1, 4, 5, 7, 9, and 10 were gathered as shown in Table 6. The values of pH, TDS, DO, TN, TP, NH_3, SO_4, NO_3, Fe, Mn, F, and O&G are within permissible limits (Egypt's Law No. 458 of 2007 and Law No. 48 1998) for all sites. On the other hand, the BOD, COD, and NO_3 show values greater than the permissible limits. In addition, the computed WQI for all sites shows a poor water quality category (C) as shown in Table 7. In addition, Fig. 5 shows a comparison between the surface WQI for the Qalyubia irrigation network for the years 2014 and 2022. The results show improvement in the water quality for sites 1, 4, 5, and 7 (good water quality). On the other hand, sites 9 and 10 indicate poor water categories for the years 2014 and 2022. The study area's water quality was improved in 2014 by the ministry of water resources and irrigation by halting point and non-point sources of pollution and by building new wastewater treatment plants. Additionally in 2020, the government put in place a variety of restrictions to hinder the COVID-19 virus from spreading within Egypt's borders. These restrictions include quarantines, partial lockdowns, movement restrictions, social isolation, and personnel layoffs that are not absolutely necessary (Tarek and Mohamed 2022). The flow of agro-food products to customers and markets may have been impeded by these restrictions, but the food supply has remained stable thus far. These precautions contributed to improving water quality. Numerous reports have shown the impact COVID-19 has had on the world's food and agriculture businesses [e.g., WAGENINGEN University and Research (https://www.wur.nl/en/Research-Results/Research-Institutes/Economic-Research/show-wecr/Research-into-the-impacts-of-COVID-19-onthe-agriculture-sector.htm), and UNESCO–IHE, Delft (https://www.oecd.org/coronavirus/policy-responses/covid-19-andthe-food-and-agriculture-sector-issues-and-policy-responses-a23f764b/)]. Additionally, non-governmental remedies were offered and certain governmental activities for COVID-19 socio-economic duties, recovery plans, and mitigation scenarios were stressed [e.g., United Nations, Egypt (https://unsdg.un.org/sites/default/files/2020-08/EGY_Socioeconomic-Response-Plan_2020.pdf)].

Table 6 Lists of the water quality metrics for samples of water collected from Sites 1, 4, 5, 7, 9, and 10 for the year 2014 (during December 2014 (winter season)) of the Qalyubia irrigation network

Location	pH	TDS	DO	BOD	COD	TN	TP	ON	NH_3	SO_4	NO_3	Fe	Mn	F	O&G	WQI
S1	8	312	6.6	6.63	9.78	1.63	0.21	0.109	0.15	74.8	3.08	0.095	0.089	0.32	0.1	57
S4	8.2	311	6.4	6.2	11.2	1.1	0.16	1.1	0.14	50.2	3.21	0.037	0.024	0.32	0.09	60
S5	8.01	341	6.8	5.92	10.86	1.98	0.18	0.092	0.12	66.94	4.89	0.034	0.0098	0.33	0.1	60
S7	8.1	334	7.2	6.23	11.24	1.22	0.108	0.11	0.14	51.22	3.43	0.029	0.022	0.21	0.09	58
S9	8.1	377	6.12	6.82	11.4	1.16	0.12	0.12	0.18	88.39	4.56	0.042	0.054	0.19	0.089	55
S10	8.1	339	6.18	7.03	12.41	1.38	0.12	0.103	0.18	39.84	3.68	0.025	0.012	0.18	0.12	52
Permissible limits (Egypt's Law No. 458 of 2007 and Law No. 48 1998)																
	6.5–8.5	1000	6	6	10	3.5	2	1	0.5	250	45	0.3	0.4	0.5	0.1	

Table 7 Surface water quality index for Qalyubia irrigation Network for the years 2014 and 2022

Location	WQI 2022	Grading	Water quality rating	WQI 2014	Grading	Water quality rating
S1	35	B	Good	57	C	Poor
S4	36	B	Good	60	C	Poor
S5	37	B	Good	60	C	Poor
S7	38	B	Good	58	C	Poor
S9	41	B	Good	55	C	Poor
S10	40	B	Good	52	C	Poor

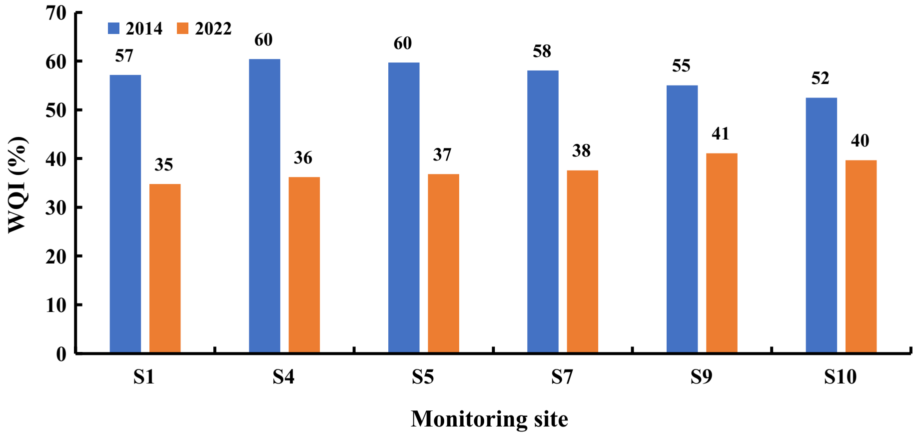

Fig. 5 WQI for Qalyubia irrigation network for the years 2014 and 2022

Correlation matrix (CM) for studied water quality parameters.

A correlation matrix (CM) was built to identify the relationship between the various water quality parameters of samples of the surface water concentration, such as BOD, Fe, Mn, and F, and the water quality index (WQI). For the 12 sites under study, this matrix was created for various parameters including pH, TDS, DO, BOD, COD, TN, TP, ON, NH_3, SO_4, NO_3, Fe, Mn, F, and O&G as well as the WQI. Spreadsheet Excel was used to execute CM (Table 8). The generated correlation matrix shows a substantial positive link between the higher values of WQI and TDS, SO_4, Fe, Mn, and F, whereas NH_3, ON, COD, and BOD also have a moderate negative relationship with the water quality index (WQI), which means that low WQI (high water quality) is associated with moderate surface water quality parameters concentrations for NH_3, ON, COD, and BOD. The correlations between pH, DO, NO_3, TP, TN, O&G, and WQI are weak. Analyzing the quality of the water can help with contamination prevention and resource exploitation (Abdel-Fatteh et al. 2020). In this work, we assessed water quality and primarily used the measured data to reveal the water quality state. The WQI performance, however, could be directly

Table 8 Correlation matrix (CM) of the WQI with the characteristics of the analyzed water quality

	pH	TDS	DO	BOD	COD	TN	TP	ON	NH$_3$	SO$_4$	NO$_3$	Fe	Mn	F	O&G	WQI
pH	1.000															
TDS	0.205	1.000														
DO	-0.054	-0.361	1.000													
BOD	0.050	-0.298	-0.599	1.000												
COD	0.107	-0.296	-0.672	0.968	1.000											
TN	0.067	0.128	-0.628	0.789	0.714	1.000										
TP	0.113	0.110	-0.694	0.854	0.807	0.910	1.000									
ON	-0.050	-0.496	-0.081	0.693	0.642	0.429	0.545	1.000								
NH$_3$	0.093	-0.256	-0.408	0.834	0.739	0.868	0.771	0.554	1.000							
SO$_4$	0.124	0.920	-0.026	-0.602	-0.613	-0.187	-0.199	-0.594	-0.537	1.000						
NO$_3$	-0.126	0.465	-0.804	0.619	0.555	0.789	0.824	0.263	0.521	0.184	1.000					
Fe	0.230	0.994	-0.312	-0.328	-0.320	0.089	0.088	-0.518	-0.304	0.933	0.417	1.000				
Mn	0.215	0.993	-0.302	-0.342	-0.335	0.073	0.073	-0.524	-0.319	0.938	0.409	1.000	1.000			
F	0.185	0.989	-0.354	-0.299	-0.296	0.152	0.112	-0.559	-0.244	0.905	0.448	0.990	0.989	1.000		
O&G	0.043	-0.152	0.650	-0.650	-0.610	-0.813	-0.855	-0.236	-0.673	0.134	-0.709	-0.137	-0.126	-0.196	1.000	
WQI	0.282	0.960	-0.215	-0.390	-0.379	-0.023	-0.045	-0.520	-0.381	0.934	0.316	0.965	0.966	0.943	0.086	1.000

impacted by human activities such as anthropogenic interference, industrial and home sewage outflow, and agricultural non-point source discharge. This phenomenon has been discovered and documented in some earlier investigations (Gad et al. 2022; Abdo et al. 2022). The overall assessment showed that the majority of the time, the water quality could be classified as "good" or "bad" and that upstream stations generally had better water quality than downstream ones. However, some parameters, such as BOD, COD, and NH$_3$-N, were found to be above threshold levels, indicating that additional efforts should be made to protect downstream water quality and that critical water parameters need to be limited in these years. Because each parameter's impact on the water status varies in some WQI aggregations, it is impossible to apply a unit weight for each one.

A low WQI rating due to a high concentration of a parameter with a high weight could lead to an incorrect perception of the water quality situation. A correct method of assigning the weights is therefore crucial. The weights utilized in this investigation were adapted from Pesce and Wunderlin, (2000) and Sun et al. (2016) and revised from those sources, which has also been supported by other studies. However, because it is outside the main focus of the study, the study did not look at the WQI weights' level of uncertainty. Therefore, more consideration must be given to the overall level of uncertainty in WQI evaluation since it is rarely investigated and analyzed. Varied protection aims and districts have different classification standards, which introduces some uncertainty in the evaluation. The WQI evaluation findings could vary if the standards are changed. The weights that different water quality parameters are given are another source of ambiguity. The weight assigned to each measure varied significantly in earlier studies on the evaluation of water quality (Ewaid et al. 2018; Seifi et al. 2020).

The Nile River in the Egypt Delta has seen new issues recently, and further investigation is still required to ascertain the precise reason for the change in water quality, which may vary with time and geography. For instance, difficulties include the growing population, urbanization, industrial effluent, agricultural fertilizers, untreated wastewater, and associated point and non-point sources of pollution (Abdel-Fatteh et al. 2020). The development of a linked hydrodynamic and water quality simulation model may help reveal the spatiotemporal variation and aid in the prediction of contamination concentration. Additionally, the WQI model built in this work can be linked with the simulation results that give data sources under various hydrological or hydrodynamic conditions to achieve comprehensive water quality evaluation. The model, which combined the physics-based hydrodynamic-water quality model and the statistical WQI model, was able to identify the source of pollution and offer exact preventative and control strategies for environments that were changing.

Conclusions

The Qalyubia Governorate in Egypt was selected to represent one of the highest population activities in the Delta. The water quality index (WQI) was used to test the overall water quality of the main water streams in the study area to determine its suitability for different uses, i.e., drinking, industrial, and irrigation. Water samples from different twelve monitoring stations (Sites S1 through S12) distributed within the Qalyubia Governorate's irrigation system were collected, analyzed, and evaluated, in 2021 and compared to water quality data from 2014 in the light of the Egyptian water quality standards for drinking and irrigation uses. These two main sets of data were chosen to reflect the WQI before and after the lockdown and halt of many human activities within the epidemic of COVID-19. A total of fifteen water quality indicators, including pH, TDS, DO, BOD, COD, TP, TN, ON, NH_3, SO_4, NO_3, Fe, Mn, O&G, and F, were assessed. The results display the WQI for the surface water monitoring sites measured in 2021 as good grade, exempting of S8, which show bad water quality index. The computed minimum, maximum, and average ± standard deviation for the WQI were 35 (good), 65 (poor), and (41 ± 7.5) (good). For S2 records, BOD concentrations were slightly above the Egyptian limit (6 mg/L), whereas S8 recorded a slight increase in Fe, Mn, and F compared to permissible concentrations. The minimum, maximum, and (average ± standard deviation) for TDS were 258.08, 318, and (249 ± 18.2) mg/L, respectively, indicating accepted quality for irrigation usage, but it should be purified before being used for drinking purposes. Water quality parameters had improved noticeably from 2014 to 2021, especially within the following sites: S1, S4, S5, S7, S9, and S10, probably due to the decrease in industrial activities during the epidemic and its illegal discharge of wastewater to the streams. The main factors contributing to the reduction in surface water quality in S8 are likely to be untreated illegal sewage discharge, inadequate industrial wastewater, and urban runoff discharge. Monitoring surface water quality is essential if water resource managers have to achieve sustainable development objectives. Management of surface water quality is a crucial step in assisting managers of water resources to accomplish their objectives for sustainable development. Future efforts to link water quality to United Nations-Water Sustainable Development Goal 6 are necessary and advised given that the research region serves as Egypt's main strategic water source and the economic and ecological hub of the Nile.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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