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Studies on Nile river pollution and water quality indicators in Egypt

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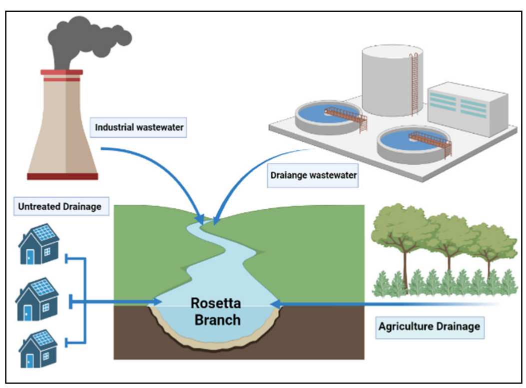
A B S T R A C T

The Nile River is an important natural and exclusive source of fresh water in Egypt. Water samples were taken monthly from twelve sites from 2015 to 2020 in El Beheira Governorate and eighteen physicochemical parameters were measured. The results show that the Rahawy drain recorded the highest values for most of the physicochemical parameters. The HPI and MI indicators in Rahawy drain were higher (70 % & 100 %) than in other sites, especially in the summer and winter seasons. The Rahawy WQI values were classified as poor quality. The IWQI results indicate that the water quality for the Rahawy was within the "severe restriction" class, with many restrictions to be used in agriculture. The water quality of the Nile River in the south of Egypt is better than that of the north and the water quality recovery takes more time and distance.



Graphical Abstract

Abbreviations

APHA American Public Health Association
HPI heavy metal pollution index
MI metal index
C_d degree of contamination
WQI water quality index
EWQS Egyptian water quality standard
IWQI irrigation water quality index

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1. Introduction

The river Nile is the main artery for fresh water in Egypt and is subjected to noncontrolled agriculture wastewater and anthropogenic effects. The Damietta branch is the eastern branch, about 229 km long. The western Rosetta branch is the primary water source for the west side of the Nile Delta, and it flows down the delta barrage to the northwest for 220 km. The water quality levels of the two branches are higher than the river Nile due to the discharge of different flows like agricultural, domestic, and industrial waste.[1] The Rosetta branch's main factors include agriculture, industrial effluents, and untreated sewage points. There are ten agricultural drains out of 43 central farming drains that follow the Egyptian standard for disposal of agriculture wastewater into the river, out of 67 drains from Aswan to the barrages of the Delta.[2] In upper Egypt, the agricultural drain's water quality is considered low in general, where Sail drain, Kom Umbo drain, and Etssa drain are the main drains identified as the main source of pollution. In Delta in northern Egypt, agricultural and domestic discharge negatively affect the drain water quality as it is receiving loads of pollution like El Rahawy, El baqr, Moheet, Umom drains.[1]

The Rahawy drain in the Delta region is one of the primary drains at the Rosetta branch, and it gets a lot of wastewaters from the Greater Cairo area. The Rahawy drain discharges approximately 2 million m^3/day of drainage water into the Rosetta branch, which significantly impacts the water quality of the branch.[3] There are two significant sources of pollution in the El Rahway drain that might impact and degrade the water quality: firstly, wastewater treatment plants, particularly Abu Rawash and Zenein, have a significant influence on the river's water quality. Secondly, farming and domestic waste from communities scattered along the drain discharge their waste straight into water canals without filtration.[4] High concentrations of organic pesticides and heavy metals pollutants which harming the aquatic ecosystem have been discovered in the El Rahawy drain outflow, according to El Bouraie *et al.*[5]

One of Egypt's largest wastewater treatment plants is the Abu-Rawash WWTP. It is regarded as a significant cause of water quality degradation by the Rahawy drain. At the Abu-Rawash facility, which can handle a peak flow of 1.654.249 m^3/day, only primary treatment is provided.[6] The plant collects more than 1.450.000 m^3 of raw wastewater each day, well above its intended capacity. Excess sewage is subsequently bypassed and dumped directly into the Rahawy drain, creating pollution in the Rahawy and Rosetta branches.

The chemical parameters for the Rahawy drain were studied and the tested variables were above the Egyptian law 48 level for raw water.[7]

Water quality assessment by measuring chemical and physical parameters is the most crucial stage in managing water ecosystems.[8] Simplifying the water parameter values for an extended period to a single value can make it easy to understand using water quality indices.[9] One of the essential tools used widely in assessing water quality for different water systems is the Canadian WQI; it can be used for a period such as a season or a year, not for a particular water quality problem.[10] The dissolved salt concentration forming the irrigated water depends on the water source, determining irrigation water suitability.[11] The IWQI is a new update for the WQI used to classify irrigation water using multiparameter analysis of surface water to minimize agricultural impacts.[12]

The heavy metal pollution indices are a qualitative method used to measure the effect of heavy metals in water. These indicators were formulated according to the importance of measuring heavy metals' negative impact. The heavy metal pollution approach is used to evaluate water suitability for drinking purposes.[13]

The Rosetta branch water quality was studied using the Canadian WQI, where WQI values felled within marginal, good, and fair categories for irrigation purposes and the tested chemical variables exceeded the standard Egyptian limit except for dissolved oxygen.[14]

A similar study was performed by Othman *et al.*[15] for the Rosetta branch. The Rahawy drain recorded 0.0 mg/L of dissolved oxygen, a high biological oxygen demand (BOD) concentration of 50.6 mg/L, and more elevated ammonia and nitrite concentrations than at other sites in the Rosetta branch.

The current study aims to: (1) assess the main Rosetta branch, Rayah Nasery canal, and Khandaq sharky canal water quality using multiple water quality indicators, including WQI, HPI, C_d, and MI, (2) assess the Rahawy drain's impact on the Rosetta branch, El-Beheira Governorate, (3) analyses the water quality for irrigation purposes, and (4) Examine the research area's geographical distribution of water quality indicators.

2. Material and methods

2.1. Study area

In the northern Cairo area, near the El-Kanater El-Khyria barrier, the river Nile separates into two main branches, the

Damietta and Rosetta branches. Rayah El-Nassery and Rayah El-Behery are two subbranches of the Rosetta branch; Rayah El-Menofy and Rayah El-Toufeky are two subbranches of the Damietta branch. The Rosetta branch is approximately 220 km long. Various pollutants flow into the Rosetta branch, among which the most critical source is the Rahawy drain. The Rahawy drain discharges 400,000 m^3/day of sewage and domestic and agricultural waste. As shown in (**Fig. 1**), the study sites extended through 3 paths. The first way, 120 km on the Rosetta branch, starting from the Nile River before mixing with the Rahawy drain (L1), Rahawy drain upstream (L2), and proceeding through Menofia and Gharbia Governorate with locations (L3, L4, L5, L6, L7) reaching Edfina city (L11).

The second path extended from northern Cairo before L1 to reach L12, called Rayah Nasery canal. The third path, the sub canal from the Rosetta branch, contains three locations L8, L9, and L10.

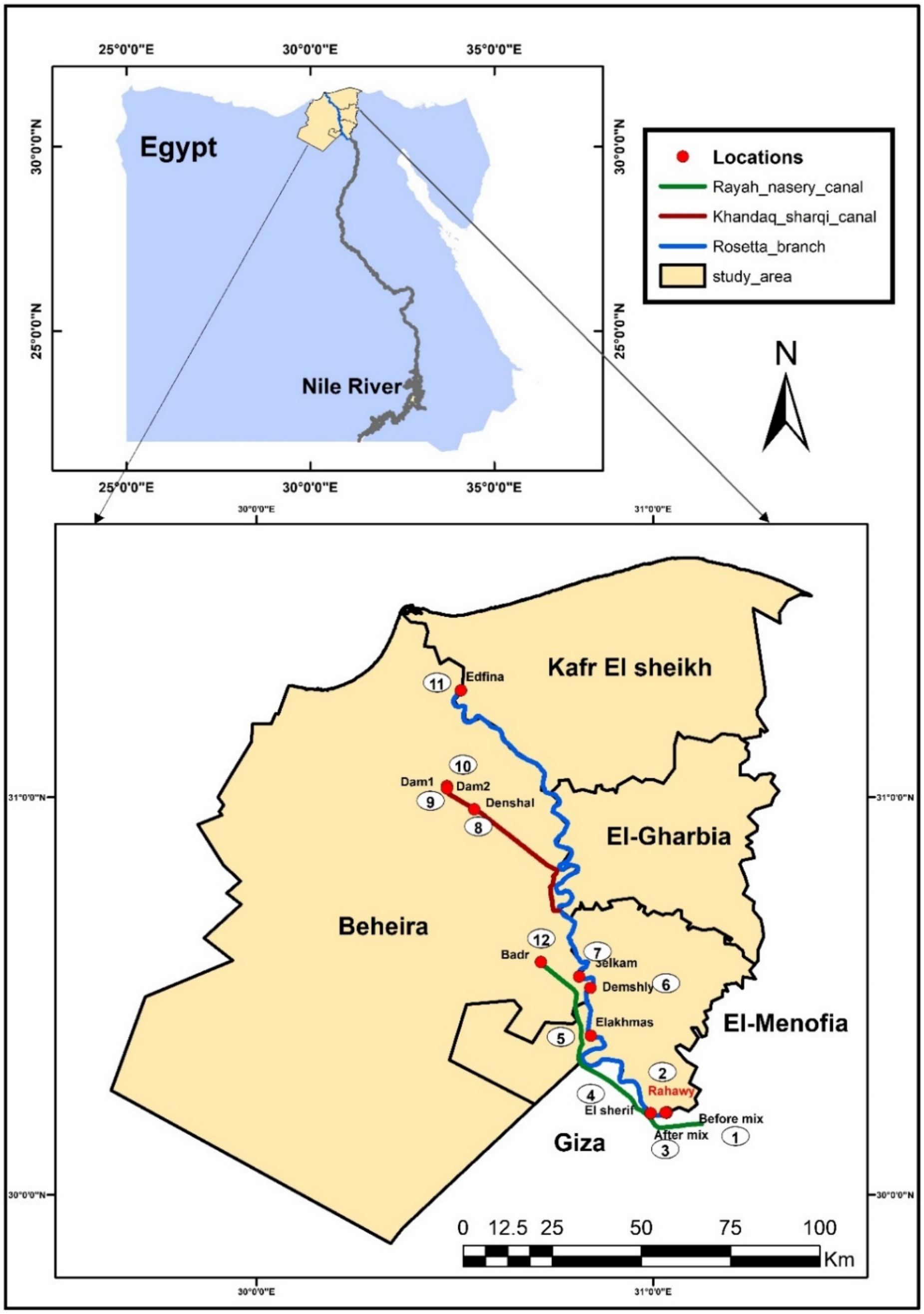

Fig. 1. The study locations cover twelve sites in the north part of the river Nile.

2.2. Sampling program

The sampling operation was conducted under technical requirements for regulating surface water and wastewater in the four seasons along the research area. Water samples were obtained just beneath the water surface, and the sampling was carried out according to the regular APHA 23rd edition water and waste examination methods. Water samples from each sampling location were obtained and examined for physical and chemical analyses. Water samples were collected from each site in various containers based on the characteristics required to be analyzed.

2.3. Sample collection

Twelve testing sites for water quality were set up, covering 320 km along the Rosetta branch, Khandaq El sharky, and El Rayah El Nasery. The area under investigation extended from Giza (30.208141 Lat. and 31.034169 Long.) to Edfina (31.269108 Lat 30.515166 Long.). Six of the twelve locations in the environmental monitoring system were chosen to study potential anthropogenic consequences of agricultural, municipal, and industrial wastewater activities on water quality. **Table 1** lists the water sampling locations.

Table 1. Sampling locations of the study area.

Site code	Name	Latitude	Longitude	Description
1.	Nile before mix	30.208141	31.034169	Rosetta branch
2.	Rahawy drain	30.205905	31.033857	Domestic and sewage wastes drain of Giza governorate
3.	Nile after mix	30.206625	31.030942	Rosetta branch
4.	El sheriff	30.20521	30.993781	Rosetta branch
5.	El akhmas	30.399875	30.842712	Rosetta branch
6.	Demshly	30.520538	30.841738	Rosetta branch
7.	Elkam	30.548944	30.81348	Rosetta branch
8.	Denshal WTP	30.969994	30.54889	Khandaq Sharky canal
9.	Damanhur 2	31.02836	30.479882	Khandaq Sharky canal
10.	Damanhur 1	31.022168	30.479964	Khandaq Sharky canal
11.	Edfina	31.269108	30.515166	Rosetta branch
12.	Badr	30.585555	30.716646	El-Rayah El Nasery Canal

2.4. Analytical procedures

For analysis of selected parameters, the study was carried out by selecting eighteen physicochemical variables that were compared with the Egyptian water quality standards, as shown in **Table 2**. A conductivity meter (Thermo, USA) and pH/mV/Temp meter (Thermo) were used for on-site pH and electric conductivity (EC). Chemical variables have been calculated following the procedures set out in the standard method.[16] A Thermo ICE 3500 atomic absorption spectrometer model (USA) was used for Fe, Mn, and Cu heavy metal measurements.[16] Cations and anions were measured by Dionex-600 (USA) ion chromatography using an instrumental manual. For each analysis, triplicate readings were recorded to assure accuracy.

Table 2. Water Quality Variables limits according to EWQS.[17]

No	Parameter	Guidelines EWQS
1.	pH	6.5-8.5
2.	TDS mg/L	1000
3.	Fe mg/L	0.3
4.	Mn mg/L	0.4
5.	Cu mg/L	2
6.	NO_3^- mg/L	45
7.	SO_4^{-2} mg/L	250
8.	NO_2^- mg/L	0.2
9.	Turbidity NTU	1
10.	Total hardness	500
11.	Cl^-	250
12.	Na^+ mg/L	200

3. Statistical Analysis and Water Quality Indices Approach

3.1 Statistical analysis

The data on the water samples for all variables were checked using a one-way ANOVA for major variations between seasons and sites. Also, using the Pearson correlation index, the relationships between different studied variables were determined.

3.2 Heavy metal pollution index (HPI)

The HPI uses a weighted arithmetic quality mean approach to assessing water quality and drinking compatibility for metals,[13] as shown in Eq. (1):

$$\text{HPI} = \sum_{i=1}^{n} Q_i W_i \,/\, \sum_{i=1}^{n} W_i \quad (1)$$

where W_i is the ith unit weight parameter, i is the ith metal subindex, and n is the number of the tested parameters. Q_i is calculated as represented in Eq. (2):

$$Qi = C_i/S_i * 100 \tag{2}$$

where C_i is the concentration of the ith metal in µg/L. S_i is the standard parameter concentration according to.[17] Prasad and Bose[13] calculated the critical value for the HPI index as 100.

3.3 Water quality index WQI

WQI is used to evaluate water quality; four or more parameters are required to calculate the WQI; the calculation equations are shown as follows:

$$\text{CCME WQI} = 100 - \left(\frac{\sqrt{f_1^2+f_2^2+f_3^2}}{1.732}\right) \tag{3}$$

F_1 (**Scope**): The % of variables exceeding the permitted value

$$F_1 = \frac{\text{No. of Failed Variables parameters}}{\text{Total No. of Variables}} * 100$$

F_2 (**Frequency**): The % of failed tests that exceeded the EWQS[17] levels

$$F_2 = \frac{\text{Total No. of Failed tests}}{\text{Total No. of Tests}} * 100$$

F_3 (**Amplitude**): Failed test values fall short of the requirements range.

$$F_3 = \frac{\text{nse}}{0.01\ \text{nse} + 0.01}$$

where $\text{nse} = \frac{\sum \text{excursion}}{\text{total number of test (Z)}}$, and $\text{excursion} = \frac{\text{Failed test value}}{\text{objectives}} - 1$

The WQI ranges from 0 to 100, representing water quality from poor to high quality. Five classes of water quality were illustrated in **Table 3** in the classification of WQI ratings according to EWQS[17].

Table 3. CCME WQI classes scheme according to the reported data.[18]

WQI value	Ecological condition
95–100	Excellent
80–94	Good
65–79	Fair
45–64	Marginal
0–44	Poor

3.4 Metallic index (MI)

The MI is another index for potable water.[19] As suggested by,[20] the expression of the metal index is given by:

$$MI = \sum (C_i / MAC_i) \tag{4}$$

where MAC_i is the maximum level of the metal i, and C_i is the mean concentration of metal i. The water quality gets worse when the metal concentration exceeds the MAC value. **Table 4** shows the classes of water quality based on the MI, where the value of MI > 1 is an alert threshold.[19]

Table 4. Classes of water quality using the metal index (MI).[19]

Class	MI	characteristics
1	< 0.3	Very pure
2	0.3-1	Pure
3	1-2	Slightly affected
4	2-4	Moderately affected
5	4-6	Strongly affected
6	>6	Seriously affected

3.5 Irrigation water Quality index IWQI

Meireles *et al.*[21] established the IWQI using the following parameters EC, HCO_3^-, Cl^-, sodium adsorption ratio: SAR and Na^+. The expression of the IWQI is given by:

$$\mathrm{IWQI} = \sum_{i=1}^{n} q_i w_i \quad (5)$$

where q_i is the parameter i quality, and w_i is the relative weight of parameter i represented in **Table 5**. The q_i values are calculated using the following equation according to **Table 6:**[22]

$$q_i = q_{imax} - \left\{ \frac{[(x_{ij} - x_{\inf}) \times q_{iamp}]}{x_{amp}} \right\} \quad (6)$$

where q_{imax} is the higher value in the q_i class; x_{ij} is the observed value for each parameter; x_{inf} is the lower limit of variable class; q_{iamp} is the class range, and x_{amp} is the parameter class range.

Table 5. The relative weight of parameters Meireles *et al.*[21]

Parameters	w_i
EC	0.211
Na^+	0.204
HCO_3^-	0.202
Cl^-	0.194
Sar	0.189
Total	1

Table 6. limiting values for quality measurements variables qi.[22]

qi	EC (µS/cm)	SAR (meq/L)	Na^+ (meq/L)	Cl^- (meq/L)	HCO_3^- (meq/L)
85–100	200 ≤ EC < 750	2 ≤ SAR < 3	2 ≤ Na < 3	1 ≤ Cl < 4	1 ≤ HCO3 < 1.5
60–85	750 ≤ EC < 1500	3 ≤ SAR < 6	3 ≤ Na < 6	4 ≤ Cl < 7	1.5 ≤ HCO3 < 4.5
35–60	1500 ≤ EC < 3000	6 ≤ SAR < 12	6 ≤ Na < 9	7 ≤ Cl < 10	4.5 ≤ HCO3 < 8.5
0–35	EC < 200 or EC ≥ 3000	SAR < 2 or SAR ≥ 12	Na < 2 or Na ≥ 9	Cl < 1 or Cl ≥ 10	HCO3 < 1 or HCO3 ≥ 8.5

Richards[23] calculated the SAR using the following equation:

$$\mathrm{SAR} = \frac{Na^+}{\frac{\sqrt{Ca^{+2} + Mg^{+2}}}{2}} \quad (7)$$

Four categories represent the IWQI results, (see **Table 7**).

Table 7. Irrigation water classes according to IWQI as calculated by Meireles *et al.*[21]

IWQI	Class
85–100	Null
70–85	Low
55–70	Moderate
40–55	High
0–40	Severe restriction

4. Results and discussion

4.1. Physical and chemical parameters change in the North of Egypt.

The water's suitability for drinking purposes was investigated by measuring the physicochemical parameters, as shown in (**Table 8** and **Table 9**).

Table 8. Physical variables for the study locations in the North of Egypt.

Location of Sampling		pH	Turbidity NTU	Ec µS/cm	TDS mg/l
Before mix	Mean	8.0	6.9	452.5	303.2
	Minimum	7.3	2.5	278.0	186.3
	Maximum	8.5	13.9	871.0	583.6
	Range	1.2	11.4	593.0	397.3
	Std. Deviation	0.3	3.1	106.2	71.1
El-Rahawy	Mean	7.4	60.9	1486.0	995.6
	Minimum	6.5	11.4	477.0	319.6
	Maximum	8.2	139.0	2504.0	1677.7
	Range	1.8	127.6	2027.0	1358.1
	Std. Deviation	0.3	28.4	392.5	263.0
After mix	Mean	7.5	27.2	886.4	593.9
	Minimum	7.1	4.2	282.0	188.9
	Maximum	8.1	60.0	1593.0	1067.3
	Range	1.1	55.8	1311.0	878.4
	Std. Deviation	0.2	14.9	326.0	218.4
El sherif	Mean	7.5	21.3	906.4	607.3
	Minimum	6.9	4.5	530.0	355.1
	Maximum	7.8	56.8	1411.0	945.4
	Range	0.9	52.3	881.0	590.3
	Std. Deviation	0.2	14.2	256.6	171.9
Elakhmas	Mean	7.5	17.5	842.5	564.5
	Minimum	6.9	2.5	459.0	307.5
	Maximum	8.0	61.5	1418.0	950.1
	Range	1.1	59.0	959.0	642.5
	Std. Deviation	0.2	14.7	247.6	165.9
Demshly	Mean	7.7	8.6	667.7	447.3
	Minimum	6.9	3.0	6.4	4.3
	Maximum	8.0	32.0	1033.0	692.1
	Range	1.1	29.0	1026.7	687.9
	Std. Deviation	0.2	5.2	206.5	138.4
Elkam	Mean	7.7	9.4	663.3	444.4
	Minimum	6.7	3.2	6.3	4.2
	Maximum	8.1	48.0	1126.0	754.4
	Range	1.4	44.8	1119.7	750.2
	Std. Deviation	0.3	7.9	215.0	144.0
Denshal	Mean	7.9	10.2	453.6	303.9
	Minimum	7.1	0.2	267.0	179.0
	Maximum	8.9	27.9	685.0	459.0
	Range	1.8	27.7	418.0	280.0
	Std. Deviation	0.3	4.7	93.6	62.7
Damanhur 1	Mean	7.9	9.9	465.5	298.6
	Minimum	7.2	2.4	305.0	0.0
	Maximum	8.3	26.8	954.0	620.1
	Range	1.2	24.4	649.0	620.1
	Std. Deviation	0.2	4.1	103.2	75.1
Damanhur 2	Mean	7.9	12.1	453.7	291.6
	Minimum	7.3	2.7	299.0	0.0
	Maximum	8.7	36.0	666.0	432.9
	Range	1.4	33.3	367.0	432.9
	Std. Deviation	0.2	6.5	83.5	62.4
Edfina	Mean	7.7	4.0	667.4	433.8
	Minimum	6.9	0.5	357.0	232.1
	Maximum	8.6	12.0	1002.0	651.3
	Range	1.7	11.5	645.0	419.3
	Std. Deviation	0.3	1.8	154.3	100.3
Badr	Mean	8.1	8.0	423.4	283.7
	Minimum	6.8	2.4	307.0	205.7
	Maximum	8.9	26.0	573.0	383.9
	Range	2.1	23.6	266.0	178.2
	Std. Deviation	0.4	4.8	67.5	45.2

Table 9. Cations and anions analysis for the study locations.

Sampling Locations		Cl^- mg/l	SO_4^{2-} mg/l	PO_4^{-3} mg/l	NO_2^- mg/l	NO_3^- mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^+ mg/l	K^+ mg/l
Before mix	Mean	47.4	43.0	0.1	42.9	6.1	12.7	35.4	39.8	5.8
	Minimum	14.0	15.0	0.0	27.0	3.8	7.5	19.6	27.0	3.8
	Maximum	205.0	148.0	1.9	130.0	12.0	24.5	48.4	69.0	7.8
	Range	191.0	133.0	1.9	103.0	8.2	17.0	28.8	42.0	4.0
	Std. Deviation	40.7	26.3	0.3	19.0	1.5	3.6	5.9	12.1	1.1
Rahawy	Mean	230.7	130.1	2.3	170.3	24.1	26.0	55.0	175.8	13.1
	Minimum	42.0	30.0	0.0	35.0	7.3	6.3	21.6	58.0	7.3
	Maximum	412.0	399.0	6.2	349.0	401.0	66.5	86.8	349.0	20.0
	Range	370.0	369.0	6.2	314.0	393.7	60.3	65.2	291.0	12.8
	Std. Deviation	92.3	62.2	1.6	65.0	64.7	13.2	15.7	61.9	3.5
After mix	Mean	123.1	77.9	1.2	97.4	9.0	46.6	17.3	97.2	9.0
	Minimum	21.0	25.0	0.0	39.0	4.6	21.6	6.3	39.0	4.6
	Maximum	337.0	157.0	3.9	208.0	20.4	83.6	35.0	208.0	20.4
	Range	316.0	132.0	3.9	169.0	15.8	62.0	28.7	169.0	15.8
	Std. Deviation	67.6	30.1	1.0	39.3	3.3	14.1	6.1	41.1	3.4
El sherif	Mean	104.6	72.9	0.9	86.3	8.9	16.9	43.5	88.0	8.8
	Minimum	21.0	22.0	0.0	9.0	0.0	9.8	28.4	10.9	5.1
	Maximum	220.0	160.0	4.4	143.0	13.3	25.5	60.0	143.0	13.3
	Range	199.0	138.0	4.4	134.0	13.3	15.7	31.6	132.1	8.2
	Std. Deviation	50.5	33.3	0.9	30.6	2.5	3.8	6.9	31.6	2.0
Elakhmas	Mean	94.5	65.7	0.8	79.8	8.2	16.0	41.3	77.8	8.0
	Minimum	35.0	28.0	0.0	37.0	2.2	4.6	13.2	37.0	2.2
	Maximum	244.0	165.0	4.0	135.0	13.5	36.5	52.4	135.0	13.5
	Range	209.0	137.0	4.0	98.0	11.3	31.9	39.2	98.0	11.3
	Std. Deviation	46.7	27.3	0.8	25.1	2.1	5.0	7.5	24.6	2.2
Demshly	Mean	71.0	53.8	0.7	64.1	7.2	14.8	39.6	63.8	7.2
	Minimum	22.0	25.0	0.0	31.0	4.0	6.5	21.2	31.0	4.0
	Maximum	126.0	125.0	3.9	104.0	10.2	36.5	56.8	104.0	10.2
	Range	104.0	100.0	3.9	73.0	6.2	30.0	35.6	73.0	6.2
	Std. Deviation	28.8	19.8	0.7	22.1	1.7	5.3	7.3	21.5	1.8
Elkam	Mean	70.8	56.1	0.6	62.1	7.3	15.0	39.7	63.4	7.2
	Minimum	32.0	23.0	0.0	0.4	3.7	6.9	21.6	32.0	3.7
	Maximum	136.0	127.0	3.6	121.0	11.4	44.0	56.4	121.0	11.4
	Range	104.0	104.0	3.6	120.6	7.7	37.1	34.8	89.0	7.7
	Std. Deviation	28.2	23.5	0.7	23.9	1.8	6.0	7.7	22.5	1.8
Denshal	Mean	31.6	35.4	0.1	0.1	1.0	34.4	13.6	38.8	6.1
	Minimum	11.9	11.0	0.0	0.0	0.0	21.2	3.8	19.0	3.2
	Maximum	74.5	84.0	2.5	0.5	5.3	50.0	21.0	67.7	8.7
	Range	62.6	73.0	2.5	0.5	5.3	28.8	17.2	48.7	5.5
	Std. Deviation	13.3	14.3	0.3	0.1	0.9	5.3	3.5	11.4	1.1
Damanhur 1	Mean	37.5	32.9	0.1	0.1	1.5	34.3	12.9	40.6	6.6
	Minimum	15.0	12.0	0.0	0.0	0.0	0.0	0.0	20.0	3.5
	Maximum	90.0	117.0	3.4	0.8	4.8	56.8	24.5	110.0	24.7
	Range	75.0	105.0	3.4	0.8	4.8	56.8	24.5	90.0	21.2
	Std. Deviation	14.7	14.9	0.4	0.1	0.9	7.7	4.2	13.3	2.6
Damanhur 2	Mean	30.9	36.4	0.1	0.1	1.4	32.5	12.0	38.7	6.9
	Minimum	12.0	15.0	0.0	0.0	0.0	0.0	0.0	7.0	1.9
	Maximum	58.0	90.0	0.5	0.7	5.0	48.0	20.6	66.0	60.2
	Range	46.0	75.0	0.5	0.7	5.0	48.0	20.6	59.0	58.3
	Std. Deviation	10.5	12.3	0.1	0.1	0.9	10.7	4.7	11.1	6.7
Edfina	Mean	70.8	53.8	0.5	0.7	3.4	42.9	16.1	64.5	7.5
	Minimum	25.0	28.0	0.0	0.0	0.0	31.2	5.5	34.0	3.7
	Maximum	160.0	97.0	2.9	3.3	14.7	60.4	24.0	110.0	11.4
	Range	135.0	69.0	2.9	3.3	14.7	29.2	18.5	76.0	7.7
	Std. Deviation	27.8	17.5	0.6	0.7	3.2	7.3	4.1	20.1	1.7
Badr	Mean	29.6	33.2	0.1	0.0	1.2	34.9	12.4	36.5	6.0
	Minimum	13.0	15.0	0.0	0.0	0.0	26.0	5.0	20.0	2.5
	Maximum	80.0	84.0	0.9	0.4	3.3	61.6	32.5	54.1	13.4
	Range	67.0	69.0	0.9	0.4	3.3	35.6	27.5	34.1	10.9
	Std. Deviation	12.3	10.7	0.2	0.1	0.6	6.2	3.8	9.3	1.5

Before and after the contamination point sources, there was a drop in all water quality parameters values. The parameter concentrations from locations 2-7 were higher than those of the other sites with water quality degradation until reaching location 8, where the water quality tends to get lower and maintain the quality of location 1. The turbidity ranged from 60.86 to 3.9 NTU, with Edfina recording the lowest value of 3.99 NTU, much higher than the EWQS permissible limit of 1 NTU. Moreover, the most significant value was 60.86 NTU at the Rahawy, as shown in (**Fig. 2**). In addition to clay and silt, suspended organic and inorganic materials, considered colloidal particles, are turbidity indicators in water and are often the leading cause of water turbidity.[10]

The turbidity showed a statistically significant difference between locations, as demonstrated by one-way ANOVA ($F_{(11,638)} = 93.65$, $p = .00$), as shown in **Table 10**. A significant difference between Rahawy and L1, with an average difference of 53.9 NTU ($p < .01$), and between Rahawy and L3, with an average difference of 33.7 NTU ($p < .01$) according to Tukey's post hoc test. Between Rahawy and L4, the average difference was 39.6 NTU ($p < .01$), and between Rahawy and L5, the average difference was 43.35 NTU ($p < .01$). Between Rahawy and L6, the average difference was 52.29 NTU ($p < .01$), and between Rahawy and L7, the average difference was 51.41 NTU ($p < .01$). Between Rahawy and L8, the average difference was 50.62 NTU ($p < .01$), and between Rahawy and L9, the average difference was 50.94 NTU ($p < .01$). Between Rahawy and L10, the average difference was 48.77 NTU ($p < .01$), and between Rahawy and L11, the average difference was 56.86 NTU ($p < .01$). Moreover, finally, between Rahawy and L12 was 52.86 NTU ($p < .01$). A Tukey's post hoc test showed no significant difference between L1, L6, L7, L8, L9, L10, and L12 ($p > .05$).

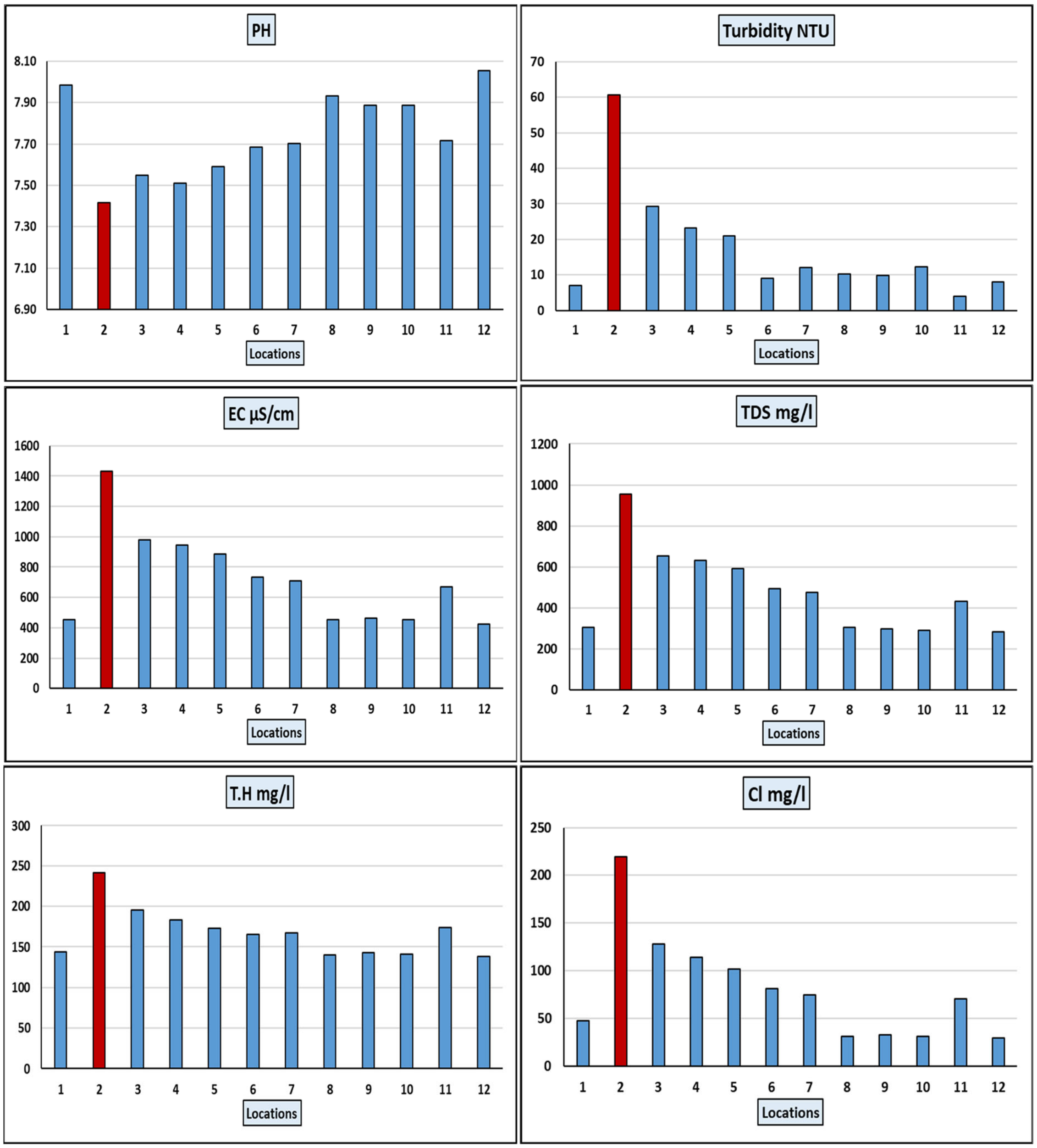

Fig. 2. The trend of the pH, turbidity, EC, TDS, T.H, and Cl^- measurements.

The investigated sample pH values vary from 7.37 to 8.06, which means that the samples are neutral to slightly alkaline. The overall pH values were within the desirable limit of 6.5-8.5 for all sampling sites (see **Table 8**). The Rahawy drain recorded the lowest pH value of 7.37 ± 0.3 (**Fig. 2**) due to the liquid waste in the drain, containing phytoplankton, bacteria, and fungi with many organic acids.[24]

The pH showed a statistically significant difference between locations, as demonstrated by one-way ANOVA ($F(11,638) = 31.79$, $p = .00$), as shown in **Table 10**. A significant difference between Rahawy and all locations ($p < .01$) except L3, L4, and L5 ($p > .05$) after applying Tukey's post hoc test. No significant difference showed between L1, L8, L9, L10, and L12 ($p > .05$).

The presence of carbonates, bicarbonate, and carbon dioxide controls the water pH level.[25] The measured pH values agree with many authors' results.[7, 26]

Table 10. ANOVA table for pH, turbidity, EC, and TDS analysis in study locations

			Sum of Squares	df	F	Sig.
pH * Location of Sampling	Between Groups	(Combined)	25	11	31.794	0.000
	Within Groups		46	638		
	Total		72	649		
turbidity NTU * Location of Sampling	Between Groups	(Combined)	102243	11	93.657	0.000
	Within Groups		63317	638		
	Total		165561	649		
Electric Conductivity µS/cm * Location of Sampling	Between Groups	(Combined)	44159668	11	117.129	0.000
	Within Groups		21866996	638		
	Total		66026664	649		
Total dissolved solids mg/L * Location of Sampling	Between Groups	(Combined)	20313496	11	119.261	0.000
	Within Groups		9909964	640		
	Total		30223460	651		

The EC showed a statistically significant difference between locations, calculated by one-way ANOVA ($F (11,638) = 117.129$, $p = .00$). A significant difference between the Rahawy and L1, with an average difference of 1031 µS/cm ($p < .01$), and between Rahawy and L3, with an average difference of 597 µS/cm ($p < .01$) based on Tukey's post hoc test. Between Rahawy and L4, the average difference was 577 µS/cm ($p< .01$), and between Rahawy and L5, the average difference was 641 µS/cm ($p< .01$). Between Rahawy and L6, the average difference was 815 µS/cm ($p< .01$), and between Rahawy and L7, the average difference was 820 µS/cm ($p< .01$). Between Rahawy and L8, the average difference was 1029 µS/cm ($p< .01$), and between Rahawy and L9, the average difference was 1018 µS/cm ($p< .01$). Between Rahawy and L10, the average difference was 1029 µS/cm ($p< .01$), and between Rahawy and L11, the average difference was 816 µS/cm ($p< .01$). Furthermore, between Rahawy and L12, the average difference was 1060 µS/cm ($p< .01$). No significant difference showed between L1, L8, L9, L10, and L12 ($p > .05$).

The mean EC values of the study area ranged from 423 to 1484 µS/cm (see **Table 8**). The high EC values at the Rahawy drain are starting to decrease until reaching Damanhur and Edfina (**Fig. 2**).

The TDS is the most critical parameter for water quality evaluation due to its correlation with water turbidity, conductivity, and hardness. The range of TDS mean values was 284-993 mg/L. TDS values were within the allowable drinking water limits. The TDS values revealed a statistically significant difference between locations as established by one-way ANOVA ($F (11,640) = 119.26$, $p = .00$). A significant difference between Rahawy and L1, with an average difference of 690 mg/L ($p < .01$), and between Rahawy and L3, with an average difference of 399 mg/L ($p < .01$) using Tukey's post hoc test. Between Rahawy and L4, the average difference was 385 mg/L ($p< .01$), and between Rahawy and L5, the average difference was 428 mg/L ($p< .01$). Between Rahawy and L6, the average difference was 545 mg/L ($p< .01$), and between Rahawy and L7, the average difference was 548 mg/L ($p< .01$). Between Rahawy and L8, the average difference was 689 mg/L ($p< .01$), and between Rahawy and L9, the average difference was 694 mg/L ($p< .01$). Between Rahawy and L10, the average difference was 701 mg/L ($p< .01$), and between Rahawy and L11, the average difference was 559 mg/L ($p< .01$). Moreover, the average difference between Rahawy and L12 was 709 mg/L ($p< .01$). Tukey's post hoc test showed no significant difference between L1, L8, L9, L10, and L12 ($p > .05$).

The Cl^- mean concentrations ranged from 29.0 to 230.5 mg/L; the Cl^- values at Rahawy drain exceeded the permissible drinking water limits of 250 mg/l according to the EWQS during the four seasons. While the Cl^- levels in most sites were below the permissible drinking water limits (see **Fig. 2**). The Cl^- values revealed a statistically significant difference between locations as established by one-way ANOVA ($F (11,628) = 100.4$, $p = .00$) (see **Table 11**). A significant difference between Rahawy and L1, with an average difference of 183 mg/L ($p < .01$), and between Rahawy and L3, with an average difference of 107 mg/L ($p < .01$) according to Tukey's post hoc test. Between Rahawy and L4, the average difference was 126 mg/L ($p< .01$), and between Rahawy and L5, the average difference was 136 mg/L ($p< .01$). Between Rahawy and L6, the average difference was 159 mg/L ($p< .01$), and between Rahawy and L7, the average difference was 159 mg/L ($p< .01$). Between Rahawy and L8, the average difference was 199 mg/L ($p< .01$), and between Rahawy and L9, the average difference was 193 mg/L ($p< .01$). Between Rahawy and L10, the average difference was 199 mg/L ($p< .01$), and between Rahawy and L11, the average difference was 159 mg/L ($p< .01$). Furthermore, the average difference between Rahawy and L12 was 201 mg/L ($p< .01$). There is no significant difference between L1, L8, L9, L10, and L12 ($p > .05$). High chloride levels in drains may be associated with sulfur compound effluent [27], attributed to the flood period. Furthermore, farm runoff discharges into drains after washing reclaimed lands.

The mean concentrations of SO_4^{2-} ranged from 30.3 to 136.3 mg/L, and sulphate showed a remarkable increase in Rahawy drain compared with other sites (**Fig. 3**). The maximum SO_4^{2-} value recorded in the Rahawy drain was 399 mg\L, much higher than the EWQS permissible limit of 250 mg\L. The SO_4^{2-} values revealed a statistically significant difference between locations as established by one-way ANOVA ($F(11,628) = 54.48$, $p = .00$), as shown in **Table (11)**. A significant difference between Rahawy and L1, with an average difference of 87 mg/L ($p < .01$), and between Rahawy and L3, with an average difference of 52 mg/L ($p < .01$) based on Tukey's post hoc test. Between Rahawy and L4, the average difference was 57 mg/L ($p < .01$), and between Rahawy and L5, the average difference was 64 mg/L ($p < .01$). Between Rahawy and L6, the average difference was 76 mg/L ($p < .01$), and between Rahawy and L7, the average difference was 73 mg/L ($p < .01$). Between Rahawy and L8, the average difference was 94 mg/L ($p < .01$), and between Rahawy and L9, the average difference was 97 mg/L ($p < .01$). Between Rahawy and L10, the average difference was 93 mg/L ($p < .01$), and between Rahawy and L11, the average difference was 76 mg/L ($p < .01$). Furthermore, between Rahawy and L12, the average difference was 96 mg/L ($p < .01$). Tukey's post hoc test showed no significant difference between L1, L8, L9, L10, and L12 ($p > .05$).

The mean NO_2^- values ranged between 0.04 and 170 mg/l at the study locations. The NO_2^- showed a remarkable level in the Rahawy drain compared with other sites, where the maximum NO_2^- value recorded in the Rahawy drain was 349 ±65 mg\L, much higher than the EWQS permissible limit of 0.2 mg\L. The high NO_2^- levels remain high in L3, L4, L5, L6, and L7 until NO_2^- concentrations drop down, starting from L8, L9, L10, L11, and L12 (see **Fig. 3**). The NO_2^- values revealed a statistically significant difference between locations as established by one-way ANOVA ($F(11,629) = 269.5$, $p = .00$), as shown in **Table 11**. This result coincides with the work of (Othman et al., 2020), where the nitrite levels showed a remarkable increase at the Rahawy site. The low nitrite levels are attributed to nitrobacteria, accelerating the conversion from nitrite to nitrate [28]. A significant difference between Rahawy and L1, with an average difference of 127 mg/L ($p < .01$), and between Rahawy and L3, with an average difference of 72.9 mg/L ($p < .01$). Between Rahawy and L4, the average difference was 84 mg/L ($p < .01$), and between Rahawy and L5, the average difference was 90 mg/L ($p < .01$). Between Rahawy and L6, the average difference was 106 mg/L ($p < .01$), and between Rahawy and L7, the average difference was 108 mg/L ($p < .01$). Between Rahawy and L8, the average difference was 170 mg/L ($p < .01$), and between Rahawy and L9, the average difference was 170 mg/L ($p < .01$). Between Rahawy and L10, the average difference was 170 mg/L ($p < .01$), and between Rahawy and L11, the average difference was 169.6 mg/L ($p < .01$). Moreover, the average difference between Rahawy and L12 was 170 mg/L ($p < .01$). Tukey's post hoc test showed no significant difference between L8, L9, L10, L11, and L12 ($p > .05$).

The NO_3^- mean concentrations ranged from 0.00 to 401 mg/L, the maximum NO_3^- value recorded in the Rahawy drain was 401 ±64.7 mg\L, while the NO_3^- levels in most sites were below the permissible drinking water limits. L12 recorded the lowest level of NO_3^- at 1.2 ±0.6 mg\L (see **Fig. 3**). The NO_3^- values revealed a statistically significant difference between locations as established by one-way ANOVA ($F(11,527) = 5.7$, $p = .00$) (see **Table 11**). A significant difference between Rahawy and L1, with an average difference of 17.97 mg/L ($p < .01$), and between Rahawy and L3, with an average difference of 15.15 mg/L ($p < .05$), according to Tukey's post hoc test. Between Rahawy and L4, the average difference was 15.24 mg/L ($p < .05$), and between Rahawy and L5, the average difference was 15.9 mg/L ($p < .01$). Between Rahawy and L6, the average difference was 16.87 mg/L ($p < .01$), and between Rahawy and L7, the average difference was 16.79 mg/L ($p < .01$). Between Rahawy and L8, the average difference was 23 mg/L ($p < .01$), and between Rahawy and L9, the average difference was 22.6 mg/L ($p < .01$). Between Rahawy and L10, the average difference was 22.7 mg/L ($p < .01$), and between Rahawy and L11, the average difference was 20.7 mg/L ($p < .01$). Furthermore, between Rahawy and L12, the average difference was 22.96 mg/L ($p < .01$). No significant difference has been shown between L1, L3, L4, L5, L6, L7, L8, L9, L10, L11, and L12 ($p > .05$).

The mean PO_4^{3-} values ranged between 0.07 and 2.34 mg/L at the study locations. The PO_4^{3-} showed a notable increase in the Rahawy drain compared with other sites, where the maximum PO_4^{3-} value recorded in the Rahawy drain was 2.34 ±1.55 mg\L. The high PO_4^{3-} levels remain high in L3, L4, L5, L6, and L7 until phosphate concentrations drop down, starting from L8, L9, L10, L11, and L12 (see **Fig. 3**). The PO_4^{3-} values revealed a statistically significant difference between locations as established by one-way ANOVA ($F(11,629) = 43.8$, $p = .00$) (see **Table 11**). A significant difference between Rahawy and L1, with an average difference of 2.2 mg/L ($p < .01$), and between Rahawy and L3, with an average difference of 1.15 mg/L ($p < .05$) based on Tukey's post hoc test. Between Rahawy and L4, the average difference was 1.4 mg/L ($p < .05$), and between Rahawy and L5, the average difference was 1.5 mg/L ($p < .01$). Between Rahawy and L6, the average difference was 1.68 mg/L ($p < .01$), and between Rahawy and L7, the average difference was 1.7 mg/L ($p < .01$). Between Rahawy and L8, the average difference was 2.22 mg/L ($p < .01$), and between Rahawy and L9, the average difference was 2.19 mg/L ($p < .01$). Between Rahawy and L10, the average difference was 2.26 mg/L ($p < .01$), and between Rahawy and L11, the average difference was 1.79 mg/L ($p < .01$). Furthermore, between Rahawy and L12, the average difference was 2.27 mg/L ($p < .01$). Tukey's post hoc test showed no significant difference between L1, L8, L9, L10, and L12 ($p > .05$).

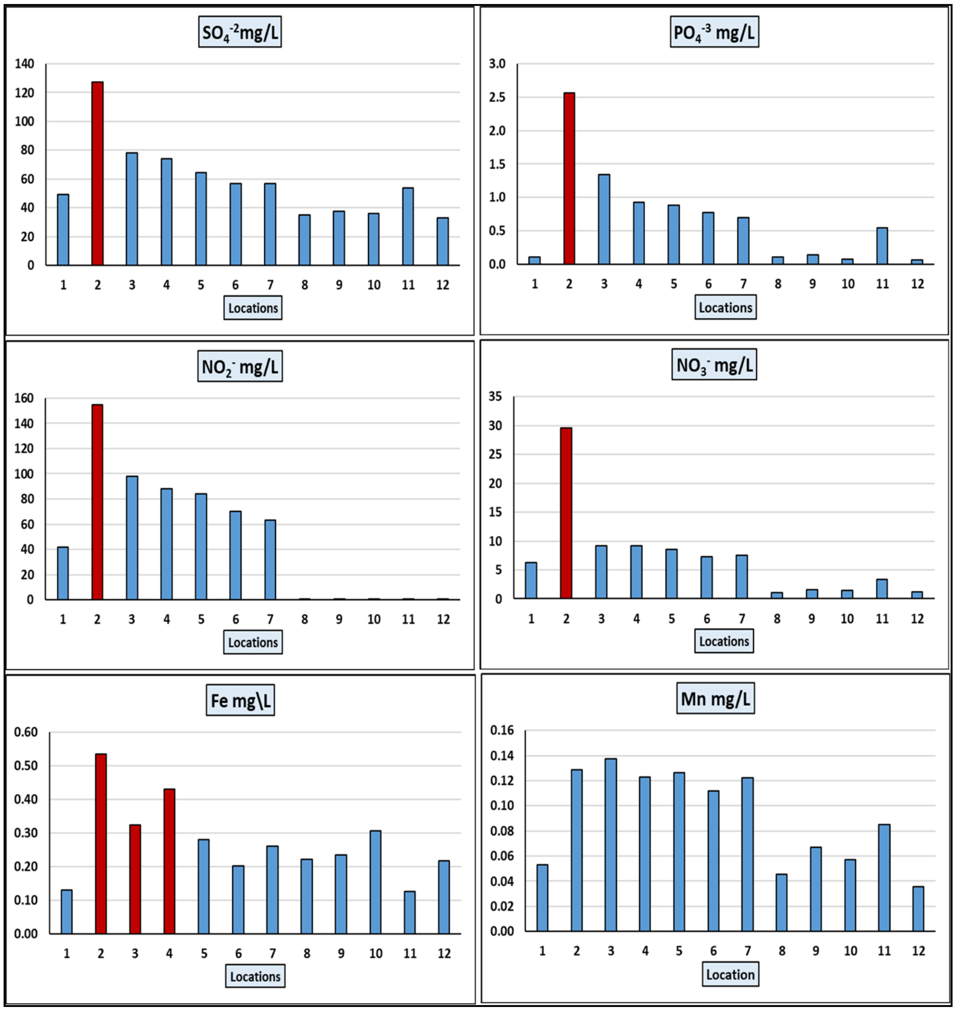

Fig. 3. The trend of SO_4^{-2}, PO_4^{-3}, NO_2^-, NO_3^-, Fe, and Mn measurements.

Table 11. ANOVA table for Cl^-, SO_4^{-2}, PO_4^{-3}, NO_2^-, NO_3^-, Ca^{+2}, Mg^{+2}, Na, and K analysis in study locations.

			Sum of Squares	df	F	Sig.
Chloride mg/l * Locations	Between Groups	(Combined)	1528417	11	100.4	0.000
	Within Groups		869443	628		
	Total		2397860	639		
SO_4^{-2} mg/l * Locations	Between Groups	(Combined)	356075	11	54.5	0.000
	Within Groups		373127	628		
	Total		729202	639		
phosphate mg/l * Locations	Between Groups	(Combined)	200	11	43.8	0.000
	Within Groups		261	629		
	Total		461	640		
Nitrite mg/l * Locations	Between Groups	(Combined)	1491565	11	269.5	0.000
	Within Groups		316436	629		
	Total		1808001	640		
Nitrate mg/l * Locations	Between Groups	(Combined)	17800	11	5.7	0.000
	Within Groups		148393	527		
	Total		166193	538		
Calcium mg/l * Locations	Between Groups	(Combined)	119492242	11	1.6	0.093
	Within Groups		4322923978	638		
	Total		4442416220	649		
Magnesium mg/l * Locations	Between Groups	(Combined)	133907	11	324.1	0.000
	Within Groups		23963	638		
	Total		157870	649		
Sodium mg/l * Locations	Between Groups	(Combined)	677617	11	101.5	0.000
	Within Groups		337980	557		
	Total		1015597	568		
Potassium mg/l * Locations	Between Groups	(Combined)	1671	11	16.4	0.000
	Within Groups		5154	557		
	Total		6825	568		

The bicarbonate anion and sodium cation were the most concentrated ions. The order was as follows: anions HCO_3^- > Cl^- > SO_4^{2-} > CO_3^-, and cations Na^+ > Ca^{2+} > Mg^{2+} ~ NH_4^+> K^+. HCO_3^- is the dominant anion, ranging from 56.0 to 340.5 mg/l with a mean value of 206.9 ±63.8 mg/l. The Rahawy drain recorded the highest HCO_3^- concentration with a mean value of 317 ±53.3 mg/l (**Fig. 4**), similar to that obtained by Othman, Al-Afify.[15] The HCO_3^- values revealed a statistically significant difference between locations as established by one-way ANOVA ($F (11,60) = 69.49$, $p = .00$). A significant difference between Rahawy and L1, with an average difference of 119.7 mg/L ($p < .01$), and between Rahawy and L3, with an average difference of 59 mg/L ($p < .01$) based on Tukey's post hoc test. Between Rahawy and L4, the average difference was 64.4 mg/L ($p< .01$), and between Rahawy and L5, the average difference was 70.9 mg/L ($p< .01$). Between Rahawy and L6, the average difference was 85.3 mg/L ($p< .01$), and between Rahawy and L7, the average difference was 93 mg/L ($p< .01$). Between Rahawy and L8, the average difference was 161 mg/L ($p< .01$), and between Rahawy and L9, the average difference was 125 mg/L ($p< .01$). Between Rahawy and L10, the average difference was 124 mg/L ($p< .01$), and between Rahawy and L11, the average difference was 246 mg/L ($p< .01$). Moreover, the average difference between Rahawy and L12 was 170 mg/L ($p< .01$). Tukey's post hoc test showed no significant difference between L1, L8, L9, L10, and L12 ($p > .05$).

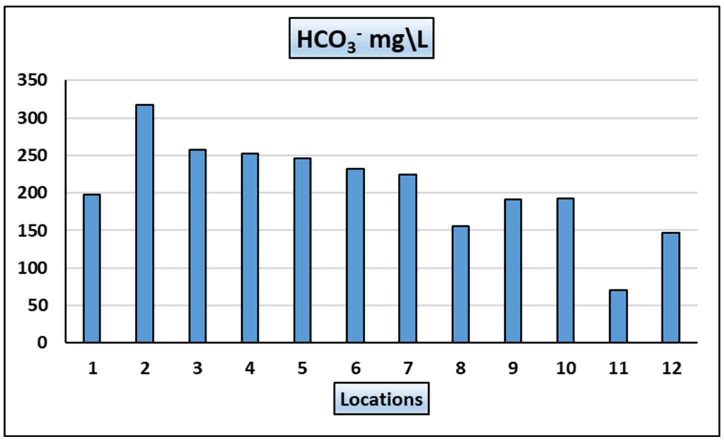

Fig. 4. The mean concentration of HCO_3^- during the study period for the twelve locations.

The dominant Na^+ cation ranges from 36.4 to 175.8 mg\L, with a mean value of 78.7 ±39.6 mg\L. The Rahawy showed the highest Na^+ concentration with a maximum value of 349 ±61.9 mg/l (**Fig. 5**), exceeding the permissible limits (200 mg/l EWQS). The Na^+ values revealed a statistically significant difference between locations as established by one-way ANOVA ($F (11,557) = 101.5$, $p = .00$). A significant difference between Rahawy and L1, with an average difference of 136 mg/L ($p < .01$), and between Rahawy and L3, with an average difference of 78.6 mg/L ($p < .01$). Between Rahawy and L4, the average difference was 87.8 mg/L ($p< .01$), and between Rahawy and L5, the average difference was 98 mg/L ($p< .01$). Between Rahawy and L6, the average difference was 112 mg/L ($p< .01$), and between Rahawy and L7, the average difference was 112.4 mg/L ($p< .01$). Between Rahawy and L8, the average difference was 137 mg/L ($p< .01$), and between Rahawy and L9, the average difference was 135 mg/L ($p< .01$). Between Rahawy and L10, the average difference was 137 mg/L ($p< .01$), and between Rahawy and L11, the average difference was 111 mg/L ($p< .01$). Moreover, between Rahawy and L12, the average difference was 139.3 mg/L ($p< .01$). Tukey's post hoc test showed no significant difference between L1, L8, L9, L10, and L12 ($p > .05$). A higher sodium concentration than calcium and a significantly lower potassium concentration due to high potassium absorption characteristics indicate chemical fertilizer in agricultural drainage water [9].

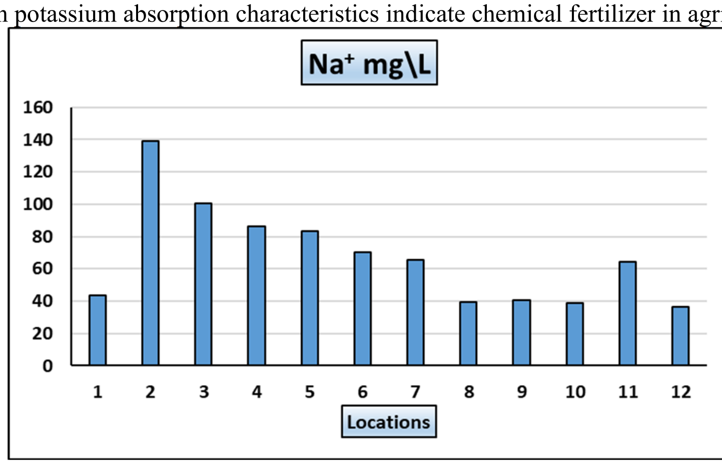

Fig. 4. The mean concentration of Na^+ during the study period for the twelve locations.

4.2. Seasonal variation and the correlations of physical and chemical parameters

Fig. 6 and **Fig. 7** present the seasonal variation in physicochemical variables of the water samples collected from 2015 to 2020.

The maximum turbidity value recorded was at the Rahawy drain in the spring, autumn, and winter season with significant variation, and the other locations showed insignificance variation between the seasons.

The Rahawy drain recorded the lowest pH value, especially in winter, compared with other seasons and the other locations showed slight variation between the seasons. The Rahawy drain recorded the highest EC values in spring, autumn, and winter, which agrees with previously obtained results H Hashem, I Tayel.[26] The lower EC value was recorded in L1 in summer, as shown in (**Fig. 6**).

The highest TDS value was recorded in the Rahawy location during the spring and winter seasons and exceeded permissible limits (1000 mg/l for drinking water. The lower TDS value was recorded in L1 in summer, as shown in (**Fig. 6**).

The maximum Cl^- value recorded in the Rahawy drain was in spring and winter. Furthermore, the recorded value in the autumn season exceeded permissible limits.

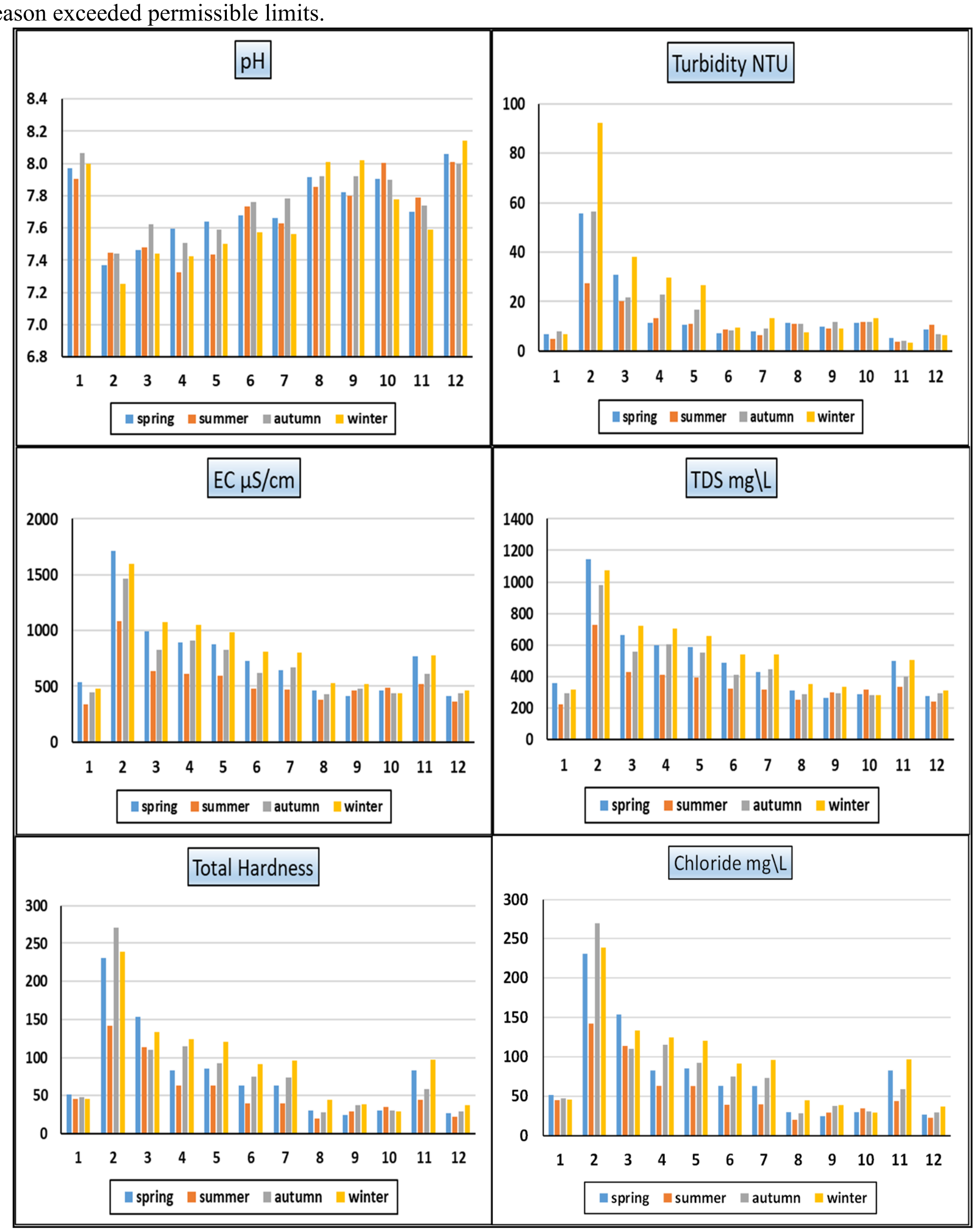

Fig. 5. Seasonal record for pH, turbidity, EC, TDS, TH, and Cl^-.

The sulphate records showed significant variation between the seasons, and the highest value was recorded in Rahawy drain in spring, autumn, and winter (**Fig. 7**).

The phosphate concentration showed significant variation between the seasons, as shown in (**Fig. 7**), where the highest values were recorded from location 2 to location 7. The Rahawy drain has the highest values among these six locations, especially in autumn and winter.

The nitrite and nitrate records starting from location 2 to location 7 have the same variation where the highest values were recorded in the spring, autumn, and winter seasons.

The iron records get over the permissible limit in the Rahawy location in spring, summer, and winter. For the other locations, the summer and winter seasons were common seasons where the iron exceeded the limit. Manganese and Copper values were below the permissible limit during the four seasons for all the locations.

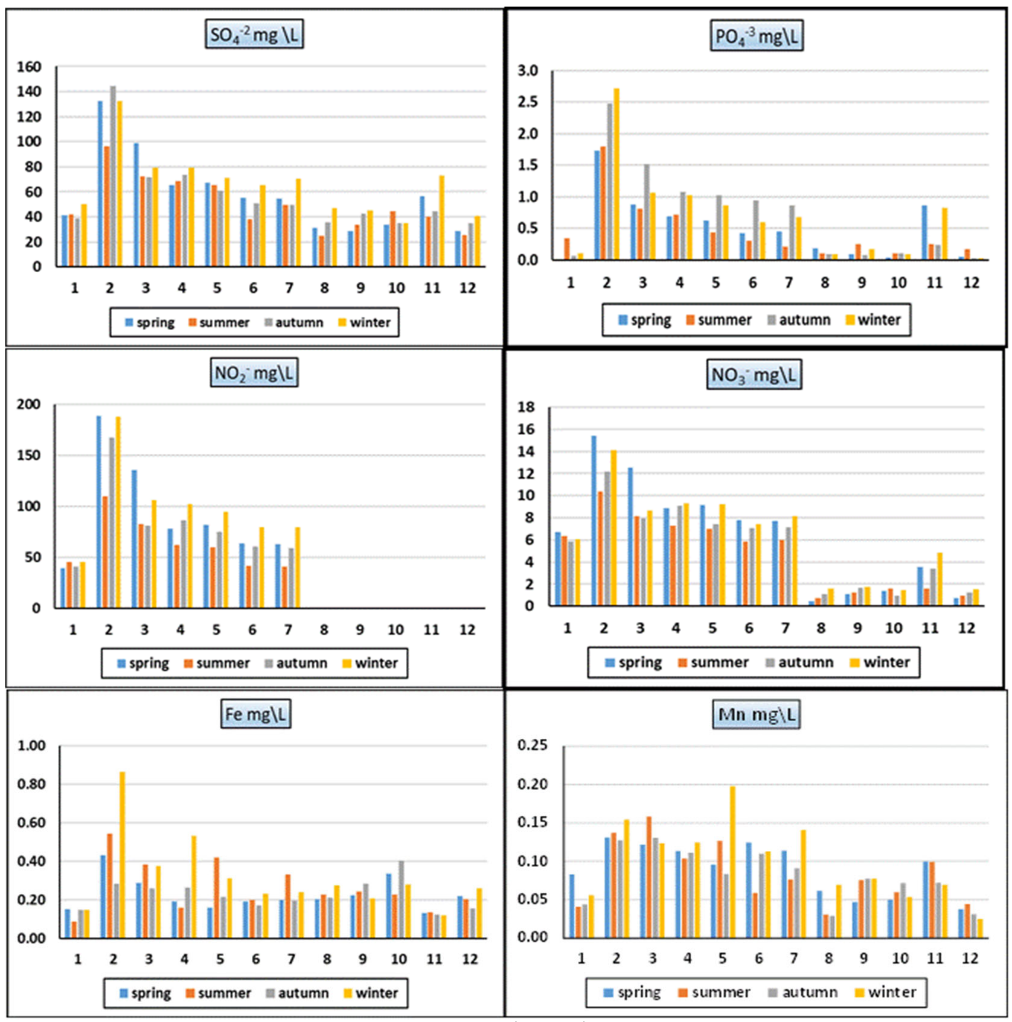

***Fig. 6**. Seasonal records for SO_4^{-2}, PO_4^{-3}, NO_2^-, NO_3^-, Fe, and Mn*

The effect of agricultural fertilizer in the study area is shown in the positive correlation between sodium, chloride, sulphate, and potassium, as shown in **Table 12**. Therefore, water contains similar sources and not a single source.[29]

Table 12. Pearson correlation between the water quality variables in the study.

		pH	Turbidity	EC	TDS	Cl-	SO4-2	PO4-3	NO2-	NO3-	Fe	Mn	Cu
pH	Pearson Correlation	1	-.39	-.48	-.48	-.46	-.47	-.42	-.49	-.13	-.17	-.26	-.09
	Sig. (2-tailed)		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.03
Turbidity NTU	Pearson Correlation	-.39	1	.74	.74	.70	.58	.54	.70	.12	.34	.23	.13
	Sig. (2-tailed)	.00		.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
EC µS/cm	Pearson Correlation	-.48	.74	1	1	.86	.75	.65	.82	.15	.18	.31	.08
	Sig. (2-tailed)	.00	.00		.00	.00	.00	.00	.00	.00	.00	.00	.06
TDS mg/l	Pearson Correlation	-.48	.74	1	1	.86	.75	.65	.83	.15	.17	.30	.08
	Sig. (2-tailed)	.00	.00	.00		.00	.00	.00	.00	.00	.00	.00	.04
Cl mg/l	Pearson Correlation	-.46	.70	.86	.86	1	.84	.63	.82	.15	.20	.31	.07
	Sig. (2-tailed)	.00	.00	.00	.00		.00	.00	.00	.00	.00	.00	.07
SO4 mg/l	Pearson Correlation	-.47	.58	.75	.75	.84	1	.57	.70	.13	.16	.27	.07
	Sig. (2-tailed)	.00	.00	.00	.00	.00		.00	.00	.00	.00	.00	.09
PO4 mg/l	Pearson Correlation	-.42	.54	.65	.65	.63	.57	1	.62	.13	.19	.23	.08
	Sig. (2-tailed)	.00	.00	.00	.00	.00	.00		.00	.00	.00	.00	.05
NO2 mg/l	Pearson Correlation	-.49	.70	.82	.83	.82	.70	.62	1	.21	.20	.32	.10
	Sig. (2-tailed)	.00	.00	.00	.00	.00	.00	.00		.00	.00	.00	.02
NO3 mg/l	Pearson Correlation	-.13	.12	.15	.15	.15	.13	.13	.21	1	.05	.05	.03
	Sig. (2-tailed)	.02	.04	.00	.00	.00	.04	.03	.00		.28	.22	.46
Fe mg/l	Pearson Correlation	-.17	.34	.18	.17	.20	.16	.19	.20	.05	1	.44	.16
	Sig. (2-tailed)	.00	.00	.00	.00	.00	.00	.00	.00	.28		.00	.00
Mn mg/l	Pearson Correlation	-.26	.23	.31	.30	.31	.28	.23	.32	.05	.44	1	.14
	Sig. (2-tailed)	.00	.00	.00	.00	.00	.00	.00	.00	.22	.00		.00
Cu mg/l	Pearson Correlation	-.09	.13	.08	.08	.07	.07	.08	.10	.03	.16	.14	1
	Sig. (2-tailed)	.03	.00	.06	.04	.07	.09	.05	.02	.46	.00	.00	

The Fe values revealed a statistically significant difference between locations as established by one-way ANOVA ($F(11,608) = 5.357$, $p = .00$) (see **Table 13**). While the Mn^{2+} values revealed a statistically significant difference between locations as established by one-way ANOVA ($F(11,608) = 8.728$, $p = .00$), and for the Cu^{2+} values ($F(11,608) = 1.217$, $p = .271$).

Table 13. ANOVA table for Fe, Mn, and Cu.

			Sum of Squares	df	F	Sig.
Iron mg/L * Location of Sampling	Between Groups	(Combined)	5.287	11	5.357	0.000
	Within Groups		54.548	608		
	Total		59.835	619		
Manganese mg/L * Location of	Between Groups	(Combined)	0.661	11	8.728	0.000
	Within Groups		4.184	608		
	Total		4.845	619		
Cupper mg/L * Location of Sampling	Between Groups	(Combined)	0.009	11	1.217	0.271
	Within Groups		0.404	614		
	Total		0.413	625		

4.3. Water quality indices result in the north of Egypt

4.3.1. Heavy metal pollution index (HPI)

The calculated HPI values indicated that the HPI for the study locations was below the critical limit except for the Rahway drain, which exceeded the critical value of 100 over the study sites, as shown in (**Fig. 7**). Seasonally, the Rahawy drain recorded the highest HPI values in summer and winter, 109 and 167 (see **Table 14**). L1 and L11 HPI values were the lowest recorded values of the index over the whole study sites. L1 recorded the lowest HPI value in summer and autumn, 20 and 30, respectively. The HPI values indicate that heavy metals are a primary source of pollution for the Rosetta branch, as shown in (**Fig. 7**).

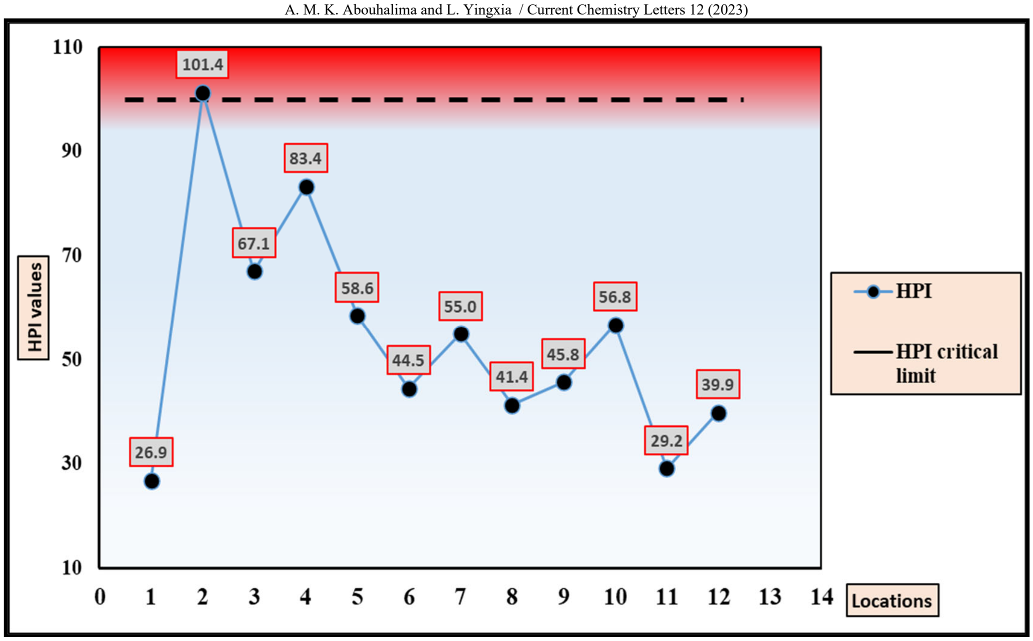

Fig. 7. the trend of HPI through the sampling locations.

4.3.2. Metallic index (MI)

The MI values varied from a moderate to a pure level. The Rahawy drain gets the highest MI values, 2.17 and 3.28 during summer and winter, within the moderate level of pollution, and 1.79 and 1.28 in spring and autumn as slightly affected by heavy metal pollution. Most of the locations were slight to pure during the four seasons (see **Table 14** and **Fig. 8**). L1 recorded the lowest MI value, especially in summer and autumn, 0.40 and 0.60, respectively. The significant variation between the MI values at Rahawy and the other two sites was consistent with the HPI results.

Table 14. Seasonal variations of HPI and MI through the sampling locations.

	HPI				MI			
Location	spring	summer	autumn	winter	spring	summer	autumn	winter
L1	35	20	30	32	0.7	0.4	0.6	0.7
L2	89	109	63	167	1.79	2.17	1.28	3.28
L3	62	33	58	78	1.27	0.77	1.20	1.58
L4	45	38	57	70	0.9	0.8	1.2	2.1
L5	38	86	46	75	0.8	1.7	0.9	1.5
L6	46	41	41	52	1.0	0.8	0.9	1.1
L7	46	66	44	56	1.0	1.3	0.9	1.2
L8	42	43	40	55	0.8	0.9	0.8	1.1
L9	44	50	58	44	0.9	1.0	1.2	0.9
L10	64	46	78	55	1.3	0.9	1.5	1.1
L11	33	34	29	28	0.7	0.7	0.6	0.6
L12	43	41	31	48	0.8	0.8	0.6	0.9

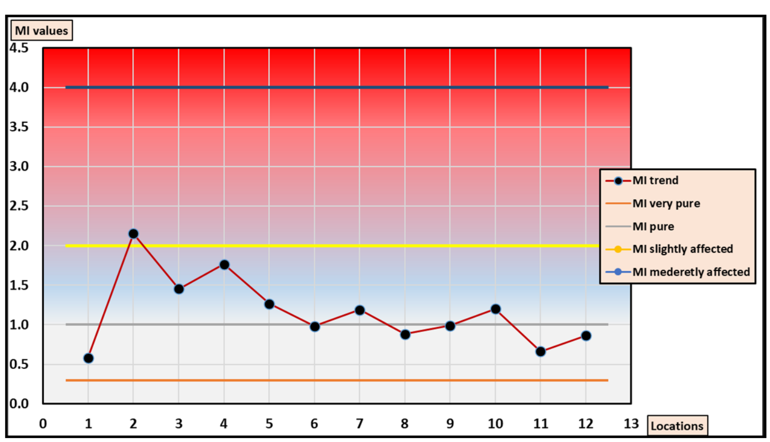

Fig. 8. MI trend variation between sampling locations.

4.3.3. Water Quality index results (WQI)

Fig. 9 represents the WQI results according to drinking water limits for the twelve sites. **Table 15** presents the limits of the guidelines used for the WQI calculations. The WQI trend started in L1 with a high value (72) within the fair level, and then a significant drop happened from the Rahawy drain (41), which is the lowest level in the trend within the poor-quality level. From L3 to L7, the WQI values raised to the marginal level. As it is getting far from the Rahawy drain, the WQI is starting to maintain its quality, as shown in the recorded values at L8, L9, and L10 within a good level. L11 was the same value as L1 (fair level). L12 obtained the highest WQI value in the trend as 89 within the good level, indicating the best water quality in the study area.

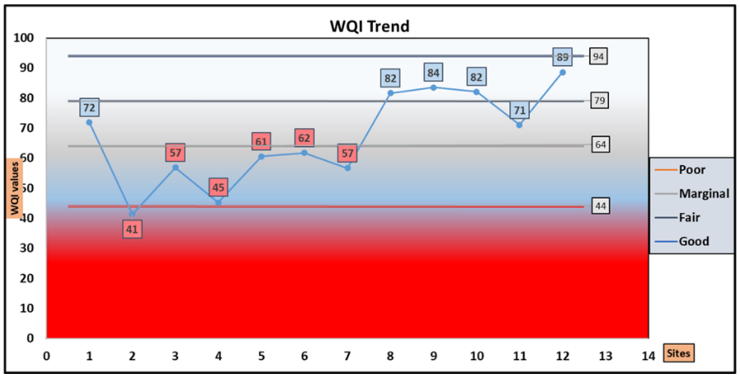

Fig. 9. Values of water quality index (WQI) in twelve sampling locations.

Table 15. water quality variables guidelines according to Egyptian Water Quality Standard.

No	Parameter	Guidelines EWQS
1	pH	6.5-8.5
2	TDS mg/L	1000
3	Fe mg/L	0.3
4	Mn mg/L	0.4
5	Cu mg/L	2.0
8	NO_3^- mg/L	45
9	SO_4^{-2} mg/L	250
10	NO_2^- mg/L	0.2
11	Turbidity NTU	1.0
12	Total hardness	500
13	Cl^- mg/L	250
14	Na^+ mg/L	200

4.3.4. IWQI evaluation results

The IWQI results obtained from the research area in monthly sequence from 2015 to 2020, illustrated in (**Fig. 10**), indicate that the water quality is assigned to different classes with variation between the twelve sites. The results showed that the IWQI for the Rahawy drain was the lowest value, 40.0, at the severe restriction level. The following locations, L3, L4, L5, L6, and L7, were within the high restriction level. Then the IWQI was raised at the locations L8, L9, L10, and L11, where the values get a higher record at the moderate level. The highest IWQI recorded were at L1 and L12, where the recorded values were within the null and low levels, respectively. IWQI results indicate that the Rahawy drain and the following five locations are unsuitable for irrigation according to the IWQI values, and the water is used only for high salt tolerance plants. The best locations suitable for irrigation without restrictions are L1, where the water has no toxicity for most plants.

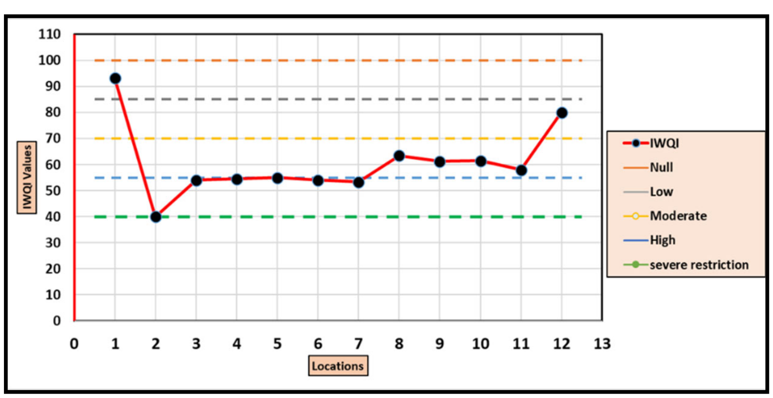

Fig. 10. IWQI values in twelve locations through 2015-2020.

4.4. WATER QUALITY IN THE SOUTH OF EGYPT [30]

A study was done by Abdel-Satar *et al*[30] in the south of Egypt in 2017, where 24 sampling sites were set up in the mainstream of the Nile river starting from the south of Egypt after the Aswan high dam to the middle of Egypt at Cairo for about 930 km. Along this area, five sites were represented as the anthropogenic sites to represent the agriculture and industrial wastewater impact on the Nile river, as shown in (**Fig. 11** and **Table 16**).

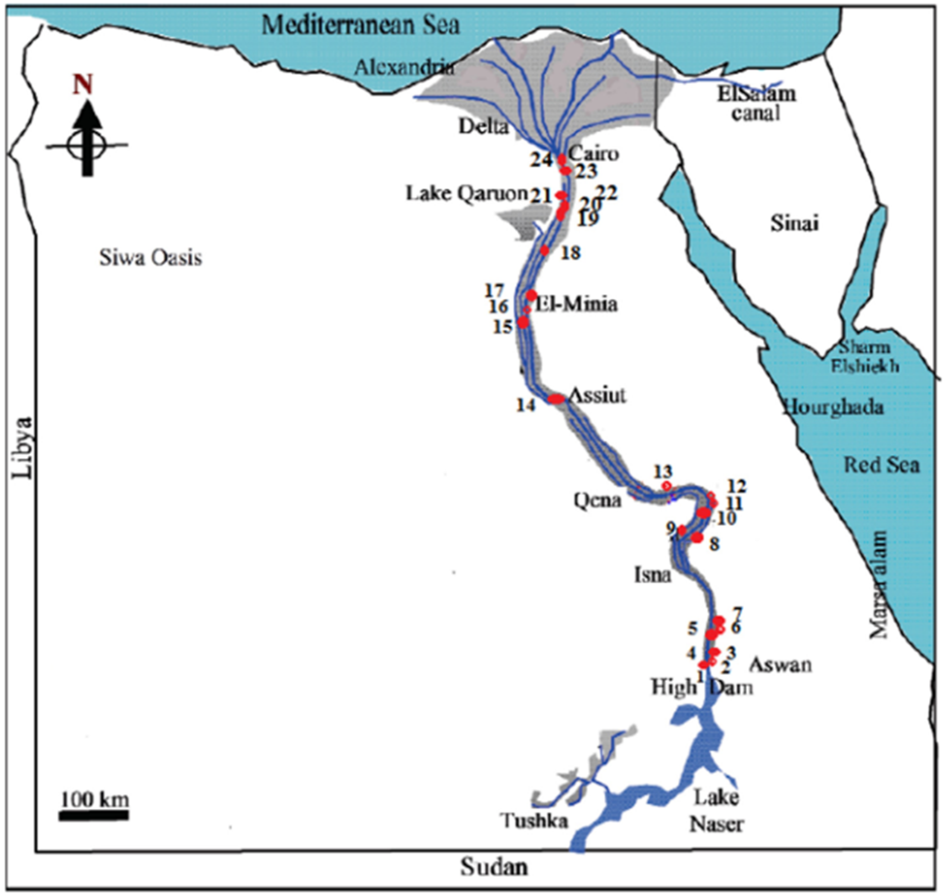

Fig. 11. Locations of sampling sites in the south of Egypt.[30]

Table 16. Locations sites description in the south of Egypt as reported by Abdel-Satar *et al*.[30]

Site number	Site name	Distance from Aswan high dam (km)
1.	Nile River	10
2.	Front of Kima factory - industrial waste drainage	11
3.	Nile River	13
4.	Nile River	19
5.	Nile River	49
6.	Front of Kom Ombo Drain-Agricultural drainage water	52
7.	Nile River	55
8.	Nile River	250
9.	Nile River	252
10.	Nile River	280
11.	Front of Ques Sugar company – industrial wastewater	282
12.	Nile River	284
13.	Nile River	370
14.	Nile River	600
15.	Nile River	700
16.	Front of Etsa Drain-agricultural drainage water	702
17.	Nile River	706
18.	Nile River	880
19.	Nile River	910
20.	Front of El-Hawamdia Company for sugar – industrial wastewater	912
21.	Nile River	914
22.	Nile River	916
23.	Nile River	930
24.	Nile River	935

4.4.1. *Water quality indices used in the study*

4.4.1.1. *Heavy metal pollution index (HPI)*

The calculated HPI values for the 24 sites are represented in (**Fig. 12**). According to the author[17], the measurements indicate that the HPI values were above the critical limit of the heavy metal pollution index of 100 at the sites (2. 6, 11, 16, 20). The five locations are industrial and agricultural wastewater polluted with high concentrations of heavy metals. The remaining locations of the study were below the critical limit of the index. The change rate between the five sites and the following locations was significant, and the stability rate remained below the critical limit as the location remained far away from the anthropogenic site, which shows the ability of the mainstream of the Nile River to recover as showing in (**Fig. 12**).

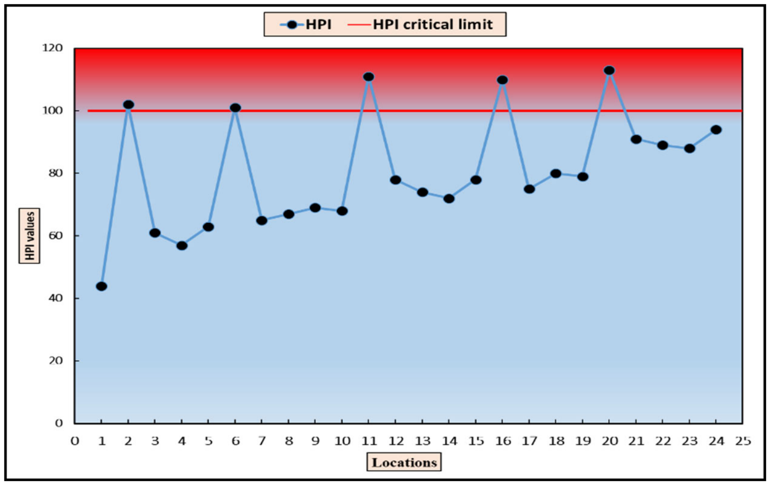

Fig. 12. Heavy metal pollution index HPI for different sites of Nile river.[30]

4.4.1.2. *Water Quality index results (WQI)*

The calculated WQI values by the author are represented in the following (**Fig. 13**), and the anthropogenic sites show very low values in the WQI trend where the five sites were at the poor level compared with the remaining sites that were between the fair and good level. The trend shows a significant change between the five locations chosen as anthropogenic points (2-6-11-16-20) and the remaining locations.

The negative impact of agricultural and industrial activity on the Nile River water quality is reflected in the mentioned sites (2, 11, 20 industrial wastewater) and (6, 16 agricultural drainage), as the WQI dropped at these sites, but gradually the WQI increased after moving far from the anthropogenic sites.

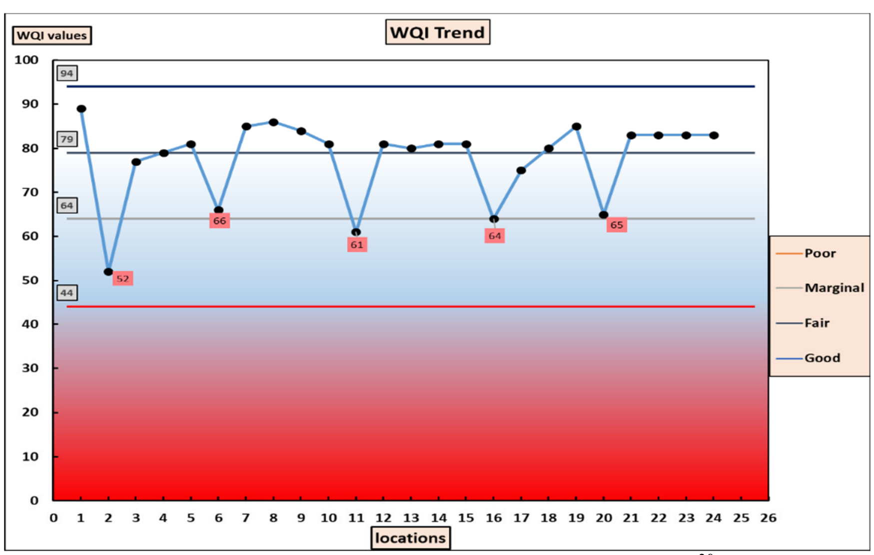

Fig. 13. WQI values for the sites along the river Nile.[30]

4.5. Comparison of water quality in northern and southern Egypt

4.5.1. HPI values and mitigation rate of Nile River

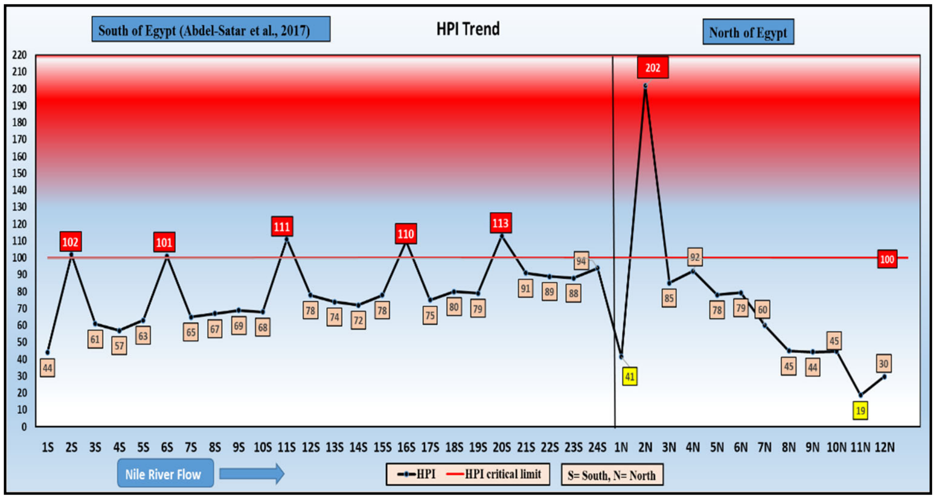

Fig. 14. The trend of HPI values from the south of Egypt to the end of the Nile in the North of Egypt in 2017.

Fig. 14 represents the HPI values in both south and north Egypt, where the Nile River shows a significant change in the mitigation rate between the sites in the south of Egypt. The following sites to the anthropogenic sites (2,6,11,16) showed a high recovery percentage compared with the sites following site no.20, where the HPI remains above 90 records.

Moving to the north of Egypt, the starting site water quality was at a good level compared with the last site in the south part, and this related that Nile River water quality was recovered due to the long distance between (site 24S from Nile and 1N from the Rosetta branch). The HPI value for the Rahawy drain shows a significant increase compared with the anthropogenic site's HPI values in the south of Egypt, which describe the heavy load of trace metals in the drain. The mitigation rate of the Rosetta branch was slightly unstable, as shown in the following five sites to the Rahawy drain until site 8N, where the water quality reached the same quality as site 1N.

4.5.2. WQI values and mitigation rate of Nile River

Fig. 15 represents the WQI values in the south and north of Egypt, where the Nile River shows a significant change in the mitigation rate between the sites in the south of Egypt. The sites following the anthropogenic sites showed a high recovery percentage and existed at a good level of the WQI trend compared with the marginal level of the sites (2,6,11,16). In northern Egypt, the mitigation rate shows a changeable variation rate as the following sites to 2S site were in both marginal and fair levels until reaching the good level by the 9S site.

By comparing WQI results for both anthropogenic sites in the north and south, the water quality of the Rahawy drain exists at a poor level and is more polluted than the anthropogenic sites in the south of Egypt, which exist mainly at the marginal level. This work confirms the previous data that clarifies the importance of scientific research in nature.[31-68]

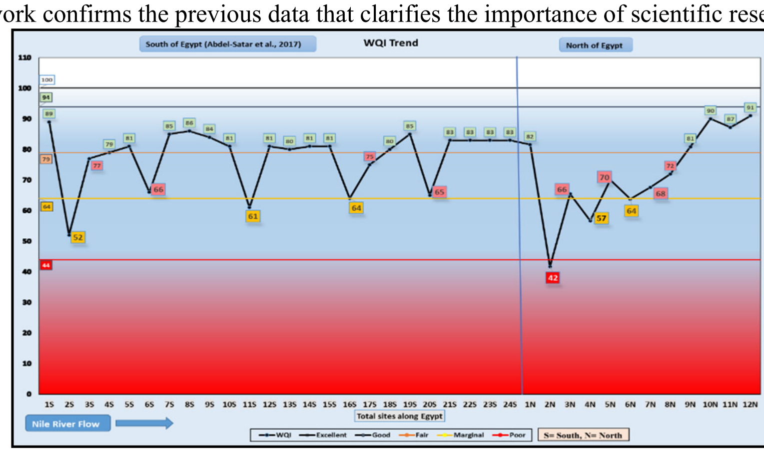

Fig. 15. The WQI values for the Nile River stream starting from Aswan high dam to the endpoint at Edfina in 2017.

4. Conclusion

A fundamental human right is to have access to safe drinking water. The Rosetta Branch's water quality is deteriorating due to the Rahawy drain's continuous discharges of water containing high concentrations of organic waste and salts from agricultural runoff. The present findings showed increases in turbidity, total dissolved solids, heavy metals, and nutritional salts, including phosphate, nitrate, and nitrite, at the Rahawy drain. The Rahawy drain had the largest share of the worst water quality indicators values, such as HPI, WQI, MI, and IWQI. The mean average score of WQI at the Rahawy drain was recorded at 41, indicating poor water quality, as well, as Damanhur and Edfina were recorded (84, 89), indicating a good water quality level. According to the heavy metal pollution index, the Rahawy drain water quality shows bad characteristics, where the HPI result exceeded the critical limit, especially in the summer and winter seasons. Per contra, the rest of the locations were below the critical limit of the HPI index. For the metallic index, the Rahawy drain values were moderate pollution in the summer and winter. Furthermore, most of the locations were slightly affected and purity levels. Studying the irrigation water suitability using IWQI, the Rahawy drain gets the lowest value within the severe restriction level, and the highest values were recorded in locations 1 and 12 in the low level of restriction.

The negative impact of wastewater sources on the Nile River in southern Egypt is limited in wastewater locations only if there is a long-term effect. The values of the HPI and WQI trends show the Nile river's ability to recover while mitigating any pollution that occurs to it. The water quality of the Nile River in the south of Egypt is better than that of the north because the amount of water in the mainstream is more than in the Rosetta branch. The heavy load of pollutants in the Rahawy drain makes the water quality recovery take more time and distance.

The WQI, HPI, MI, and IWQI approaches were helpful methods for assessing the overall quality of the Nile River mainstream and the Rosetta branch in the current investigation. The findings highlight the negative impact of the industrial and agricultural drains on the Nile River and the importance of proper secondary treatment of drains water waste before it is released into the Nile River, mainly and any water body in general.

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Competing interests

There are no competing interests declared by the authors.

Authors' contributions

Ahmed M. AbouHalima designed the study, performed the searches, and screened investigations for eligibility, extracted the data, drafted the manuscript, and Yingxia LI critically revised the manuscript. The final version got approval from all authors.

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