Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 27(6): 117 – 139 (2023)
www.ejabf.journals.ekb.eg

Water Quality and Bacteriological Assessment of Two Drains; in the Deltaic Mediterranean Coast of Egypt

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ARTICLE INFO

Article History:
Received: Oct. 23, 2023
Accepted: Nov. 5, 2023
Online: Nov. 29, 2023

Keywords:
Physicochemical parameters,
Total bacterial count,
Total coliforms,
quality,
Nutrients

ABSTRACT

This study examined the physicochemical characteristics, nutrients, and bacteriological indicators of surface water from ten sampling sites along Kitchener and New Damietta drains, the Nile Delta, Egypt. The mean values of pH were recorded at 8.99 and 8.86; temperature values ranged between 32 and 32.5ºC; salinity levels were 6.08 and 6.88‰; TDS values were recorded at 5610 and 6679.6mg/l; TSS was registered with values 23.28 & 19.59mg/l; EC values were evaluated (9.81, 11.39mS/cm), DO recorded values of 3.98 & 2.48mg/l, and those of OM were 5.89 and 12.86mg/l, at the Kitchener and New Damietta drains, respectively. Variations in SiO_4, NH_4, PO_4, NO_3, and NO_2 in the Kitchener and New Damietta drains showed how anthropogenic pollution has affected the pollution along the drains. The low N/P ratio indicated that nitrogen was the limiting factor for phytoplankton growth at all sites in both drains except S10, where phosphorus was the limiting nutrient factor. Results of the average water quality index (AWQI) confirmed that Kitchener and New Damietta drains have poor water quality. In addition, the bacteriological indicators (Total Bacterial Count (TBC) and Total Coliforms (TC)) were found in the studied drains' water. The determined TBC results exceed (1000CFU/ml) the recommended level specified by Egyptian Law No. 48/1982 for pollution protection of the Nile and waterways. Similarly, the TC values exceed the World Health Organization's (WHO) acceptable limit for wastewater usage in irrigation (1000CFU/100ml). As a result, tight rules and frequent monitoring are necessary to protect the water quality of these drains. The obtained results would be useful for the optimal management of both drains.

INTRODUCTION

Water quality evaluation has emerged as one of the most critical processes in environmental hydrology applications. As a result of the detrimental effects of population growth and anthropogenic activities, most of the world's water bodies are suffering from a range of water quality challenges **(Ameen *et al.*, 2021; Mohsen *et al.*, 2022)**. Water quality is not the static state of a system that can be represented by measuring only one attribute. Numerous chemical, physical, and biological elements can affect water quality, and hundreds of variables can be analyzed and evaluated. Some factors provide a broad picture of water pollution, while others enable direct monitoring of pollution sources **(Ali *et al*., 2014)**.

Agricultural drainage water reuse is commonly used in Egypt, particularly in the Nile Delta region. Drainage water is one of Egypt's most significant water resources, produced by extensive and huge irrigation and drainage systems. However, drainage reuse practices are put at risk by deteriorating drain water quality caused by municipal and industrial wastewater pollution **(Abdel -Azim & Allam, 2004; Hassan *et al*., 2017)**. The Nile Delta area in north Egypt has the lowest level height relative to the rest of Egypt; hence, most of the drainage water from the rest of Egypt accumulates here **(Shokr *et al*., 2016)**. The Nile Delta contains numerous drains, including the Kitchener and New Damietta Drains, two of the largest and most polluted **(El-Alfy *et al*., 2017; Darwish *et al*., 2023)**. To discharge all solid waste, as well as agricultural and industrial waste, from some of the delta lowlands to the Mediterranean Sea, the Kitchener and the New Damietta drains were constructed **(EEAA, 2008)**.

Additionally, using polluted water from drain outfalls on agricultural and fish farms can have extremely harmful environmental effects on ecosystem **(Soliman *et al*., 2022)**. When wastewater or effluent is dumped into a natural stream, bacteria transform the organic materials into ammonia, nitrates, sulphates, and other chemicals **(Ahmed *et al*., 2013)**. Ammonium, nitrate, nitrite, and phosphate ions are released into the environment as salts. They exist as a result of the excessive fertilizer use brought on by the intensification of agriculture. As they are plant nutrients, they may cause eutrophication (the enrichment of water with nutrients), which speeds up the growth of algae and other macrophytes and disturbs the balance of aquatic ecosystem. Eutrophication also decreases the quality of the water **(Abd El-Hamid *et al*., 2017)**. The primary source of these ions is agriculture, while the manufacturing of basic inorganic compounds and fertilizers generates 29 and 25%, respectively, of all direct industrial releases of nitrogen and phosphorus into water **(Inglezakis & Poulopoulos, 2006)**.

Microorganisms from human or animal excreta are the principal cause of microbiological contamination, which enters humans via contaminated groundwater from wastewater, landfills, or wastewater treatment plants, creating serious health problems **(Lugo Luis *et al*., 2021)**. The presence of pathogenic bacteria in the water supply can lead to water-borne illnesses, such as salmonellosis, typhoid, paratyphoid, cholera, amoebic dysentery, poliomyelitis, and infectious hepatitis **(Stupar *et al*., 2022)**. Coliforms and *Escherichia coli* are important bacterial indicators used to define water quality and health risks. Coliform bacteria have long been used to signal fecal pollution of water and, as a result, a health risk **(Al-Afify *et al*., 2019)**. A standard plate count is used for measuring the potential for bacterial growth in wastewater **(Soliman *et al*., 2022)**. Water contaminants can have an impact on both lower and higher plant and animal populations. As a result, biological indicators can demonstrate the level of water pollution

(Zaghloul *et al*., 2020). The present study was conducted to assess the physicochemical and bacteriological properties of water in the Kitchener and New Damietta drains, the Nile Delta, Egypt.

MATERIALS AND METHODS

1. Study area

The study area is the middle part of the Nile Delta of Egypt at two drains, the Kitchener and the New Damietta Drains (Fig. 1). The Kitchener Drain is Egypt's longest, stretching 69km through three governorates in the Delta (Dakahlia, Gharbia, and Kafr El-Sheikh). The Kitchener Drain extends through Kafr El-Sheikh Governorate for 46 kilometers before draining into the Mediterranean Sea **(Metwally *et al*., 2023)**. Kitchener drain gathers El-Gharbia Governorate agriculture, industrial drainage water, and sewage drainage water from Kafr El-Sheikh City, as well as industrial drainage from Kafr El-Sheikh spinning plants. As a result, drainage water is contaminated with salts, agricultural pesticides, and other pollutants such as pathogens from household sources **(Gad & Fadi, 2015)**. The New Damietta drain is located in the Egyptian City of the New Damietta and captures agricultural, industrial, and residential waste.

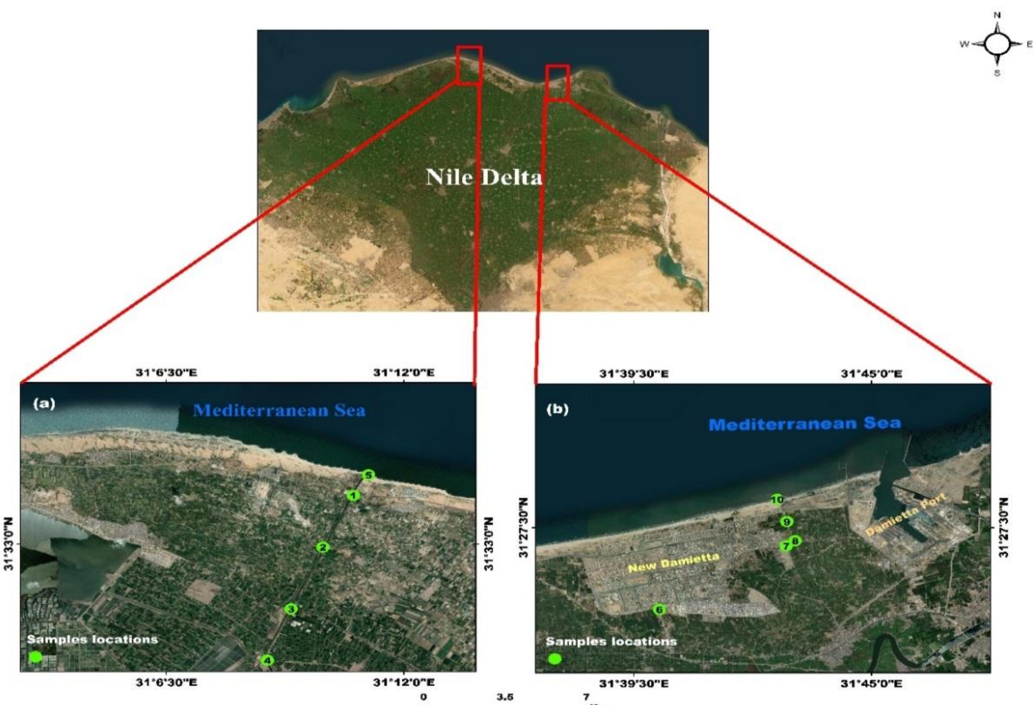

Fig. 1. Location map of the Nile Delta of Egypt showing the sampling sites in (a) Kitchener and (b) New Damietta drains

2. Water sampling

Ten water samples were collected from ten sites (S1–S10) along the Kitchener and New Damietta Drains. Each site in each drain was at least five kilometers apart from its neighbor site and was picked based on the level of pollution. The drain outlets into the Mediterranean Sea were located at sites five and ten (Table 1 & Fig. 1). The samples were gathered from 20cm beneath the water's surface by plunging the acid-washed plastic bottle into the water and then brought to the lab in an icebox for further analysis.

Table 1. Latitudes and longitudes of sampling sites

Drain	Site No.	Latitude	Longitude
Kitchener	1	31° 34.321′	31° 10.832′
	2	31° 32.919′	31° 10.127′
	3	31° 31.243′	31° 09.392′
	4	31° 29.853′	31° 08.842′
	5	31° 34.877′	31° 11.183′
New Damietta	6	31° 25.285′	31° 40.088′
	7	31° 27.009′	31° 43.028′
	8	31° 27.148′	31° 43.236′
	9	31° 27.666′	31° 43.043′
	10	31° 28.271′	31° 42.818′

3. Physico-chemical parameters and nutrient salts analysis

Analyses of water's physicochemical characteristics were performed using APHA's **(APHA, 1999)** standard procedures. Water temperature and DO were monitored in the field with a Lutron YK-22 DO meter. The pH meter (Model Lutron YK-2001, pH meter) was used to measure the pH. The EC was measured with an EC-meter (Thermo, Orion 150 A+ advanced conductivity). A CORNING (Cole-Parmer type Check-mate 90) conductivity meter was used to measure the salinity (‰). The pergmentate oxidation method was used to determine organic matter (OM). Total dissolved solids (TDS) and total suspended solids (TSS) were measured gravimetrically in accordance with the procedure outlined by **Clesceri *et al*. (1998)**. Some significant main dissolved ions (e.g., Ammonium (NH_4^+), Nitrates (NO_3^-), Nitrites (NO_2^-), Silicates (SiO_4^{4-}), and Phosphates (PO_4^{3-}) were measured and analyzed in water samples from both drains using the following conventional methods: APHA 4500-F **(APHA, 2017)**. The measurements' accuracy and precision were optimized and confirmed using external reference standards and quality control samples.

4. Water quality assessment

4.1. Water quality index

The water quality index (WQI) is a mathematical formula that combines several parameters into a single number. The WQI can be used to assess changes in water quality within a zone or to follow changes over time. In this study, WQI was calculated using the **Tiwari and Manzoor (1988)** equation, which may also be used to obtain the quality rating (q_i) of the water quality factor:

$$q_i = 100 \times [V_i / S_i] \text{ ……… (1)}$$

Where, S_i denotes the stream water quality standard, and V_i is the observed data of the factor at a particular sampling point for all parameters. Equation (1) ensures that q_i = 100 if the observed value is just equal to the standard value. As a result, the higher the qi value, the more polluted the water. Equation (2) can be used to construct WQI by determining the quality rating qi that corresponds to a parameter. Overall, the WQI was:

$$WQI = \Sigma q_i \text{ ………… (2) Where i=1}$$

The average water quality index (AWQI) for n parameters was derived using the following equation (3):

$$AWQI = \Sigma q_i / n \text{…………. (3)}$$

Where, n: represents the number of parameters. The AWQI was classified into four levels: good (0.0–100), medium (100–150), poor (150–200), and very bad (over 200).

5. Bacteriological analysis

The total bacterial count (TBC) was performed using the dilution plate method as described in **APHA (2017)**. TBC was calculated using plate count agar media, whereas total coliform (TC) was calculated using Eosin Methylene Blue Agar medium **(APHA, 2017)**.

6. Statistical analysis

The t-test was used to determine homogeneity and normality. The data were validated for normality and variance equality. When the samples were not homogenous, logarithms or square roots were used to transform the data, or multiple comparisons were done using non-parametric tests (Kruskaul-Wallis H and Mann-Whitney U) **(Dytham, 2003; Zar, 1999)**. The Pearson's r coefficient was used to determine whether there was a linear relationship between water quality parameters and bacteriological indicators (TBC and TC) in the water from the two drains. For all statistical analyses, the statistical software package SPSS version 16.0 (SPSS Inc., Chicago, USA) was utilized.

RESULTS AND DISCUSSION

1. Physico-chemical characteristics

Results from the current study revealed no significant variations ($P > 0.05$) in the values of temperature, pH, salinity, EC, TDS, TSS, OM, and DO between the two drains (Table 2). Fig. (2) depicts the fluctuation of physicochemical parameters (e.g., temperature, pH, EC, salinity, DO, OM, TDS, and TSS) along the two drain sites. Water temperature in canals and drains is critical for water quality since it directly impacts the majority of physical, biological, and chemical parameters **(Stahl *et al*., 2009)**. The mean surface water temperature in the Kitchener and New Damietta Drains were 32 and 32.5

°C, respectively, with no significant differences across the sampling sites (Fig. 2A). These results are in the same range as those of **Metwally *et al*. (2023)** and **El-Amier *et al*. (2017)**, who stated that the mean temperatures at Kitchener Drain were 30.76 and 30.29, respectively.

The pH of the wastewater could show the overall pattern of the drain's basic level. The mean pH observed in the two drains is shown in Fig. (2B). The water pH in the Kitchener and New Damietta drains ranged between 8.41–9.65 and 8.44–9.12, respectively, which is a semi-higher than the permissible limits of Law 48 for the year 1982, 7.0–8.5, with the exception of S5 and S10. The slight rise in surface pH levels is mostly due to an increase in photosynthetic activity on the surface, where photosynthesis consumes CO_2, leading to a rise in pH values **(Elbahnasawy *et al*., 2021)**. Results are equivalent to those found in previous studies **(El-Alfy *et al*., 2017; Aitta *et al*., 2019; Metwally *et al*., 2023)** at the Kitchener Drain (8.3-8.48-8.20), indicating that they are alkaline (pH > 7.0) and more alkaline than those at the New Damietta Drain (6.83) **(Beheary *et al*., 2018)**.

Salinity has a significant impact on detecting a variety of aquatic biological processes and natural water chemistry conditions **(Magouz *et al*., 2021)**. The salinity values in the two drains (Fig. 2C) showed that salinities varied widely between 1.4 and 24.4; 0.1 and 24.3 at the Kitchener and New Damietta drains, respectively, with the highest value noted in sites 5 and 10 (drain outlet), whereas the highest values were associated with sea water. The New Damietta and Kitchener Drain sites 8 and 4, on the other hand, had the lowest values, measuring 0.1 and 1.4, respectively. Due to human activities and the quality and amount of water runoff in the drains, low salinity levels showed that the water content in the drains is primarily freshwater ***(*Alprol *et al*., 2022)**.
Electrical conductivity (EC) at the Kitchener Drain fluctuated between 2.19 and 38.2mS/ cm, with an overall mean value of 9.81mS/ cm, but the EC at the New Damietta Drain fluctuated between 0.31- 38.3mS/ cm, with an overall mean value of 11.39mS/ cm (Fig. 2D). The lowest value of EC was recorded at site 8 at the New Damietta Drain. While, the maximum values were found at sites 5 and 10. The rise in EC values at sites 5 and 10 may be attributed to a drop in water level caused by high evaporation rates and a reduction in the volume of drainage water poured into the drain outlet. Lower levels, on the other hand, may be due to the direct influence of dilution by drainage water **(Al-Afify *et al*., 2019)**. These results are higher than those obtained at the Kitchener Drain by **Aitta *et al.* (2019)**.

Total suspended solids (TSS) is a measure of the amount of particulate matter suspended in water. All total suspended solids concentrations were within the acceptable limit of 60mgl^{-1}, as shown in Table (2) and Fig. 2E. These TSS values are lower than those previously reported in Kitchener and New Damietta drain water (637 and 398.22mgl^{-1}, respectively) by **Beheary *et al.* (2018)** and **Abd-Elfattah *et al*. (2021)**. Total dissolved solids (TDS) is a measure of the amount of dissolved components in water **(Uwidia & Ukulu, 2013)**. All TDS concentrations in the Kitchener and New Damietta drains (Table 2 and Fig 2F) exceeded the **(WHO, 2006)** permitted limits of 1500mgL^{-1}. The high TDS value reported in the two-drainage water could be attributed to waste discharge from the settlements and high evaporation rate at the two drains **(Sonja, 2010)**. These TDS values are higher than those (2480mgl^{-1}) previously reported in the Kitchener drain water **(Abd-Elfattah *et al*., 2021)**.

Dissolved oxygen (DO) is crucial in water bodies because it is required for aquatic creatures respiration and primary photosynthesis **(Abo-Taleb *et al*., 2020)**. DO levels were between 2.2 and 7.9mg/l for water samples obtained from the Kitchener Drain and 0 and 6.5mg/l for water samples collected from the New Damietta Drain, according to Fig, (2G). Except for the drains´ outlets (S5 and S10), all DO levels were lower than the allowable limits under Law 48/1982 (not less than 5mg/l). The decrease in DO is due to the discharge of domestic wastewater into these drains, which causes a depletion of free oxygen by bacteria **(Stahl *et al*., 2009)**. These results are lower than those obtained by **El-Amier *et al*. (2017)** and **Metwally *et al*. (2023)** at Kitchener Drain.

The oxidizable organic matter ranged between 2.56 and 11.2mg/ l & 3.5 and 20.48mg/ l at Kitchener and New Damietta Drains, respectively, as displayed in Fig. (2H). The New Damietta Drain exhibited higher organic matter levels than the Kitchener Drain. High levels of oxidizable organic matter suggested the presence of water pollution, which was linked to sewage effluent dumped into the region **(Okbah *et al.*, 2017)**.

Table 2. The mean ± SD values of physicochemical parameters in water at two drains (Kitchener and New Damietta)

Location	pH	Temp	Salinity	EC	TDS	TSS	OM	DO
Kitchener Drain	8.99± 0.44	32.00± 1.73	6.08± 10.24	9.81± 15.88	5610.0± 9841.03	23.28± 14.74	5.89± 3.44	3.98± 2.28
New Damietta Drain	8.86± 0.25	32.00± 0.83	6.88± 9.87	11.39± 15.32	6679.6± 9481.95	19.59± 13.52	12.86± 7.79	2.48± 2.73
***p* value**	**0.577**	**0.736**	**0.903**	**0.876**	**0.865**	**0.691**	**0.154**	**0.373**
WHO	**6.5-8.5**	**20**	**-**	**2.5 ds/m**	**1500**	**500**	**-**	**5**
Egyptian Law No. 48/1982	**7-8.5**	**5 degree above normal**	**-**	**-**	**Not exceed 500 mg/l**	**-**	**-**	**≥5**

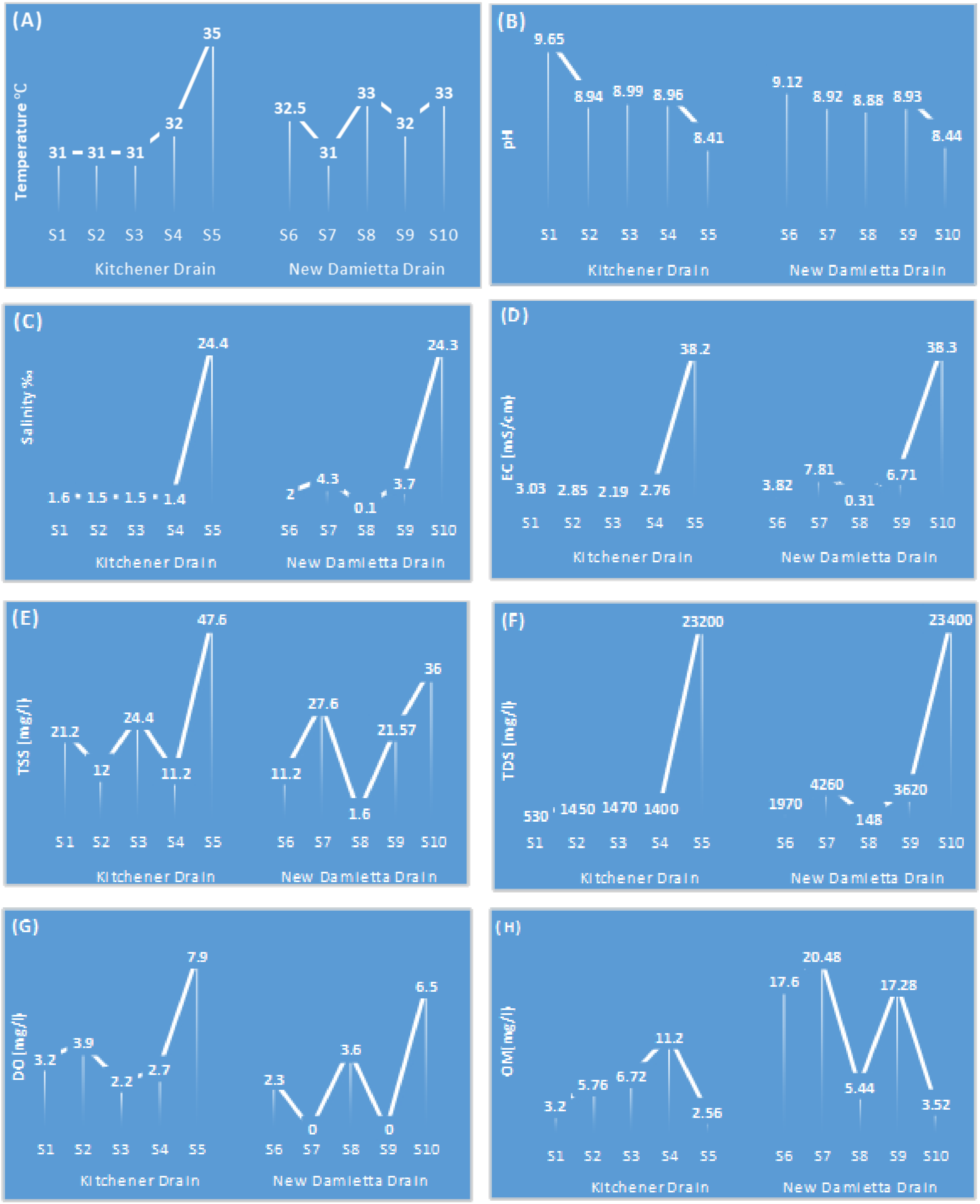

Fig. 2. Distribution plots of physicochemical parameters of water samples collected from both drains: temperature (A), pH (B), salinity (C), EC (D), TSS (E), TDS (F), DO (G), and OM (H)

2. Nutrients

The variance in nutrients found in the Kitchener and New Damietta drains demonstrates the impact of the watershed and human-caused pollution along the drains. According to the results, no significant variation ($P > 0.05$) was detected in the levels of the analyzed nutrients in the current study, with the exception of NO_2, which had a significant difference ($P < 0.05$) in its variant amount between the two drains (Table 3). The SiO_4 concentration ranged from 0.61 to 13.21mg/ l and 1.23 to 20.68mg/ l at the Kitchener and New Damietta drains, respectively (Fig. 3a). The concentration of silicate in the New Damietta Drain is higher than that recorded in the Kitchener Drain due to the large amount of agricultural effluent poured into the former. These results are greater than those reported in a previous study on the Kitchener drain by **El-Amier *et al*. (2017)**, which varied between 0.86 and 1.77mg/l, and the present values are in the same range recorded in the study of **Al-Afify *et al.* (2019)** addressing the El Batts Drain (3.17–20.61mg/ l).

NH_4^+ is dangerous to the ecosystem due to its toxicity to fish, ease of oxidation, and rapid depletion of DO **(Soliman *et al.*, 2022)**. The NH_4 data showed that the highest levels were reported at sites 3 and 7, with concentrations of 1.57 and 2.03mg/ l at the Kitchener and New Damietta drains, respectively (Fig. 3b). This rise could be attributed to excessive levels of sewage, agricultural, and industrial effluent dumped into drains. It might also be explained by a lack of oxygen, which caused nitrate to be reduced to another form in the reducing form of nitrogen, as well as rapid organic matter decomposition **(El-Amier *et al*., 2017)**. The NH_4^+ levels in the majority of water samples exceeded the acceptable limits of the Egyptian Law 48 for 1982 (numbers should not exceed 0.5mg/ L), with the exception of S5, S8, and S10, which were under the limits (0.17, 0.14, and 0.07mg/ L, respectively). This result is nearly totally compatible with the findings of **El-Amier *et al*. (2017)**, who claimed that the NH_4^+ level at the Kitchener Drain ranged from 0.84 to 1.75mg/ l.

Phosphorus entering the aquatic system via anthropogenic sources, such as fertilizer runoff, has the potential to be absorbed into either the inorganic or organic fraction. Once phosphorus accumulates in a drain, it can circulate through the water column continuously, promoting algal blooms **(Edwards & Withers, 2008)**. PO_4^{-3} concentrations have been found to be in the 32.47-111.8 and 12.56-374.6µg/l ranges at the Kitchener and New Damietta drains, respectively (Fig. 3c). The concentration of PO_4^{3} in the New Damietta Drain is higher than in the Kitchener Drain due to the dumping of domestic and industrial sewage. According to **FAO (1994)**, all phosphate (PO_4^{-3}) values in the current investigation are within the acceptable limit of 2000µg/ l. These results agree with earlier studies at these drains by **El-Amier *et al*. (2017)** and **Abd-Elfattah *et al*. (2021)**.

Nitrate (NO_3^-) may enter water due to an overabundance of mineral nitrate fertilizers. It can also be generated inside water in drains and water networks by the oxidation of other N-reduced forms (ammonia and nitrite) or organic N-substances such as amino acids **(Kidd, 2011)**. Fig. (3d) shows that nitrate concentrations ranged from 90.72- 185.37µg/ l and 144.56- 259.63µg/ l at the Kitchener and the New Damietta drains, respectively. The nitrate concentration is higher in the New Damietta Drain than in the Kitchener Drain due to non-point source discharge of household, municipal, and agricultural waste **(Malik & Nadeem, 2011)**. The current investigation shows that all nitrate values are within the **FAO (1994)** allowed range of 10000µg/ l and are consistent with the earlier studies on these drains by **El-Amier *et al*. (2017)** and **Abd-Elfattah *et al*. (2021)**.

The results from Fig. (3e) show that the highest concentrations of NO_2 were 178.92 and 176.73µg/l at S7 and S8 at the Kitchener Drain, respectively. On the other hand, the lowest concentrations were 51.3 and 114.8µg/l at S7 and S8 at the New Damietta Drain. The nitrite concentration of the Kitchener Drain is higher than that of the New Damietta Drain, which is due to agricultural fertilizers and mostly domestic drainage as well as waste from fish farms **(Darwish *et al*., 2018)**.

Table 3. The mean ± SD values of nutrient salts in water from two drains (Kitchener and New Damietta)

Location	SiO_4 (mg/l)	NH_4 (mg/l)	PO_4 (µg/l)	NO_3 (µg/l)	NO_2 (µg/l)
Kitchener Drain	8.69± 5.18	1.23± 0.60	90.92± 33.29	140.93± 42.63	170.47± 8.36
New Damietta Drain	8.70± 7.51	1.11± 0.97	173.55± 161.46	186.19± 53.97	109.73± 33.49
***P*- value**	**1.000**	**0.826**	**0.602**	**0.179**	**0.004**

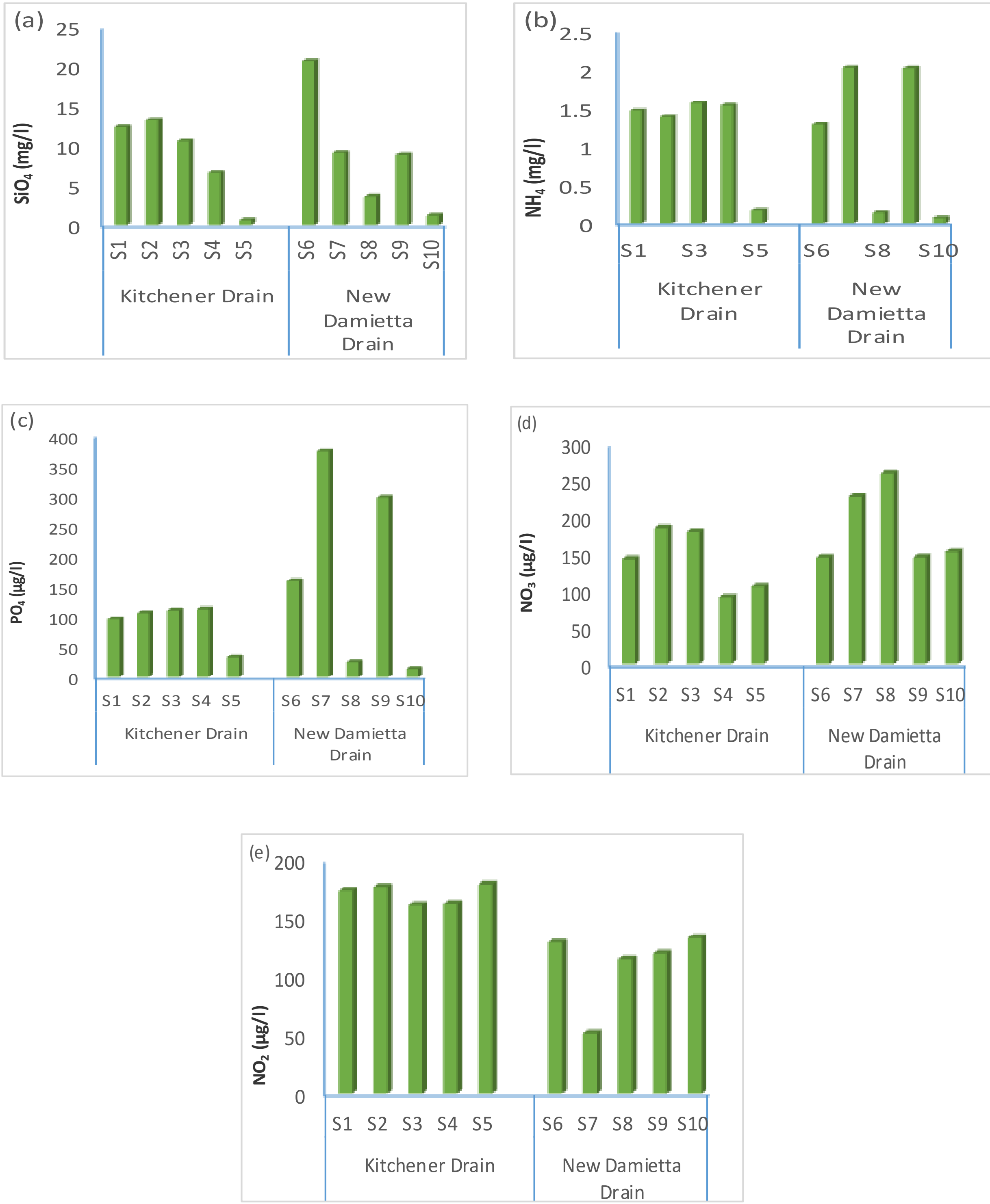

Fig. 3. Distribution plots of nutrient salts of water samples collected from both drains: SiO_4 (a), PO_4 (b), NH_4 (c), NO_3 (d), and NO_2 (e)

3. N/P ratio (Eutrophication)

Aquatic ecosystems become eutrophicated when water is overly enriched with nutrients, particularly phosphorus and nitrogen **(Okbah *et al*., 2017)**. To evaluate how urban, agricultural, and industrial activities affect the physicochemical characteristics of Kitchener and New Damietta drains, the N/P ratio was calculated. The N/P ratio was calculated using nitrogen as DIN (NH_4^+, NO_2^-, and NO_3^-) and phosphorus as reactive phosphate ($PO4^{3-}$) data from the analyzed region **(Mcpherson *et al*., 1982)**. Fig. (4) shows that the estimated N: P ratio is lower than the Redfield ratio (16:1) **(Redfield, 1934)** at all sites, except for S10. This could be attributed to the higher rate of consumption of inorganic nitrogen than reactive phosphate, indicating that nitrogen is the limiting factor for phytoplankton growth at these sites in both drains except S10, where phosphorus is the limiting nutrient factor.

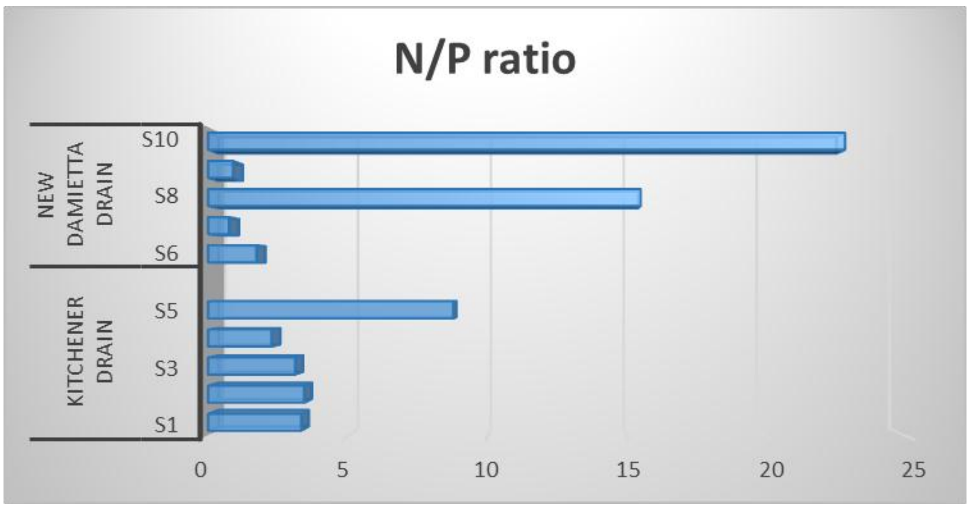

Fig. 4. Values of N/P ratio in the sampling sites along the two drains

4. Bacteriological indicators

The total bacterial count (TBC) estimates the total amount of bacteria in water and represents the water's overall microbial state **(Aksu & Vural, 2004)**. Total coliforms are bacteria that indicate the presence of human or animal waste in the water **(Al-Afify *et al*., 2019)**. The findings showed that there was no significant variation (*P*> 0.05) between the two drains in total bacterial count and total coliform (Table 4). Total bacterial count (TBC) at the Kitchener and New Damietta drains' water ranged between 7×103 to 147×103CFU/ml and 27×103 to 433×103CFU/ ml, respectively (Fig. 5a). The highest value was recorded at S7 at the New Damietta drain. On the other hand, the lowest value was recorded at S1 at the Kitchener Drain. The obtained results showed a higher microbial load at the New Damietta Drain than at the Kitchener Drain. The high organic matter load in the drainage effluents encouraged the active growth of the bacteria, according to **Sabae (2004)**. These results are lower than those of **Al-Afify *et al*. (2019)** and **Abdelkader *et al*. (2022)** who conducted studies on some drains in the Nile Delta.

The total coliforms (TC) counts in the water along the Kitchener and New Damietta drains fluctuated between 2×103 to 30×103CFU/ ml and 5×103 to 138×103CFU/ ml, respectively (Fig. 5b). The discrepancy in total coliform levels in the drain water samples could be attributed to the sites' different point sources of pollution **(Abakpa *et al*., 2013)**. The New Damietta Drain had a greater TC group count than the Kitchener Drain, which could be explained by the effect of residence and agricultural waste flow from the urbanized surrounding area **(Al-Afify *et al*., 2019)**. The total coliform counts at both drains exceed the permissible limit of 10CFU/ ml, according to the **WHO (1989)**, and these results agree with those of **Abd-Elfattah *et al*. (2021)** addressing the Kitchener Drain.

Table 4. The mean ± SD values of TBC and TC in water from two drains (Kitchener and New Damietta)

Location	TBC	TC
Kitchener Drain	44.00×10^{3}±59.23	10.0×10^{3}± 11.73
New Damietta Drain	161.40×10^{3}± 0.47	38.60×10^{3}± 57.25
***P*- value**	**0.188**	**0.306**

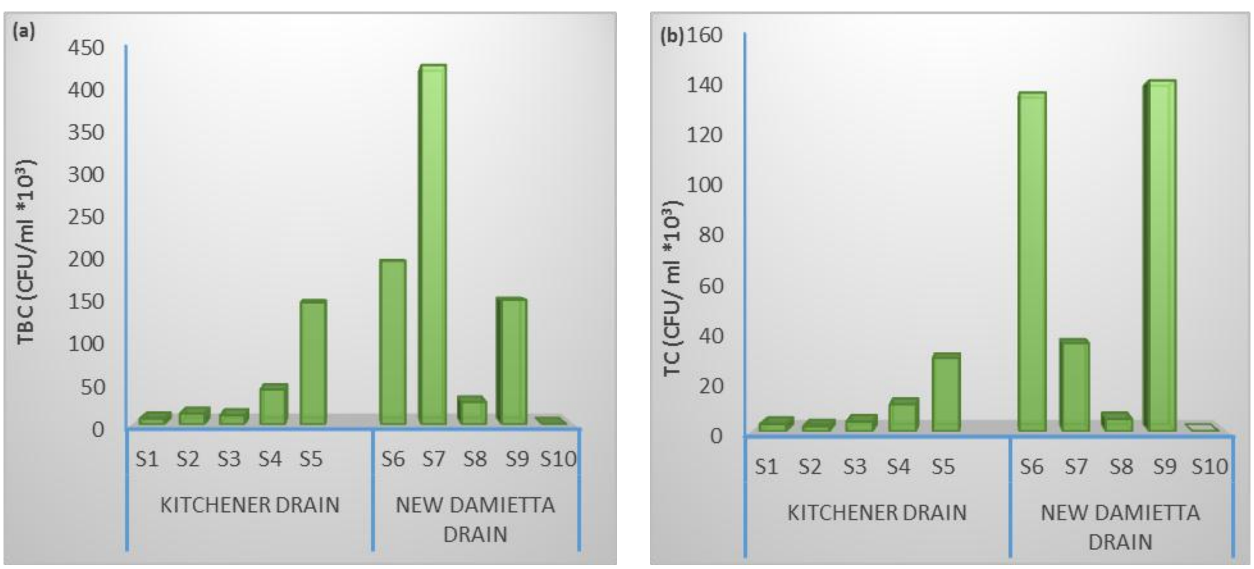

Fig. 5. The bacteriological indicators TBC (a) and TC (b) in both drains water

5. Assessment of water quality

According to WHO, FAO and EPA, eleven water quality parameters were utilized to estimate WQI in this study, including pH, temperature, salinity, DO, EC, TDS, TSS, NO_3, NO_2, NH_4, and PO_4 **(Alprol *et al*., 2022)**. The WQI and AWQI along the two drains were shown in Table (5). AWQI levels were 110.27 and 112.71, respectively, along the Kitchener and New Damietta drains. This signifies that the two drains' waters were rated as having poor water quality during the sampling period. Pollution levels in the Kitchener and New Damietta drains are mostly caused by untreated residential and sewage water, as well as industrial waste water. These results are consistent with those on El-Batts and El-Wadi drains by **(Al-Afify *et al*., 2019)**.

Table 5. WQI and AWQI of Kitchener and New Damietta drains' water

Parameter	Reference	Kitchener Drain			New Damietta Drain		
		S_i	V_i	q_i	S_i	V_i	q_i
pH	WHO	8.5	8.99	105.76	8.5	8.86	104.24
Temp (ºC)	EPA	27	32	118.52	27	32	118.52
Salinity (‰)	EPA	34	6.08	17.88	34	6.88	20.24
DO (mg/l)	WHO	5	3.98	79.6	5	2.48	49.6
EC (mS/cm)	FAO	3	9.81	327	3	11.39	379.67
TDS (mg/l)	WHO	1500	5610	374	1500	6679.6	445.31
TSS (mg/l)	WHO	500	23.28	4.66	500	19.59	3.92
NH_4 (mg/l)	EPA	0.2	1.23	615	0.2	1.11	555
NO_3 (µg/l)	EPA	10000	140.93	1.41	10000	186.19	1.86
NO_2 (µg/l)	EPA	3000	170.47	5.68	3000	109.73	3.66
PO_4 (µg/l)	FAO	2000	90.92	4.55	2000	173.55	8.68
$WQI = \sum q_i$		1654.06			1690.68		
$AWQI = \sum q_i/n$		110.27			112.71		

6. Correlation analysis

Pearson's correlation coefficient between the physicochemical parameters and microbial characteristics of Kitchener and New Damietta drain water are summarized in tables (6) and (7), respectively. pH at the Kitchener drain demonstrated a negative correlation with the majority of the parameters studied, with the exception of OM, SiO_4, NH4, PO_4, and NO_3, which had no discernible link with them. This negative connection could lend credence to the idea of a hostile relationship. This result agrees with that of **El-Alfy *et al*. (2017)** who stated that pH had a significant negative correlation with EC at the Kitchener Drain, and **Abdelkader *et al*. (2022)** who found that the TC was negatively correlated with pH. pH at the New Damietta Drain had the same trend as the Kitchener Drain except for TBC and TC, which had no effect on them.

Water temperature at the Kitchener Drain had a highly significant positive correlation ($P< 0.01$) with salinity, EC, TDS, TBC, and TC (r = 0.967, 0.969, 0.970, 0.999, and 0.997, respectively) and a significant positive correlation with DO ($P < 0.05$, r = 0.912). These findings are almost entirely consistent with those made by **Abd El-Hamid *et al*. (2017)**, who stated that temperature had a significant correlation with salinity, and **Abdelkader *et al*. (2022)**, who found that total coliform (TC) was positively correlated with temperature. Eminently, temperature had a significant negative correlation with SiO_4, NH_4, and PO_4 (r = -0.958, -0.952, and -0.923, respectively) and a negative correlation with OM and NO3 (-0.336 and -0.647, respectively). On the other hand, temperature at the New Damietta Drain had a negative correlation with TSS, OM, SiO_4, NO_3, and TC, a significant positive correlation with NH_4, and a highly significant correlation with PO_4, while it had a significant positive correlation with TBC.

There was a significant positive correlation between TDS and TSS ($P \leq 0.05$, r = 0.915), indicating that the water in the study area included more dissolved and suspended particles. Both of them followed the same pattern, as both demonstrated a significant negative correlation with NH_4 and PO_4 and a negative correlation with SiO_4 (r = -0.878 and -0.764, respectively) and NO3 (r = -0.456 and -0.283, respectively). They have a highly significant correlation ($P \leq 0.01$) with salinity and EC. TDS had a highly significant correlation with TBC ($P \leq 0.01$, r = 0.975) and a significant correlation with TC ($P \leq 0.05$, r = 0.956). These findings coincide with those of **Abdel-Rahim *et al.* (2013)**, who noticed that TDS and TSS revealed a positively strong correlation with EC. On the other hand, at the New Damietta Drain, they had a negative correlation with OM, SiO4, NO3, and TC and a highly positive correlation with EC and salinity ($P \leq 0.01$, r = 1.000).

A negative correlation was found between DO and OM (r = -0.613) at the Kitchener Drain and a significant negative correlation between them at the New Damietta Drain. The use of oxygen by microbial decomposition of organic matter explains the inverse relationship between DO and OM **(Silva *et al*., 1991)**. It was noticed that, DO had a significant positive correlation with TDS ($p \leq 0.05$, r = 0.958) and a highly significant positive correlation with salinity ($P \leq 0.01$, r = 0.962) and EC ($P \leq 0.01$, r = 0.965). This significant positive correlation indicates some interdependence with DO. DO had a highly significant negative correlation with PO_4 (r = -0.968) and NH_4 (r = -0.986). In addition, DO had a negative correlation with SiO_4 (r = -0.756). It was noted that the amount of DO had a significant negative correlation with the TBC; these are in harmony with the findings of **Abdelkader *et al.* (2022)**, who stated that DO was negatively correlated with the TBC in the summer. On the other hand, DO at the New Damietta Drain had a significant negative correlation with NH_4 and PO_4 and a negative correlation with SiO_4, NO_3, TBC, and TC. Whereas, OM at the Kitchener Drain had a negative correlation with all the studied parameters, except SiO_4, NH_4, PO_4, and NO_3, which had no noticeable relationship with them. On the other hand, OM at the New Damietta Drain had a negative correlation with NO_3, NO_2, EC, and salinity, while it had a significant positive correlation with NH_4 and PO_4.

There was a highly positive correlation between salinity and EC at the two drains ($p \leq 0.01$, r = 1.000); this may be traced back to the fact that dissolved salts and other inorganic compounds conduct electricity; conductivity rises with salinity **(Rath *et al.*, 2019)**. Both of them at the Kitchener Drain had a highly positive correlation with TBC (r = 0.971, 0.972, respectively) and a significant positive correlation with TC (r = 0.952, 0.953, respectively). In contrast, they had a negative correlation with SiO_4 and NO_3. In addition, both of them had a highly significant negative correlation with PO_4 (r = -0.983, -0.984) and NH_4 (r = -0.994, -0.995), respectively. Although at the New Damietta Drain, both of them had a negative correlation with SiO_4, NH_4, PO_4, NO_3, and TC.

There was a highly positive correlation between TBC and TC at the Kitchener Drain ($P \leq 0.01$, r = 0.995). Both of TBC and TC had a negative correlation with SiO4, NH_4, PO_4, and NO_3. While, NO_2 had a negative correlation with SiO_4, NH_4, and PO_4 at the Kitchener Drain. In addition, there was a highly significant correlation between NH_4 and PO_4 at the New Damietta Drain ($P \leq 0.01$, r = 0.975). It is worthnoting that, correlations were related to nutrient enrichment, which acts as an indicator of charged water from drains.

Table 6. Correlation coefficients for the relationships between TBC, TC and physicochemical parameters in water of Kitchener drain

	pH	Temp	Salinity	EC	TDS	TSS	OM	DO	SiO_4	NH_4	PO_4	NO_3	NO_2	TBC	TC
pH	1														
Temp	-.770	1													
Salinity	-0.733	0.967**	1												
EC	-0.729	0.969**	1.000**	1											
TDS	-0.763	0.970**	0.999**	0.999**	1										
TSS	-0.560	0.834	0.923*	0.918*	0.915*	1									
OM	0.001	-0.336	-0.547	-0.546	-0.519	-0.676	1								
DO	-0.684	0.912*	0.962**	0.965**	0.958*	0.828	-0.613	1							
SiO_4^{-2}	0.764	-0.958*	-0.869	-0.869	-0.878	-0.764	0.097	-0.756	1						
NH_4	0.724	-0.952*	-0.994**	-0.995**	-0.992**	-0.895*	0.581	-0.986**	0.829	1					
PO_4^{-3}	0.604	-0.923*	-0.983**	-0.984**	-0.974**	-0.929*	0.672	-0.968**	0.792	0.985**	1				
NO_3	0.280	-0.647	-0.459	-0.468	-0.456	-0.283	0.218	-0.382	0.760	0.423	0.422	1			
NO_2	-0.197	0.437	0.568	0.576	0.550	0.446	-0.783	0.757	-0.167	-0.649	-0.667	0.031	1		
TBC	-0.791	0.999**	0.971**	0.972**	0.975**	0.835	-0.341	-0.919*	-0.952*	-0.958*	-0.924*	-0.621	0.448	1	
TC	-0.768	0.997**	0.952*	0.953*	0.956*	0.827	-0.288	0.878	-0.976**	-0.929*	-0.901*	-0.680	0.369	0.995**	1

*. Significant at *P*< 0.05.

**. Highly significant at *P*< 0.01.

Table 7. Correlation coefficients for the relationships between TBC, TC and physicochemical parameters in water of the New Damietta drain.

	pH	Temp	Salinity	EC	TDS	TSS	OM	DO	SiO_4	NH_4	PO_4	NO_3	NO_2	TBC	TC
pH	1														
Temp	-.389	1													
Salinity	-0.916*	0.326	1												
EC	-0.911*	0.305	1.000**	1											
TDS	-0.916*	0.323	1.000**	1.000**	1										
TSS	-0.648	-0.305	0.790	0.804	0.792	1									
OM	0.737	-0.845	-0.550	-0.530	-0.549	-0.024	1								
DO	-0.742	0.825	0.720	0.704	0.719	0.153	-0.902*	1							
SiO_4^{-2}	0.819	-0.279	-0.525	-0.516	-0.525	-0.314	0.720	-0.480	1						
NH_4	0.598	-0.879*	-0.462	-0.440	-0.460	0.156	0.957*	-0.933*	0.530	1					
PO_4^{-3}	0.502	-0.960**	-0.413	-0.391	-0.410	0.232	0.919*	-0.919*	0.390	0.975**	1				
NO_3	0.082	-0.125	-0.402	-0.411	-0.401	-0.434	-0.172	-0.080	-0.375	-0.204	-0.046	1			
NO_2	-0.221	0.865	0.301	0.287	0.297	-0.176	-0.541	0.593	0.012	-0.545	-0.709	-0.567	1		
TBC	0.517	0.951*	0.402	-0.382	-0.399	0.174	0.873	-0.770	0.469	0.816	0.885*	0.159	-0.854	1	
TC	0.686	-0.104	-0.374	-0.369	-0.374	-0.301	0.534	-0.229	0.957*	0.296	0.167	-0.354	0.103	0.350	1

*. Significant at $P< 0.05$.

**. Highly significant at $P< 0.01$.

CONCLUSION

The current study measured the physicochemical, nutrient salts, and bacteriological properties of water quality along the Kitchener and New Damietta drains, the Nile Delta, Egypt. Results showed that pH readings are alkaline. DO values showed insufficient aeration conditions throughout the water column at the two drains, with levels lower in the majority of sites. Low salinity levels demonstrated that the water content in the drains is primarily freshwater. TSS values were within the acceptable limit, and TDS values were higher than the World Health Organization (WHO) permitted limits at the two drains. The nutrient concentrations reflected the two drains' vastly varied fertility. The New Damietta Drain has greater NO_3, PO_4, and SiO_4 values than the Kitchener Drain. The Kitchener Drain has greater NO_2 and NH_4 values compared to the New Damietta Drain. The lowest values of the N/P ratio suggest that nitrogen is the most limiting factor for the growth of phytoplankton at the two drains. Based on the current findings, we can conclude that municipal and agricultural sewage wastes discharged into the two drains cause major water quality issues. The AWQI measurements demonstrated that the drains' water quality was poor for irrigation. The standard plate method was used to count the total number of bacteria. The TBC of all the measured sites at the two drains is above the recommended limit by the Egyptian Law No. 48/1982 for pollution protection of the Nile and its waterways. The TC values at both drains showed sewage and municipal wastewater drainage pollution levels that were much above the World Health Organization's (WHO) acceptable guideline for wastewater usage in irrigation. According to the current results, strict vigilance and continual monitoring are required to maintain the water quality of these drains.

AKNOWLEDGEMENT

Authors acknowledge Dr. Afify Basiony at the National Institute of Oceanography and Fisheries, NIOF, Egypt, and Dr. Rasha Abu Samra at the Faculty of Science, Damietta University, Egypt for their help in the field work and generating the location map.

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