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Assessment of the Water Quality in the Damietta Branch of the Nile River, Egypt

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ABSTRACT

The Damietta branch of the River Nile is the main source of drinking and irrigation water for the El-Qalubia, El Dakhlyia, and Damietta governorates. It receives various types of pollutants, such as industrial and agricultural waste, as well as sewage, which have negative effects on water quality and human health. This study was designed to investigate the potential variations in the quality of surface water in this branch of the Nile River. The study focused on five stations (El-Kanater El-Khayria, Benha, Zefta, Talkha, and El-Serw) and analyzed the physico-chemical characteristics, as well as some heavy metals (Fe, Mn, Zn, Cu, Ni, Co, Pb, Cd, and Cr). The findings of the current study indicated that the physico-chemical parameters and heavy metal concentrations in the water of the examined stations were within the acceptable limits. Notably, El-Serw station exhibited the highest levels of BOD, COD, Cl, SO_4, CO_3, and HCO_3. Additionally, El-Kanater El-Khayria station displayed the highest concentration of SiO_2. Furthermore, a strong positive correlation was observed among the majority of the parameters. The concentrations of the studied heavy metals in water were found to be below the permissible levels of the Egyptian standards. Among the heavy metals, the highest levels of Fe, Zn, Cu, Ni, Co, Pb, and Cd were observed at Talkha station, while the highest concentration of Cr was recorded at El-Serw station. It is worth noting that all the heavy metals studied showed a positive correlation with each other.

INTRODUCTION

Rivers play a crucial role in a country's economy, providing not only drinking water but also serving various other purposes such as irrigation, fishing, navigation, industry, hydropower generation, and waste disposal **(Mohamed *et al*., 2015)**. However, the quality of the water has become a major concern worldwide, with a focus on eliminating pathogenic organisms and toxic substances. The quality of the water depends on the source's location and the level of environmental protection in a given area. Unfortunately, the increasing human activities along riversides have significantly impacted the river water quality. The main sources of the river water pollution are domestic, industrial, and agricultural waste **(Spyra *et al*., 2017)**. Egypt, in particular, faces significant challenges related to water pollution due to the expansion of agriculture projects, urbanization, and industrial developments. As urbanization and industrialization continue, water pollution problems have become more apparent, leading to severe ecological and environmental issues **(Ma *et al*., 2022)**.

The cost of the environmental degradation caused by water pollution is significantly high, leading to severe health issues and a decline in the quality of life. Additionally, it exacerbates the problem of water scarcity. Therefore, the increase in water pollution not only degrades water quality but also poses a threat to human health, the equilibrium of aquatic ecosystems, economic development, and social well-being. Egypt's closed water system makes it particularly susceptible to the deterioration of water quality, especially in the northward direction toward the Nile Delta **(Fouad *et al*., 2022)**.

Precipitation and surface runoff are natural processes that occur seasonally and are influenced by various factors, including climate changes and agriculture. These processes lead to variations in water characteristics, making it necessary to conduct monitoring programs that involve regular water sampling at different locations and the analysis of various physico-chemical parameters. However, the resulting data matrix is often complex and challenging to interpret, requiring a sophisticated data interpretation approach **(El-Tohamy *et al*., 2018)**.

Intensive research has been conducted on heavy metals in aquatic and terrestrial environments due to their harmful effects on organisms and humans through the food chain **(Memoli *et al*., 2017; Kortei *et al*., 2020)**. Fish, being continuously exposed to these toxic metals, absorb them directly from the environment through their blood, leading to a contact with their organs and tissues **(Goher *et al*., 2018)**. Even at low concentrations, heavy metals negatively impact humans, causing abnormal fetal development, reproductive failure, immune deficiency, carcinoma, organ dysfunction, physical and mental disorders, neurological disorders, renal tumors, nephritis, osteoporosis, nasopharyngeal congestion, increased blood pressure associated with cardiovascular diseases, reduced life expectancy, and in some cases death **(Mohanta *et al*., 2020)**.

Throughout the Egyptian history, the Nile River has got a significant impact on the economy, culture, public health, social life, and political aspects. Located approximately 28km northwest of Cairo in Manshat El-Kanater, the river splits into two branches known as Rosetta and Damietta. The Damietta branch serves as the primary source of drinking and irrigation water for the El-Qalubia, El-Dakahlyia, and Damietta governorates **(Abdel Galil *et al*., 2020)**. Unfortunately, this branch also receives various pollutants from different sources, leading to the accumulation of chemical pollutants such as salts, heavy metals, pesticides, and other harmful substances. It is expected that these pollutants will continue to increase annually in the water, sediments, and fish flesh, ultimately having detrimental effects on water quality and human health **(Briffa *et al*., 2020)**.

Recent studies have shown that water requirements are expected to increase by 20% after 2020 **(Abdallah *et al.*, 2021)**. It is crucial that water quality meets the specified standards for each use. In Egypt, managing water resources and monitoring water quantity and quality are considered national responsibilities for achieving a sustainable development. To address the pollution issue, it is necessary to understand the characteristics of the Nile River system and analyze its water quality. By comparing the results with international and Egyptian standards, we can assess the impact of pollution on the system **(Hereher *et al*., 2022)**. The present study aimed to evaluate the water quality and heavy metals distributions at five different sites in the Damietta branch of the Nile River (El-Kanater EL-Khayria, Benha, Zefta, Talkha, and El-Serw) by analyzing the physico-chemical characteristics of the water.

MATERIALS AND METHODS

1. Study area

As illustrated in the Fig. (1), the study area extends about 78km in Damietta branch. The depth varied between 1 and 7.5m, with an average of 3.5m. Water samples were collected from five key points on a monthly basis during 4 seasons in 2020. The global positioning system (GPS) was used for recording the geographical location of samples. Water samples were collected from the central area of each site at a depth of 20-30cm.

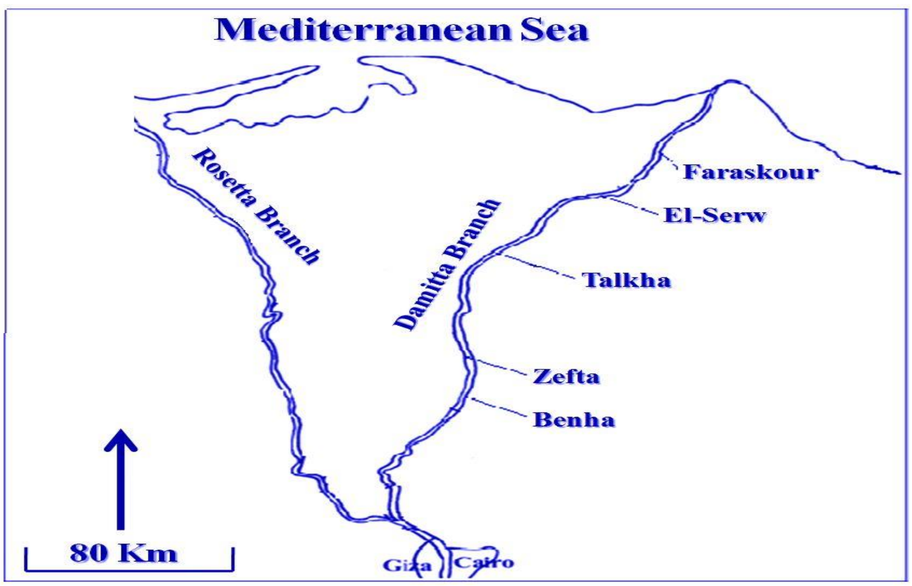

Fig. 1. Map of the Nile River (Damietta branch) indicating the locations of the sampling stations (El-Kanater EL-khayria, Benha, Zefta, Talkha, and El-Serw)

2. Physico-chemical analysis

In-situ measurements of pH/ temperature were carried out using a pH meter (model HI 8314, Hanna Instruments Ltd). Electrical conductivity (EC), total dissolved solids (TDS), and dissolved oxygen (DO) were measured *in-situ* using Pensions portable conductivity meter (Hach). In the laboratory, the physicochemical parameters, namely nephelometric turbidity units (NTU), chloride (Cl^-), alkalinity ($CaCO_3$), nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+) and inorganic dissolved phosphorus (PO_4^{-3}) were analyzed by the standard method for the examination of the water and wastewaters of the American Public Health Association which were adapted for the analysis of various water quality parameters **(Adams, 1990; APHA, 2005)**. Moreover, these physico-chemical measurements were analyzed along with the chemical oxygen demand (COD) and the biochemical oxygen demand (BOD) after 5days as an incubation period.

3. Measurement of heavy metals

Nine metals (Fe, Mn, Zn, Cu, Ni, Co, Pb, Cd, and Cr) were determined by inductively coupled plasma-optical emission system (ICP-OES). Briefly, 500cm^3 aliquot of the water sample was taken in a 1000cm^3 conical flask and boiled over a hot plate until the volume was reduced to 100cm^3. The digestion of the water samples were then achieved by the method described by **APHA (2005)**. The equipment was calibrated with standard solutions prepared from commercially available respective standards (Chemlab-Belgium). Analytical blank was used before the estimation of every metal. The analysis was performed in duplicates, and the results were represented as averages of the duplicates **(Voutsa *et al*., 2001)**.

4. Statistical analysis

The statistical positive and negative correlations were assessed among the monitored parameters using one-way analysis of variance (ANOVA) with the Statistical Package for Social Sciences (SPSS for Windows, version 11.0). Correlations with *P*-values less than 0.05 were deemed significant, while those with *P*-values less than 0.01 were considered highly significant.

5. Water quality index (WQI)

The water quality index was calculated for each sampling point using the following empirical equation in order to evaluate the water quality **(Pesce & Wunderlin, 2000)**.

$$WQI = k \frac{\sum_i C_i w_i}{\sum_i w_i}$$

Where, k is a subjective constant representing the visual impression of the river water quality; WQI usually ranges from 25 (highly polluted water) to a maximum value of 100 (excellent water quality); Ci is the value assigned to each measured parameter after normalization on a scale from 0 to 100; zero indicates water that is not suitable for the intended use and 100 represents perfect water quality, and Wi is the relative weight assigned to each parameter. A maximum weight of 4 was assigned to parameters of relevant importance for aquatic life, viz. DO and ammonium, while the minimum value (unity) was assigned to parameters with minor relevance, such as temperature and pH **(Sanchez *et al*., 2007)**. These normalized values are then calculated into a statement of water quality depending on the suggested equation, which represented as excellent, good, medium, bad and very bad. In this work, the constant k was not considered in order not to introduce a subjective evaluation **(Stambuk-Giljanovic, 1999)**.

6. Metal quality indices (MQI) in water

The pollution index (PI) and metal index (MI) are the most common indices used to determine the grades of metals contamination in the water for aquatic life utilizations. The PI is based on the individual metal concentration, which means that each metal has its own PI value. It was calculated using the equation according to **Caerio *et al*. (2005)**.

$$\mathrm{PI} = \frac{\sqrt{\left[\frac{C_i}{S_i}\right]^2_{\max} + \left[\frac{C_i}{S_i}\right]^2_{\min}}}{2}$$

Where, Ci is the concentration of each heavy metal, and Si is the metal level according to the national water quality criterion.

The MI is based on a comprehensive trend evaluation of the current status and summarizes the status of the study area with a single value. The higher the concentration of a metal compared to its respective MAC value, the worse the water quality. An MI value > 1 is a warning threshold **(Bakan *et al*., 2010)**. MI was calculated using the equation from **Tamasi and Cini (2004)**.

$$\mathrm{MI} = \sum_{i=1}^{n} \frac{C_i}{(MAC)_i}$$

Where, Ci is the concentration of each heavy metal; n is the number of measured heavy metals, and MAC is the maximum allowable concentration of the ith metal.

RESULTS AND DISCUSSION

1. Water quality

The results obtained from the current study were evaluated. The physico-chemical characteristics offer a reasonable understanding of the water quality for any water body. The monitoring of physico-chemical parameters is crucial in assessing aquatic pollution, identifying and quantifying toxicants, and providing data for regulatory purposes **(Ma *et al*., 2020)**.

The compiled variations in the physico-chemical parameters of the water at the selected stations are presented in Table (1). Temperature is a significant factor that influences the physicochemical characteristics of water and directly impacts the life of animals and plants in freshwater **(Kazmi *et al*., 2022)**.

The findings revealed that water temperature reached its lowest point during winter and its highest point during summer. The surface water temperature of the collected samples ranged from 19 to 29^{o}C, with variations depending on the time of sampling. This variation was influenced by various factors, including the season, sampling time, and the temperature of waste water effluents that are discharged into the river. These factors also impacted the solubility of gases in water such as oxygen. It is important to note that the elevated temperatures can have negative effects on the aquatic flora and fauna **(Zlatanović *et al*., 2017)**. It is worth noting that the Talkha station experienced a slight rise in the water temperature, which can be attributed to thermal pollution originating from the nearby electrical power station in the area **(Redwan & Elhaddad, 2020)**. It was noticed that the minimum temperature was recorded at El-Kanater El-Khayria station (19.20°C) and the maximum temperature was recorded at Talkha station (29.20°C). Temperature is negatively correlated with EC, TDS, DO, Cl, SO_4, Ca, and Na at $P< 0.01$, and with pH and COD at $P<0.05$. It is positively correlated with F and SiO_2 at $P<0.01$, and with PO_4 and TP at $P<0.05$.

EC measures the conductivity of an aqueous solution, indicating its ability to carry an electric current. In the present study, the EC values were observed in the range between 339- 532µS/ cm. The El-Serw station recorded the highest EC value, while the lowest value was observed at the El-Kanater El-Khayria station. This discrepancy can be attributed to the elevated levels of anions and cations resulting from the discharge of domestic and agricultural waste at the El-Serw station **(Sen, 2023)**. Additionally, conductivity increases with higher levels of total dissolved solids and water temperature. Conversely, during winter, the decrease in EC is primarily attributed to the sedimentation of suspended solids containing ionic salts, resulting in a decline in chemical elements **(Abdo *et al*., 2022)**. It was noticed that the minimum EC value was recorded at Benha station (399.00µS/ cm), and the maximum value was recorded at El-Serw station (532.00µS/ cm). EC is positively correlated with TDS, Cl, SO_4, Ca, Mg, Na, K, CO_3, and HCO_3 at $P< 0.01$, and with DO and NH_4 at $P< 0.05$.

The data presented indicates that the total dissolved solids (TDS) ranged from 263 to 351mg/ L. The lowest value was observed at the El-Kanater El-Khayria station in winter, while the highest value was recorded at the El-Serw station in summer. This variation in TDS levels may be attributed to the discharge of domestic and agricultural waste into the northern area of the branch. Additionally, the elevated TDS levels during summer can be attributed to the flood period, which leads to an increase in the content of anions and cations. It is worth noting that the TDS values in the studied stations of the Damietta branch generally fall within the permissible limit of 500mg/ L, except for the El-Serw station, which experiences a high pollution load **(El Sayed *et al*., 2023)**. It was noticed that the minimum TDS value was recorded at Benha station (263.34 mg/ l) and the maximum value was recorded at El-Serw station (351.12mg/ l). TDS is positively correlated with Cl, SO_4, Ca, Mg, Na and HCO_3 at $P< 0.01$, and with TDS and NH_4 at $P< 0.05$.

The water pH is a crucial indicator of water quality and pollution levels **(Saalidong *et al*., 2022)**. The findings of this study indicate that the pH values of the water in

Damietta branch were on the alkaline side (pH>7) during the investigation period. The lowest recorded pH value was 7.99 at the Zefta station, while the highest registered pH value was 8.45 at El-Kanater El-Khayria. These results are consistent with the findings of **Zlatanović *et al*. (2017)**, who stated that the optimal pH range for the growth of aquatic life is between pH 6.5 and 9. It was noticed that the minimum pH value was recorded at Zefta station (7.99) and the maximum value was recorded at El-Kanater El-Khayria station (8.45). Notably, the pH is positively correlated with CO_3 at $P< 0.01$ and negatively correlated with SiO_2 at $P< 0.05$.

2. Oxygen forms (DO, BOD and COD)

Dissolved oxygen (DO) plays a crucial role in supporting various forms of the aquatic life **(El Shakour & Mostafa, 2012)**. It is an important parameter for assessing water quality **(Hejna *et al*., 2022)**. In the current study, the lowest recorded value of dissolved oxygen (DO) was 5.91mg/ l at Talkha station, while the highest value of 8.65mg/ l was recorded at El-Serw station. Our sample from the river revealed that the average DO value was comparatively higher at El-Kanater El-Khayria station, indicating a better water quality in this region compared to the downstream Damietta region **(Zlatanović *et al*., 2017)**. Furthermore, the high oxygen content increases the water pH, thereby enhancing the sedimentation of metals **(Senze *et al*., 2023)**. Additionally, the high oxygen content increases the value of redox potential, leading to the precipitation of materials produced at low redox potential **(Husson, 2013)**.

The biochemical oxygen demand (BOD) is the amount of DO required by microorganisms to decompose the organic matter in water. It increases with higher chemical oxygen demand **(Phu, 2014)**. The El-Kanater El-Khayria station recorded the highest BOD value of 3.95mg/ l. This finding is consistent with **Atta *et al*. (2018)** observation that BOD tends to increase during summer due to the rise in microorganism population and activity caused by elevated temperatures. Consequently, the rate of oxygen consumption through biological activities of these microorganisms increases during hot periods, particularly in summer. Conversely, the lowest BOD value of 2.36mg/ l was recorded at the El-Kanater El-Khayria station, while the highest value of 4.45mg/ l was observed at the El-Serw station during summer. This finding aligns with those of **Vigiak *et al*. (2019)** in their report, elucidating that BOD serves as a reliable indicator of organic pollution in rivers, with higher levels found in the downstream of the wastewater inlets.

The concentrations of chemical oxygen demand (COD) in the freshwater samples collected ranged from 5.63 to 7.05mg/ l. It is a reliable parameter for assessing the level of organic pollution in the water, as it measures the amount of oxygen needed for the chemical oxidation of organic matter. In our study, the water samples collected from the Damietta district showed relatively higher values of both BOD and COD. These elevated values indicate a high load of organic matter, likely due to increased pollution levels in the aquatic ecosystem of the Damietta region. This pollution has a negative impact on the water quality **(Hereher *et al*., 2022)**. It was noticed that the minimum DO, BOD, and COD values were recorded at Zefta station (6.07, 7.99 and 3.28mg/ l, respectively), and the maximum values were recorded at El-Serw station (4.45, 8.65 and 7.98mg/ l, respectively). DO is negatively correlated with COD, PO_4 and TP at $P< 0.01$, and with NO_3 and F at $P< 0.05$. It is positively correlated with Cl at $P< 0.01$, and with NH_4, SO_4, Ca, Mg, Na, and HCO_3 at $P< 0.05$. BOD is positively correlated with NO_2 at $P< 0.01$, and with TP at $P< 0.05$. While, COD is negatively correlated with HCO_3 at $P< 0.05$. It is positively correlated with NO_3, PO_4 and TP at $P< 0.01$, and with TP at $P< 0.05$.

3. Major anions

The alkalinity can be used as an indication of the presence of the first two constituents, CO_3^{-2} and HCO^{3-}. The determination of water alkalinity is very important in predicting its biodegradability for fish life **(Dey *et al*., 2021)**. The concentrations of CO_3^{-2} were observed to be lower than HCO^{3-} concentrations, which can be attributed to the decomposition of dead phytoplankton leading to the release of CO_2, which dissolves into the water in the form of HCO^{3-} **(Eisaman *et al*., 2023)**. The carbonate concentrations were completely depleted at the Talkha station due to the presence of industrial chemicals that decrease the alkalinity of water, while the maximum value was recorded at Benha and El-Serw stations due to the increase in photosynthetic activity and the increase in the water temperature, leading to a decrease in the solubility of carbon dioxide **(Thompson *et al*., 2017)**.

Chlorinity is one of the most important factors directly affecting the survival and distribution of fish at different stages of their lives, or indirectly by changing the number of plankton, which is the main food source for the early larval stages of fish **(Hameed *et al*., 2021; Allan *et al*., 2022)**. Regarding the Damietta branch, it was found that the minimum Cl value was recorded at Zefta station (23.31mg/ l) and the maximum value was recorded at Talkha station (33.58mg/ l). It is positively correlated with SO_4, Ca and Na at $P< 0.01$. The highest recorded value was at El-Serw station, likely due to the discharge effluent of the drain containing an excess of agricultural, industrial, and domestic wastes, as well as a decrease in water level during drought periods **(Ahmed *et al*., 2024)**. Conversely, the lowest values were recorded at other stations due to the dilution effect during the flood season **(Thiele-Eich *et al*., 2015)**. In winter, the chloride contents increased due to the release of chloride ions from the bottom sediment, which is still affected by previous fish cages in the area over the last two decades, in addition to the effects of the drought period. Conversely, their values decreased during summer owing to the rising water level throughout the flood period **(Melo Júnior *et al*., 2023)**.

Regarding fluorides, it was noticed that the minimum F value was recorded at Talkha station (0.29mg/ l), and the maximum value was recorded at El-Serw station (0.53mg/ l). It is negatively correlated with Cl at $P< 0.05$ and with SO_4 and Ca at $P< 0.01$. While, it is positively correlated with PO_4, TP and K at $P< 0.01$ and with SiO_2 at $P< 0.05$.

Sulfates are naturally occurring in many minerals and are primarily produced in the chemical industry **(Francioso *et al*., 2020)**. In industrial waste, they are released into water through the atmospheric deposition, but the highest levels are typically found in groundwater **(Saavedra *et al*., 2021)**. It was found that the minimum SO_4 value was recorded at Benha station (18.36mg/ l), and the maximum value was recorded at Talkha station (25.42mg/ l). It is positively correlated to Ca and Na at $P< 0.01$ and with Mg at $P< 0.05$. The results of the current study showed an increase in the sulfate levels in the Damietta branch, particularly at the Talkha and El-Serw stations due to the detrimental effects of effluents on the water quality of the branch, as demonstrated by **Redwan and Elhaddad (2020)**. In the Damietta branch, the lowest value was recorded at the El-Kanater El-Khayria station during the summer season, which is attributed to the rising water levels during the flood period. Conversely, the highest value was recorded at the El-Serw station during winter due to the discharge of effluent heavily laden with agricultural, domestic, and industrial wastes. These findings are consistent with those of **Li *et al*. (2020)**.

4. Major cations

Calcium is a more abundant constituent of natural water than any other aquatic element **(Jaishankar *et al*., 2014)**. It is often analyzed together with magnesium in water analysis, as both contribute to water hardness **(Sengupta, 2013; Cao *et al*., 2019)**. This may be due to the dilution effect of floods during the hot season, as well as an increase in the precipitation of carbonates ($CaCO_3$) due to elevated temperatures **(Abualhaija & Mohammad, 2021)**. In the Damietta branch, it was observed that the minimum Ca value was recorded at El-Kanater El-Khayria station (26.32mg/ l), and the maximum value was at El-Serw station (33.93mg/ l). It is positively correlated to Na at $P< 0.01$ and with HCO_3 at $P< 0.05$. While, it is negatively correlated to K and Na at $P< 0.05$. The highest level of calcium was observed at the Talkha station during the autumn season. This is ascribed to the presence of excessive industrial and agricultural effluents, as well as the absence of oxygen in this station, which led to a decrease in the precipitation of calcium ion as calcium carbonate **(Yadav *et al*., 2021)**. Conversely, the lowest value was recorded at the El-Kanater El-Khayria station, which is traced back to the proliferation of phytoplankton, leading to an increase in the photosynthesis process and the precipitation of calcium ion as calcium carbonate. Additionally, this phenomenon is related to the rise in the water temperature, which results in a decrease in the solubility of calcium carbonate **(Müller *et al*., 2015)**. It was reported that, the decrease in calcium ion levels in summer is due to the decrease of carbonic acid, leading to the precipitation of $CaCO_3$ **(Pan *et al*., 2021)**. **Anderson *et al*. (2017)** stated that the increase of calcium ion concentration in winter may be described as the increase of their solubility and re-dissolution of $CaCO_3$ by the effect of CO_2 derived from the decay of organic matter.

Magnesium ions play an important role in photosynthetic process, production of carbohydrates, fatty acids proteins, alcohols, phenols, and chlorophyll **(Bonora *et al*.,**

2012). During chemical weathering, magnesium ions are released mainly as the soluble $MgCl_2$ and $MgSO_4$ like sodium although it is partly precipitated as carbonate **(Hameed *et al*., 2021)**. It was observed that the minimum Mg value was recorded at El-Kanater El-Khayria station (12.01mg/ l), and the maximum values were at Zefta and El-Serw stations (14.88mg/ l). It is positively correlated to HCO_3 at $P< 0.01$ and to Na at $P< 0.05$. The maximum magnesium content was recorded at Zefta station due to the discharge effluent which is loaded with domestic, agriculture and industrial wastes. While, the minimum value was recorded at El-Kanater El-Khayria station due to raising water level during the flood period causing a dilution and also due to adsorption of $MgCO_3$ onto clay particles and deposition to the bottom, especially by the rise in water temperature **(Francioso *et al*., 2020; Melo Júnior *et al*., 2023)**.

The obtained results indicate that the concentration of magnesium ions increased during the cold seasons (winter and autumn) more than in the hot seasons (summer and spring). This increase is attributed to the adsorption of $MgCO_3$ onto clay minerals and deposition to the bottom caused by the rise in water temperature **(Pashkevich *et al*., 2023)**. Additionally, the present results show a lower concentration of Mg^{+2} compared to Ca^{+2}, which is attributed to the behavior of dissolved CO_2 in water. The presence of CO_2 can affect the concentration of magnesium ions in solution, as CO_2 reacts with calcium ion salts more than with magnesium ions, converting large quantities of calcium into soluble bicarbonate **(Kang *et al*., 2020)**.

Sodium is generally predominant in high salinity water, with its concentration increasing regularly with conductivity and total ionic concentration **(Liu *et al*., 2022)**. It was observed that the minimum Na value was recorded at Talkha station (27.17mg/ l) and the maximum value was recorded at El-Serw station (38.98mg/ l). It is positively correlated to HCO_3 at $P< 0.01$. The highest recorded value was at the El-Serw station due to discharge effluents. These results align with those obtained by **Ahmed *et al*. (2024)**. Sodium occurs in water as positive ions, facilitating permeability through cells and maintaining the osmolarity of intracellular and extracellular fluids, which is essential for muscle contraction and nerve function **(Goff, 2018)**. Overall, sodium and potassium in aquatic systems affect the partitioning and desorption of trace metals. The presence of dissolved sodium at higher concentrations than trace metals can compete for particulate binding sites **(Phiri *et al*., 2021)**. This observation suggests that an increase in dissolved sodium inhibits the sorption of trace metals to particulates and increases the concentration of dissolved trace metals **(Abd El-Aal *et al*., 2020)**.

Potassium is the seventh most abundant element, and it is often bound to clay minerals in soils from dead plant and animal material before dissolving in water **(Alengebawy *et al*., 2021)**. It was observed that the minimum K value was recorded at El-Kanater El-Khayria station (8.14mg/ l), and the maximum value was recorded at Talkha station (13.33mg/ l). The notable increase in potassium concentration during winter is mainly attributed to the drought period. However, the decrease in water levels may lead to the decomposition and decay of dead organisms and phytoplankton, facilitating the release of K^+ into the overlying water. These results are consistent with those of **Thiele-Eich *et al*. (2015)**. Lower values were recorded during spring, which could be due to its consumption in the biological growth of aquatic microorganisms and phytoplankton. The relative decrease in K^+ concentrations during summer may be attributed to the dilution effect of the flood period **(Ulloa-Cedamanos *et al*., 2021)**.

During the present study, the data of the water quality parameters show high positive significant ($P< 0.01$) correlations among most of the parameters. This indicates that the monitored parameters, which did not show a significant correlation with any parameter, may share a common origin source **(Brraich & Jangu, 2015)**. According to our data, the four sampling sites and the four seasons are significantly different regarding the selected water quality parameters.

5. Nutrients salts

Nitrite is an intermediate product of the aerobic nitrification bacterial process **(Bhatnagar & Devi, 2013)**. It is not stable and its concentration in the Nile River ranged from 0.07 to 0.11µg/ l **(Dorgham *et al*., 2019)**. The results of the current study revealed an irregular distribution of nitrite, with a significant increase during the spring and autumn seasons. During spring, there is a conversion of ammonia to nitrite in the presence of dissolved oxygen, while in autumn, the decay of phytoplankton leads to the release of different forms of nitrogen **(Goher *et al*., 2018)**. The lowest recorded value of 0.05mg/ l was found at the Benha station, which can be attributed to the oxidation of nitrite into nitrate. This is likely due to the high levels of DO at this station. This explanation is in accordance with that found by **Ulloa-Cedamanos *et al*. (2021)**. The highest value of nitrate, 0.18mg/ l, was found at El-Serw station. It was noticed that the minimum NO_2 value was recorded at Benha station (0.05mg/ l), and the maximum value was recorded at El-Serw station (0.18mg/ l). Nitrite is negatively correlated to NO_3 at $P< 0.05$.

Nitrate is the final stable form of oxidation and decay of organic matter from domestic, industrial, and agricultural sources. It was noticed that the minimum NO_2 value was recorded at Zefta station (0.26mg/ l), and the maximum value was recorded at El-Serw station (0.89mg/ l). Nitrate is positively correlated to TN at $P< 0.01$, and with PO_4 at $P< 0.05$. While, it is negatively correlated with HCO_3 at $P< 0.05$. The highest value of 0.61mg/ l was recorded at El-Serw station, reflecting good water quality of the Nile River at Dakahlia Governorate. However, the Nile at Damietta district might be subjected to various sources of water pollution.

Ammonium is mostly produced by the decomposition of organic matter and by the hydrolysis of urea **(Sigurdarson *et al*., 2018)**. It was noticed that the minimum NH_4 value was recorded at El-Kanater El-Khayria station (0.13mg/ l) and the maximum value was recorded at Talkha station (0.49mg/ l). Ammonia is positively correlated to Mg at $P< 0.01$, and to HCO_3 at $P< 0.05$. The highest concentration of ammonium was noticed at the Talkha station (0.36mg/ l). Relatively higher values of ammonium were reported for water samples collected from the Damietta district, reflecting anthropogenic sources of pollution downstream in the region of the Damietta Governorate **(ElBagoury *et al*., 2023)**. Generally, the presence of high levels of ammonium is an evidence of sewage inflow into a water body.

It was noticed that the minimum TN value was recorded at El-Kanater El-Khayria and Benha stations (0.89mg/ l), and the maximum value was recorded at El-Serw station (1.56mg/ l). It is positively correlated to TP at $P< 0.05$.

The primary human-caused sources of phosphate in water include domestic sewage, agricultural effluents, and industrial wastewater **(Zhu & Ma, 2020)**. Freshwater samples collected from Talkha and El-Serw stations showed relatively higher levels of phosphate and total phosphorus compared to samples from other stations. The highest levels of ammonium, phosphate, and total phosphorus were found at Talkha and El-Serw stations, indicating agricultural drainage at these sites.

It was noticed that the minimum phosphate values were recorded at El-Kanater El-Khayria, Benha and El-Serw stations (0.02mg/ l), and the maximum value was recorded at El-Serw station (0.07mg/ l). Phosphate is negatively correlated to Cl at $P< 0.05$ and it is positively correlated to TP and F at $P< 0.01$. The high values recorded at these stations may be attributed to the discharge effluent from the Talkha power station, which activates the mineralization process by microorganisms. Additionally, the decrease in the phytoplankton population in the water may lead to a reduction in the uptake of PO_4^{-3}, resulting in an increase in its concentration in the water **(Badr, 2016)**. On the other hand, the minimum orthophosphate value recorded in El-Kanater El-Khayria, Benha, and Zefta stations might be related to the uptake of phosphorus by algae, bacteria, phytoplankton, and zooplankton. This might also refer to the sorption of phosphate onto humic matter, forming humic-iron-phosphate complexes, which reduces the total amount of available phosphate **(Ulloa-Cedamanos *et al*., 2021)**.

As anticipated, it was noticed that the minimum TP value was recorded at El-Kanater El-Khayria station (0.03mg/ l), and the maximum value was recorded at El-Serw station (0.11mg/ l). TP is negatively correlated to Cl at $P< 0.05$, and it is positively correlated to F at $P< 0.01$. The highest TP content was found at Talkha and El-Serw stations, which is related to the discharge of domestic waste containing a high amount of organic matter. Conversely, the lowest TP content was observed at El-Kanater El-Khayria and Benha stations due to the low zooplankton population resulting in reduced phosphate excretion and the increased consumption by phytoplankton. Additionally, phosphate was adsorbed onto silt and clay particles suspended in the water column **(Wahab *et al*., 2018)**.

Silicon is a non-metallic element found in the cell walls of diatoms, making up 10 to 30% of their dry weight **(Gügi *et al*., 2015)**. In water, silicon exists as orthosilicic acid, $Si(OH)_4$, and the hydrated form of silica, SiO_2. The biological silicon cycle revolved around the transformation of dissolved silicic acid into amorphous silica by organisms

(Al-Shalawi *et al*., 2023). It was found that the minimum SiO_2 values were recorded at Benha and El-Serw stations (2.04mg/ l), and the maximum value was recorded at Zefta station (5.68mg/ l). It is negatively correlated to Cl, SO_4, Ca, and Na at $P< 0.01$ and positively correlated to K at $P< 0.01$. The highest concentration of silicate in the Damietta branch was found at the El-Kanater El-Khayria station, likely due to the discharge of effluents containing various wastes. Conversely, the lowest concentration was recorded at the El-Serw station, likely due to uptake by diatoms, bacteria, fish, fungi, and algae **(Mahmoud *et al*., 2022)**.

Similar to other studied nutrient salts and parameters, the concentration of silicate in the Damietta branch may increase due to the influx of waste and sewage along its length. Fluctuations in silicate concentration may be caused by biological factors and the upwelling of deep water with high silicate content, as well as water movements, turbulence, temperature, pH, and salinity, particularly during floods. It is likely that the silicate content is influenced more by the physico-chemical conditions of the branch water than by diatom consumption **(Dorgham *et al*., 2019)**.

6. Water quality index

The WQI promotes the adequate classification of water quality and allow the public and decision makers to receive water quality information **(Pesce & Wunderlin, 2000)**. According to **Sanchez *et al.* (2007)**, WQI is classified as follows: 0- 25 (very bad), 26- 50 (bad), 51- 70 (medium), 71- 90 (good) and finally 91– 100 (excellent), as presented in Table (2) and illustrated in Fig. (2). It was noticed that all the sampling sites (El-Kanater El-Khayria, Benha, Zefta, Talkha and El-Serw) exhibited the category of good (71– 90) for drinking and irrigation and fair (51– 70) for aquatic life.

Table 1. Summary of the minimum, maximum, mean values, and standard deviations among the physico-chemical measurements in sampling stations and during the four seasons 2021

Cpt	Unit	El-Kanater El-Khayria				Benha				Zefta				Talkha				El-Serw			
		Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Temp.	^oC	19.20	28.40	24.48	4.19	20.30	28.30	24.83	3.92	20.80	29.10	25.15	4.41	19.80	29.20	25.23	4.45	19.60	28.70	24.63	4.31
Trans.	Cm	80.00	105.00	93.75	11.09	110.00	160.00	128.75	21.75	90.00	140.00	122.50	23.63	100.00	130.00	115.00	12.91	120.00	170.00	138.75	22.50
EC	µS/Cm	411.00	468.00	439.50	24.06	399.00	475.00	441.00	31.75	408.00	520.00	465.00	45.75	405.00	528.00	465.75	50.33	431.00	532.00	476.00	41.74
TDS	mg/l	271.26	308.88	290.07	15.88	263.34	313.50	291.06	20.95	269.28	343.20	306.90	30.19	267.30	348.48	307.40	33.22	284.46	351.12	314.16	27.55
pH	-	8.21	8.45	8.34	0.13	8.03	8.38	8.27	0.16	7.99	8.41	8.25	0.19	8.11	8.42	8.23	0.14	8.23	8.39	8.33	0.07
DO	mg/l	6.22	8.41	7.72	1.01	6.11	8.42	7.56	1.04	6.07	7.85	7.22	0.84	5.91	8.36	7.12	1.11	6.20	8.65	7.24	1.22
BOD		2.36	3.33	2.76	0.44	2.79	3.19	3.00	0.19	3.28	4.22	3.66	0.41	3.25	4.33	3.67	0.52	3.47	4.45	3.95	0.40
COD		5.14	6.66	5.72	0.70	5.32	6.15	5.63	0.38	5.98	7.87	6.56	0.90	5.97	7.86	6.76	0.82	6.33	7.98	7.05	0.68
CO_3^{--}		0.00	4.00	2.00	2.31	0.00	4.00	3.00	2.00	0.00	4.00	2.00	2.31	0.00	4.00	1.00	2.00	0.00	4.00	3.00	2.00
HCO_3^-		138.00	156.00	148.50	7.72	138.00	156.00	148.50	7.72	140.00	156.00	150.00	7.12	138.00	158.00	149.50	8.39	138.00	158.00	151.00	8.87
Cl^-		23.41	32.22	27.43	3.87	23.56	33.11	27.33	4.33	23.31	32.99	27.72	4.46	23.64	33.58	27.86	4.28	24.07	33.54	28.31	4.21
SO_4^{--}		18.45	23.26	20.28	2.10	18.36	24.63	20.95	2.68	18.47	24.36	21.00	2.65	20.10	25.42	22.03	2.49	21.35	24.99	22.83	1.72
Ca^{++}		26.32	32.59	28.49	2.80	27.26	32.95	29.28	2.53	26.37	33.81	29.42	3.16	27.35	32.59	29.51	2.20	27.90	33.93	29.48	2.96
Mg^{++}		12.01	13.88	12.95	0.95	12.04	14.38	13.52	1.02	12.34	14.87	13.87	1.08	12.54	14.26	13.71	0.79	12.58	14.88	13.75	0.95
Na^+		28.25	37.22	31.28	4.04	28.35	37.48	31.75	3.97	27.63	37.95	32.49	4.23	27.17	38.85	32.52	4.95	29.47	38.98	33.23	4.13
K^+		8.14	12.55	10.56	1.87	9.03	12.53	10.88	1.48	8.64	12.69	10.37	1.73	8.79	13.33	11.21	2.42	8.89	12.67	10.72	1.94
NO_2		0.06	0.09	0.08	0.01	0.05	0.10	0.07	0.02	0.07	0.15	0.10	0.03	0.09	0.14	0.11	0.02	0.06	0.18	0.10	0.05
NO_3		0.35	0.58	0.47	0.09	0.33	0.66	0.54	0.15	0.26	0.64	0.50	0.18	0.32	0.85	0.54	0.23	0.42	0.89	0.61	0.21
NH_4^+		0.13	0.35	0.25	0.09	0.25	0.41	0.31	0.07	0.15	0.43	0.33	0.12	0.23	0.49	0.36	0.10	0.23	0.37	0.28	0.06
TN		0.89	1.13	1.04	0.12	0.89	1.51	1.20	0.25	0.93	1.41	1.21	0.24	1.15	1.54	1.31	0.17	1.07	1.56	1.29	0.25
PO_4^{---}		0.02	0.05	0.03	0.01	0.02	0.03	0.03	0.00	0.03	0.04	0.03	0.00	0.03	0.05	0.04	0.01	0.02	0.07	0.04	0.02
TP		0.03	0.09	0.06	0.03	0.05	0.08	0.06	0.01	0.08	0.09	0.08	0.00	0.05	0.10	0.09	0.02	0.06	0.11	0.09	0.03
SiO_2		2.33	5.53	4.07	1.32	2.05	5.37	3.75	1.37	2.32	5.68	3.94	1.38	2.68	4.38	3.64	0.80	2.04	4.28	3.39	1.05
F^-		0.34	0.42	0.37	0.03	0.33	0.40	0.37	0.03	0.32	0.43	0.38	0.04	0.29	0.50	0.39	0.09	0.30	0.53	0.39	0.10

Table 2. Water quality index of measured physicochemical parameters (μg L^{-1}) in the water of the Damietta branch in 2021

	Drinking		Aquatic life		Irrigation	
Label	**CWQI**	**Category**	**CWQI**	**Category**	**CWQI**	**Category**
El-Kanater El-Khayria	**86**	**Good**	**79**	**Fair**	**85**	**Good**
Benha	**87**	**Good**	**79**	**Fair**	**84**	**Good**
Zefta	**84**	**Good**	**72**	**Fair**	**85**	**Good**
Talkha	**81**	**Good**	**72**	**Fair**	**84**	**Good**
El-Serw	**85**	**Good**	**73**	**Fair**	**84**	**Good**
Branch	**82**	**Good**	**73**	**Fair**	**84**	**Good**

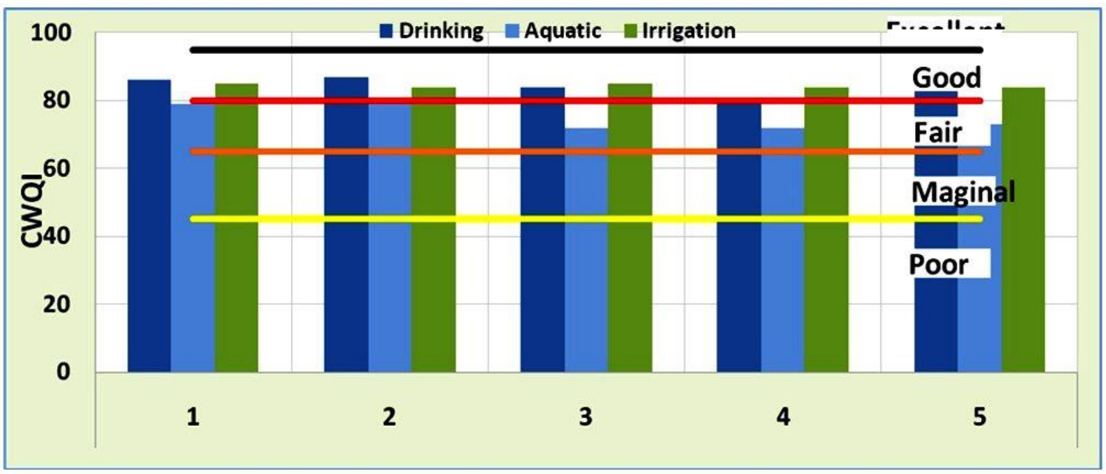

Fig. 2. Water quality index of measured physicochemical parameters (μg L^{-1}) in the water of the Damietta branch in 2021. **1:** El-Kanater EL-khayria, **2:** Benha, **3:** Zefta, **4:** Talkha, and **5:** El-Serw

7. Heavy metals

Heavy metals are of a great ecological concern due to their toxicity and accumulative behavior. Therefore, determination and speciation of heavy metals is a primary focus in environmental research **(Alengebawy *et al.*, 2021; Negahban *et al.*, 2021)**. Heavy metals such as Fe, Mn, Zn, Cu, and Pb are among the most common pollutants and are widely distributed in aquatic environments **(El-Amier *et al.*, 2020)**. Concentrations of the selected metals are presented in Table (3). The findings indicate that Talkha station has the highest metal values, whereas El-Kanater El-Khayria station has the lowest values. Among the metals, Fe was found to be high compared to the others, while Co was the lowest. Iron is the second most abundant metal in the earth's crust and is essential for the biological life. It plays a crucial role in the cellular processes of both plants and animals **(Tchounwou *et al*., 2012)**.

Iron (Fe) is a coenzyme that is essential for the synthesis of hemoglobin. It was found that the minimum Fe value was recorded at El-Kanater El-Khayria station (55.0µg/ l), and the maximum value was recorded at El-Serw station (173.0µg/ l). It is positively correlated to Mn, Cr, Zn and Pb at $P< 0.05$. The highest recorded value was at the Talkha station, while the lowest occurred at El-Kanater El-Khayria. The increase in Fe in the water is primarily due to the release of ferrous ions from sediments and industrial waste effluent from the Talkha fertilizer factory, as well as re-cooling water from the electrical station in the area. Additionally, the rise in Fe concentration may be attributed to the flow of the water from nearby shores carrying soil, as the earth's crust contains abundant amounts of metals **(Vasistha & Ganguly, 2020)**. However, the lower values may be due to the oxidation of Fe^{2+} to Fe^{3+}, which precipitates as $Fe(OH)_3$ in the sediment of oxygenated water. These findings are consistent with the data obtained by **Jiang *et al*. (2020)**. The concentration of iron in the water at all studied stations was still below the permissible levels (0.3mg/ L) recommended by the **Egyptian Organization for Standardization (1993)**.

Manganese is closely related to iron in the economy of rivers and lakes and behaves in a similar manner. It is toxic only in higher amounts; however, at low levels, it is considered a micronutrient **(Abd El-Aal *et al*., 2020)**. It was found that the minimum Mn values were recorded at El-Kanater EL-khayria and El-Serw station (1.0µg/ l), and the maximum value was recorded at Talkha station (7.00µg/ l). It is positively correlated to Cd at $P< 0.01$ and to Zn and Pb at $P< 0.05$. The concentrations of Mn decrease during the cold seasons, which may be due to the oxidation of Mn^{+2} to insoluble (MnO_2) in the presence of excess dissolved oxygen and a high pH value **(McCormick *et al*., 2021)**. During hot seasons, the high content of manganese may be attributed to the release of manganese from the sediment into the overlying water, influenced by both high temperatures and a fermentation process resulting from the decomposition of organic matter. Additionally, the increase in manganese concentration may be due to the decomposition of organic debris by microbial activity **(Ali *et al*., 2020)**.

Zinc can exist in water as free cations or soluble complexes associated with chlorides and sulfates, and it can also be adsorbed onto suspended matter **(Kołodziejczak-Radzimska & Jesionowski, 2014)**. It was found that the minimum Zn value was recorded at El-Serw station (36.0µg/ l) and the maximum value was recorded at Talkha station (141µg/ l). It is positively correlated with Pb at $P< 0.05$. The highest concentration of Zn was recorded at the Talkha station, likely due to a decrease in the sorption of Zn with the drop in water levels and the dissolution of clay containing zinc ions, resulting in a high content of Zn in the water. It is also possible that the decay of phytoplankton contributed to this high concentration **(Mo *et al*., 2020)**. The concentration of Zn in the studied area falls within the permissible limit (5mg/ L) set by the **Egyptian Organization for Standardization (1993)**. Copper is a crucial micronutrient essential for all forms of life. Its level of toxicity varies depending on the chemical characteristics of water, such as pH, hardness, temperature, dissolved oxygen, alkalinity, and the presence of complexing agents **(Abd El-Aal *et al*., 2020)**. The concentration of Cu in the water at the studied stations is still below the permissible level recommended by the **Egyptian Organization for Standardization (1993)**. It was observed that the minimum Cu value was recorded at El-Kanater El-Khayria station (3.00µg/ l), and the maximum value was recorded at Talkha station (75.0µg/ l). It is positively correlated to Co, Fe, and Cd at $P< 0.01$ and to Zn at $P< 0.05$. The decrease in Cu concentration may be due to its tendency to form complexes with organic ligands and humic matter, which leads to a decrease in the presence of free ions in the water. In fact, 90% of the Cu in the water was found to be complexed by dissolved organic materials and suspended matter **(Barber-Lluch *et al*., 2023)**. Nickel (Ni) is generally considered an essential trace element subject to homeostatic regulation and mobilization in response to disease and physiological stress **(Pishchik *et al*., 2021)**. It was observed that the minimum Ni value was recorded at El-Kanater El-Khayria station (5.00µg/ l) and the maximum value was recorded at Talkha station (15.0µg/ l). It is positively correlated to Co, Cr, Zn and Pb at $P< 0.01$ and to Mn at $P< 0.05$. The maximum concentration of Ni was recorded at Talkha station, possibly related to elevated temperatures accelerating fermentation and the decomposition of organic matter, as well as the liberation of nickel from sediment to the overlying water **(Cheng-Wen *et al*., 2020)**. Additionally, industrial wastes, pH, organic matter, and alkalinity play an important role in the distribution of Ni in the investigated stations, as demonstrated by **Helal *et al*. (2022)**. Similar to iron, the highest Ni concentration was recorded in Talkha station, possibly attributed to the rapid precipitation of suspended matter carrying iron after velocity reduction of the rapid flowing water. Regarding cobalt (Co), it was found that the minimum Co value was recorded at all studied stations (0.00µg/ l) and the maximum value was recorded at Talkha station (5.00µg/ l). It is positively correlated to Fe, Mn, Zn and Cd at $P< 0.01$ and to Pb at $P< 0.05$. According to **Qasem *et al*. (2021)**, the lowest concentration of Co was found at El-Kanater El-Khayria, Benha, and El-Serw stations, while the highest concentration was recorded at Talkha station. The researchers proposed that chemical coagulants aid in the sedimentation of heavy metals and micro pollutants from industrial wastewater.

Lead (Pb) is a toxic heavy metal that is widely distributed in the atmosphere, soils, and waters **(Jaishankar *et al*., 2014)**. It was found that the minimum Pb value was recorded at El-Serw station (4.00µg/ l) and the maximum value was recorded at Zefta station (22.0µg/ l). The highest levels of Pb were found in Zefta and Talkha, attributed to industrial effluent, agricultural drainage, and sewage waste, while the lowest levels were found in Benha and El-Serw. These findings are consistent with the results reported by **El-Amier *et al*. (2015)**.

Cadmium (Cd) is a persistent, bioaccumulative, and toxic heavy metal that poses a significant threat to humans, plants, and animals **(Abedi & Mojiri, 2020; Jadaa & Mohammed, 2023)**. It was found that the minimum Cd value was recorded at El-Kanater El-Khayria station (0.23µg/ l), and the maximum value was recorded at Talkha station (1.32µg/ l). The highest recorded levels of Cd were found at the Talkha station, likely due to the quantity of sewage discharge, agricultural discharges, domestic waste, and industrial discharges flowing into the river **(Schilling & ränckner, 2020)**. Additionally, the increase in Cd concentration may be attributed to agricultural, domestic, and industrial wastewaters being discharged into the Nile River. A significant portion of Cd is typically associated with organic matter, particularly humic acid **(Qu *et al*., 2023)**. Conversely, the low levels of Cd recorded at El-Kanater El-Khayria may be ascribed to the precipitation of Cd salts under high pH and dissolved oxygen conditions, with many of these salts likely present in the form of cadmium carbonate, as reported by **Atta *et al*. (2018)**.

Regarding chromium (Cr), the lowest concentration of Co was observed at El-Kanater El-Khayria and Benha stations, while the highest concentration was recorded at El-Serw station. This finding is consistent with **Ali *et al*. (2023)**, who investigated techniques for removing toxic hexavalent Cr ions from wastewater and aqueous solutions. It was found that the minimum Cr value is recorded at Talkha station (13.0µg/ l) and the maximum value was recorded at El-Serw station (31.0µg/ l). It is positively correlated to Pb at $P< 0.05$.

The overall findings revealed that concentrations of heavy metals, particularly Zn, Ni, Pb, and Cd, experienced an increase during the dry and hot seasons. This rise can be attributed to the release of metals from the sediment at the bottom, which then entered the water column above. The high temperatures and fermentation process were identified as the main factors influencing this phenomenon **(Tafa & Assefa, 2014; Abd El-Aal *et al*., 2020)**.

The data presented reveal a strong positive correlation among all the heavy metals studied. This finding aligns with the research conducted by **Ali *et al*. (2020)**, which suggests that these metals are interconnected due to their similar distribution patterns and mutual dependence. Furthermore, they are believed to originate from a shared source within the aquatic ecosystem, either during transportation or through deposition reactions.

Table 3. Summary of basic descriptive statistics among measurement of heavy metals in the sampling stations and during the four seasons 2021

Cpt	Unit	El-Kanater El-Khayria				Benha				Zefta				Talkha				El-Serw			
		Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Fe	µg/l	55.0	87.0	76.0	0.015	86.0	98.0	91.0	0.005	112.0	147.0	135.0	0.016	136.0	168.0	155.0	0.013	123.0	173.0	140.0	23.0
Mn		1.00	3.00	2.00	0.001	3.00	5.00	4.00	0.001	4.00	6.00	5.00	0.001	4.00	7.00	5.00	0.002	1.000	4.00	3.00	1.00
Zn		55.0	81.0	71.0	0.011	67.0	96.0	80.0	0.012	46.0	113.0	91.0	0.031	39.0	141	106.0	0.046	36.0	99.0	71.0	29.0
Cu		3.00	12.0	8.00	0.004	6.00	14.0	10.0	0.003	9.00	24.0	16.0	0.006	49.0	75.0	62.0	0.012	21.0	39.00	30.0	8.00
Ni		5.00	11.0	8.00	0.003	7.00	10.0	8.00	0.001	6.00	13.0	10.0	0.004	7.00	15.0	11.0	0.003	40.0	13.000	9.00	4.0
Co		0.00	0.00	0.00	0.000	0.00	1.00	0.00	0.001	0.00	3.00	1.00	0.001	0.00	5.00	3.00	0.002	0.00	0.000	0.00	0.00
Pb		6.00	11.0	9.00	0.002	6.00	9.00	8.00	0.002	5.00	22.0	13.0	0.007	9.00	18.0	13.0	0.004	4.000	13.00	8.00	4.00
Cd		0.23	0.68	0.46	0.019	0.52	0.95	0.70	0.018	0.48	1.12	0.73	0.028	0.65	1.32	0.93	0.028	0.41	0.65	0.49	11.00
Cr		14.0	28.0	22.0	0.006	16.0	28.0	2.00	0.005	17.0	29.0	23.0	0.007	13.0	27.0	23.0	0.006	22.0	31.0	25.00	4.00

8. Metal quality indices

According to the pollution index (PI) values, the water in the Damietta Branch suffers from significantly different contamination levels with the measured metals for aquatic life use. Cobalt (Co), cadmium (Cd), iron (Fe), and manganese (Mn) showed no pollution effects at any of the sites along the branch. However, chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) exhibited serious pollution effects at all the studied locations according to the aquatic life criteria, as indicated in Table (4) and illustrated in Fig. (3). According to the metal index (MI) values, all the selected sites along Damietta branch were seriously threatened by metal pollution for drinking and aquatic life usage (MI> 1), as indicated in Table (5).

Table 4. Pollution index (PI) of measured heavy metal concentrations (µg L^{-1}) in the water of the Damietta branch in 2021

	Fe	Mn	Zn	Cu	Ni	Co	Pb	Cd	Cr
Egypt[1]	0.303	0.035	0.024	0.019	0.388	0.500	1.118	0.223	0.336
Rank	-	-	-	-	-	-	**Polluted**	-	-
WHO[2]	0.303	0.035	0.146	0.019	0.111	0.500	1.118	0.223	0.336
Rank	-	-	-	-	-	-	**Polluted**	-	-
Irrigation[3]	0.018	0.018	0.036	0.188	0.039	0.050	0.056	0.067	0.168
Rank	-	-	-	-	-	-	-	-	-
Aquatic life[4]	0.303	0.071	1.455	9.382	0.310	0.833	1.597	0.670	1.681
Rank	-	-	**Polluted**	**Polluted**	**Polluted**	-	**Polluted**	-	**Polluted**

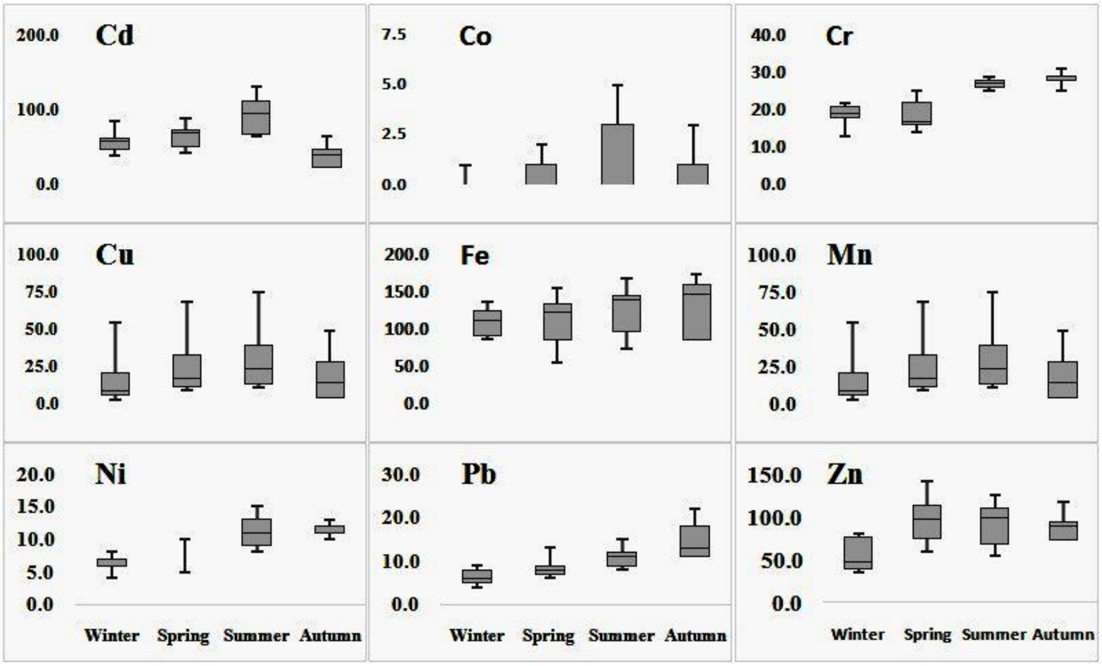

Fig. 3. Multiple box and whisker plots of measured heavy metal concentrations (µg L^{-1}) in the water of the Damietta branch in 2021

Table 5. Metal index (MI) of measured heavy metal concentrations (µg L^{-1}) in the water of the Damietta branch in 2021

Station	Drinking water				Irrigation		Aquatic life	
	Egypt		WHO					
El-Kanater El-Khayria	2.17	Polluted	2.01	Polluted	0.44	Unpolluted	7.88	Polluted
Benha	2.26	Polluted	2.10	Polluted	0.49	Unpolluted	8.04	Polluted
Zefta	3.27	Polluted	3.08	Polluted	0.62	Unpolluted	11.57	Polluted
Talkha	3.69	Polluted	3.49	Polluted	0.90	Unpolluted	17.21	Polluted
El-Serw	2.46	Polluted	2.27	Polluted	0.61	Unpolluted	10.56	Polluted
Min	**2.17**	-	**2.01**	-	**0.44**	-	**7.88**	-
Max	**3.69**	-	**3.49**	-	**0.90**	-	**17.21**	-
Mean	**2.77**	-	**2.59**	-	**0.62**	-	**11.05**	-
SD	**0.67**	-	**0.66**	-	**0.18**	-	**3.79**	-

CONCLUSION

Findings of the current study indicate that the physico-chemical parameters in water at the examined stations were within the acceptable limits. The WQI showed that all the selected sites along Damietta branch (El-Kanater EL-khayria, Benha, Zefta, Talkha, and El-Serw) exhibited the category good (71– 90) for drinking and irrigation and fair (51 – 70) for aquatic life. Regarding concentrations of studied heavy metals, the highest levels of Fe, Zn, Cu, Ni, Co, Pb and Cd were observed at Talkha station, while the highest concentration of Cr was recorded at El-Serw station. Values of the MI showed that all the selected sites were seriously threatened by metal pollution for drinking and aquatic life usage. Therefore the agricultural, sewage and domestic wastes as well as industrial effluents discharging into the Damietta branch must be ceased.

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