*Catrina* (2024), 33(1):43-56

# Assessment of Drinking Water Quality and Heavy Metal Pollution in Treatment Plants in Damietta Governorate, Egypt

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Received: January 1, 2024; Accepted: July 9, 2024

## ABSTRACT

Ensuring safe surface water management is crucial to meet global drinking water standards. Thus, this study was conducted to evaluate the water quality of some drinking water treatment plants in Damietta governorate, including the inlet fresh water of the Nile River and the outlet drinking water. Water samples were collected from 11 treatment plants located at the River Nile, and the physicochemical parameters, in addition to some heavy metals, were analyzed seasonally through the year 2022. Water quality and heavy metal pollution indices were employed to assess the status of water quality. A One-way Analysis of Variance (One-way ANOVA) was applied to compare the spatial and temporal variation of the Water Quality Index (WQI). The results illustrated that the average value of turbidity, pH, Electrical Conductivity (EC), Total Hardness and Total Dissolved Solid (TDS) of plant inlets was 3.37 NTU, 8.05, 359.3 µmohs/cm, 162.6 and 188.9 mg/l, respectively. Besides, chloride, sulphate, calcium, magnesium, iron, lead, cadmium, and zinc concentrations were 24.6, 28.5, 10.9, 6.2, 0.04, 0.029, 0.006, and 0.15 mg/l, respectively, whereas plant outlet results indicated that the average value of turbidity pH, EC, TDS, and Total Hardness was 0.61 NTU, 7.51, 372.7 µmohs/cm, 155.8, and 201.2 mg/l, respectively. The concentrations of chloride, sulphate, calcium, magnesium, iron, lead, cadmium and zinc were 30.4, 33.4, 37.9, 16.8, 0.02, 0.01, 0.003 and 0.065 mg/l, respectively. In conclusion, all the investigated parameters were within the permissible limits according to WHO (2017), except lead and cadmium in plant inlets, which slightly exceeded the standard limit. The Average Water Quality Index values confirmed that Nile River water was good (52.4), while the outlet drinking water quality was excellent (45.5).

**Keywords:** Drinking Water Quality; Heavy Metals; Nile River; Physicochemical Parameters; Treatment Plants.

## INTRODUCTION

The Nile River is the basic source of fresh water necessary for drinking, agriculture, fisheries, and industry. Most water treatment plants intakes on the River Nile are influenced by excess concentration of contaminants produced from agricultural drainage that lies on either side, industrial streams, and household wastes from villages that don't have sanitation systems (Geriesh *et al*., 2008; Hussein *et al*., 2023).

Secure drinking water is safe for consumption, food preparation, personal hygiene, and washing. It must meet physical, chemical, and biological quality standards at the point of supply. Poor management and misapplication of water resources can lead to decreased quality and supply, as well as the spread of diseases (Aly *et al*., 2022). To determine the appropriate treatment for drinking purposes, water quality guidelines should be seriously applied in addition to continuous measurement of physicochemical parameters to determine water constituents and quality. Guidelines for water intake and quality standards are crucial for maintaining human health; chemical components and contaminants should be carefully disposed of (FAO, 2023).

A multi-barrier approach is needed to ensure clean water for human health, including protecting raw water from pollution and accurately treating it. Surface water treatment plants use physical, chemical, and biological processes to remove contaminants, distribute the treated water, and incorporate advanced technologies for further purification (Ahmed, 2021; Afifi *et al.*, 2023). There are two main types of conventional purifying plants: central plants, which are designed to offer water to large urban areas or districts with a capacity above 17 thousand $m^3$/day (Saravanan *et al.*, 2021), and compact plants, which are responsible for providing water to villages and small communities, and their capacity is determined based on the population size. In Egypt, small-sized plants employ advanced technologies such as mobile units, direct filtration, or slow sand filtration units to provide clean and safe drinking water (Zebra *et al.*, 2021; Mossad *et al.*, 2022). These compact plants are designed to be easily transportable and can be quickly set up in areas with limited infrastructure. They are particularly beneficial in remote or disaster-stricken regions where access to clean water is crucial for survival and public health.

Water quality parameters are crucial in determining the quality of water in an aquatic environment (El-Emam, 2023). Nevertheless, the extensive range of water quality indices and their significant fluctuations caused by both natural and human-related variables frequently present challenges in drawing meaningful conclusions from the water quality data (Xu *et al.*, 2022). Monitoring programs are required to assess water quality via physicochemical parameter determination, which gives a large data matrix that

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oftentimes utilizes the water quality index (García-Avila *et al*., 2022), which is a concise measure of water quality, aiding in determining treatment methods and assessing drinking water sources' suitability. However, water quality declines vary across bodies due to pollution-causing activities (Manna and Biswas, 2023).

It is crucial to develop an adjusted WQI that considers local pollution sources because factors and variations affect water quality indices. This reduces analytical expenses and time, and strong correlations have been found between simplified WQI values and real results, making it more cost-effective and efficient. (Uddin *et al*., 2022).

The objective of the present study is to systematically evaluate the water quality of selected drinking water treatment plants in Damietta Govern-orate by assessing the physicochemical parameters and heavy metal concentrations in both the inlet freshwater from the Nile River and the outlet drinking water. Through seasonal analysis over the year 2022, this research seeks to identify the extent of water quality compliance with global drinking water standards, particularly those set by the World Health Organization (WHO). Additionally, the study aims to employ water quality and heavy metal pollution indices to quantitatively assess the status of water quality while investigating spatial and temporal variations using statistical methods. Ultimately, this study will contribute to the understanding of surface water management practices and their efficacy in providing safe drinking water in the region.

## MATERIALS AND METHODS

### Study Area

Map (1) shows the study area along the Damietta Branch of the Nile River in Damietta, spanning 24.2 km. Samples were taken from eleven typical drinking water treatment plants. From Tanzania's Lake Tanganyika (Lat. 30S) to Egypt's Mediterranean Sea (Lat. 31º15'N), the River Nile spans 6625 km, with 1352 km within Egypt. The Nile River crosses multiple geological and climatic zones. Egypt has a pleasant winter (November-April) and a hot summer (May-October).

The Delta's average annual temperature rises southward to the Sudanese border, where it matches the open deserts to the east and west (Negm *et al*., 2017). The Nile River drains Africa from Lake Victoria's equatorial climate to its Mediterranean delta. The Nile River originates in Lake Victoria, but its drainage basins include the rivers that flow into Victoria, George, Edward, and Albert lakes. Some tributaries join the river's mainstream above Khartoum, making it the White Nile (which drops over 500 m from the east African plateau to the Sudan plains). Blue Nile drains Ethiopia's highlands and meets White Nile in Khartoum (Badr *et al*., 2013).

The Damietta branch discharges 30 million cubic meters of water daily and receives 10.50 million $m^3$ per day of drainage water, which constitutes 35% of its maximum flow at various locations. This branch is significantly polluted by the Omar-Bek drain, Kafr Al-Batekh, and the Talkha power stations, particularly those contributing to thermal pollution. Numerous settlements and drains along the branch contaminate the Omar-Bek drain with household, industrial, and agricultural waste (Mostafa and Peters, 2015). Additionally, large cities and populated villages dispose of rubbish into the river along the Damietta branch, while thousands of cultivated acres typically discharge irrigation water into the river. Furthermore, many river-side companies and power stations release industrial waste into the waters of the river branch (El-Rayes *et al.*, 2018).

### Collection of samples

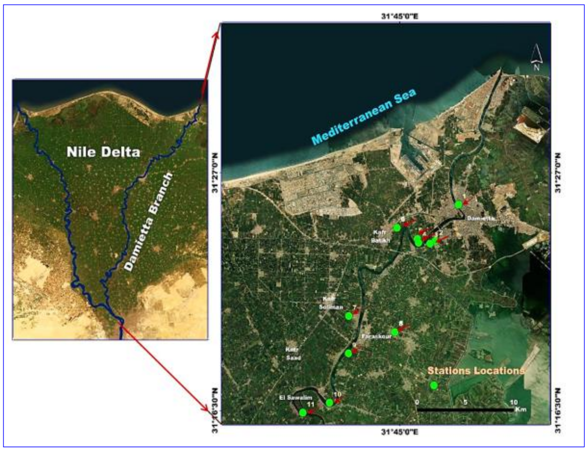
Water samples were collected quarterly over the course of one year including winter, spring, summer, and autumn of 2022. Eleven typical drinking water treatment plants were selected for water sample collection. For each plant, two sampling locations were analyzed: the untreated water (inlet) and the treated water (outlet). To ensure that the water samples remained free of contaminants, they were stored in acid-treated high-density polyethylene (HDPE) bottles that had been thoroughly cleaned with deionized water, dried, and securely capped for storage.

Water sample was collected below the water surface by dipping containers into the water. *In situ* characteristic physiochemical parameters were analyzed immediately after sampling. The samples were then transported in an ice box to the Water Pollution Research Laboratory in the Environmental Sciences Department and the Microanalysis Unit at the Faculty of Science, Damietta University, for further analysis. Nile water samples were collected from the central zone at a depth of 0.5 meters.

### Analysis of Physicochemical Parameters

Temperature, turbidity, pH, EC, and TDS of surface water at both the intake and outlet were measured on-site using portable multi-probe water quality analyzers that were calibrated prior to use. In laboratory analysis, preservation methods were restricted to pH regulation, chemical supplementation, freezing, and refrigeration. The pH of the samples was directly measured using a pH meter (model 211 HANNA; USA) following the electrometric method described in APHA (2017). Turbidity was measured using the Nephelometric method with Turbidity-meter (Al 1000, aqualytic, Germany) capable of measuring 0-200 NTU, as speci-fied in APHA (2017). The TDS (mg/l) and EC (µS/cm) were determined by a digital meter (Digital Portable TDS/Conductivity meter model. 8033 HANNA, USA). In addition, chlorides, alkalinity, residual chlorine, calcium, magnesium total hardness, and macronutrients such as ammonia and sulphate were analyzed using the standard methods for examining of water and wastewater as outlined in the APHA (2017) guidelines.

The heavy metals (cadmium, iron, zinc, and lead) were quantified using inductively coupled plasma-mass spectrometry 7000 with Perkin Elmer Optima 3000 (USA). The instruments were calibrated before measurement in accordance with the manufacturer's guidelines. The obtained results were verified using the pro-



**Map (1):** The location and layout of water treatment plants in the Damietta Governorate along the Damietta branch of the River Nile (El-Emam *et al*., 2024).

cesses of standardization and triplication of samples. The treatment plant's overall efficiency was determined by employing the subsequent formula:

$$Treatment\ efficiency(\%) = \frac{C_i - C_e}{C_i} X100$$

Where, *Ci* and *Ce* are the inlet and outlet concentration of the studied parameter, respectively.

## Water Quality Index

Various WQI models have been developed and implemented worldwide in recent years to evaluate the quality of surface and groundwater. These models utilize the weighted arithmetic index technique to generate the WQI. The fourteen essential physiochemical parameters (turbidity, pH, temperature, EC, TDS, alkalinity, calcium and magnesium hardness, total hardness, calcium, chloride, magnesium, sulphate, and ammonia) were utilized regarding their appropriateness for human consumption. The equation devised by Tiwari and Manzoor (1988) was used to calculate WQI in the present study. The quality rating (qi) for the water quality parameter is determined using the following equation:

$$qi = \frac{100\ Vi}{Si}$$

Where, Vi represents the measured value of the parameter at a specific sample location; Si represents the establishment standard for stream water quality.

The equation demonstrates that qi equals 100 when the observed value is identical to the standard value. Consequently, the higher qi value indicated the presence of contaminated water. Water Quality Index (WQI) can be created using the quality rating (qi) associated with the parameter (Tiwari and Manzoor, 1988) in the following expression: The overall WQI was calculated as follow:

$$WQI = \sum qi$$

Where, qi is the quality rating for parameter i. At i=1, the average water quality index (AWQI) for n parameters was determined (Tiwari and Manzoor, 1988) using the following relation:

$$AWQI = \sum_{i=1}^{n} q/n$$

Where, $\sum_{i=1}^{n} qi$ represents the sum of all quality ratings for the parameters, and n is the number of parameters. AWQI was classified into 5 categories: <50, excellent: this range indicates very high water quality, suggesting that the water is safe for consumption and suitable for recreational activities. It reflects minimal contamination and optimal conditions for aquatic life. 50-100 - Good: Water in this category is generally safe for drinking and recreational use, but it may have slight contamination or quality issues. This level indicates that while the water is acceptable, some parameters may require monitoring. 100-200 - Poor: this classification suggests significant concerns regarding water quality. The water may pose health risks if consumed without treatment and could affect aquatic ecosystems. It indicates a need for immediate attention and potential remediation efforts. However, the range of 200-300 – is very poor, in which water in this range is likely unsuitable for drinking and recreational use without treatment. It poses health risks to humans and wildlife, indicating severe contamination issues that require urgent intervention. WQI with >300 – range is unsuitable for consumption. This level denotes extremely poor water quality, making it unsafe for any use, including drinking and recreation. Immediate action is necessary to address the sources of contamination and restore water quality.

## Metal Pollution index

The pollution index (PI) was employed to assess the extent of heavy metal pollution in water samples (Emoyan *et al*., 2005; Odukoya and Abimbola, 2010). The acceptable level refers to the concentration of elements in water that is deemed safe for human consumption. The PI is determined by calculating the levels of different metals and then classified into five categories (Table 1) using the following equation (Caerio *et al*., 2005):

$$PI = \sum_{i=1}^{n} \frac{Ci}{Si} / \mathrm{Nm}$$

Where, Ci represents the concentration of heavy metals in water, Si represents the allowed level of heavy metals, and Nm represents the number of heavy metals.

**Table (1):** Water quality classification according to pollution index (Caerio *et al*., 2005).

| PI Level (Category) | Water Quality Status |
|---|---|
| <1 | No effect |
| 1-2 | Slight effect |
| 2-3 | Moderate effect |
| 3-4 | Strong effect |
| 4-5 | Severe effect |

### Statistical Analysis

Descriptive statistics were calculated for the variables measured in the collected water samples. The Pearson correlation coefficient was utilized to explore the relationships between each pair of characteristics. The Water Quality Index (WQI) was computed using software applications, specifically Microsoft Excel. To evaluate the regional and temporal variations in WQI values, a statistical analysis using One-way Analysis of Variance (ANOVA) was performed with SPSS statistical software (IBM Version 26.0, SPSS Inc., Chicago, USA).

## RESULTS

### Physicochemical parameters and heavy metals

The physicochemical parameters and plant efficiency are summarized in Tables 2 and 3, and Figures 2, 3, 4, and 5. The results revealed that the average temperature values for the plant inlets and outlets were 25.88 ± 5.046 ºC and 25.85 ± 4.70 ºC, respectively. The maximum temperatures recorded were 33.1 ºC at the inlet of Station 4 and 32 ºC at the outlet of Station 1 during the summer, while the minimum temperature recorded was 16 ºC at both the inlet and outlet of Station 9 in the winter.

The average turbidity values for plant inlets and outlets were 3.36 ± 1.14 NTU and 0.61 ± 0.22 NTU, respectively. The significantly highest turbidity value recorded was 7 NTU at the inlet of Station 4 during spring, while the lowest value was 1.8 NTU at the inlet of Station 2 in winter. Additionally, the maximum turbidity value observed at the outlet of Station 4 was 1 NTU, while the lowest value at the outlet of Station 8 in autumn was 0.25 NTU. Meanwhile, the average values of pH for plant inlets and outlets were 8.04 ±0.257 and 7.5 ± 0.23. The maximum values (8.5 and 8.3) were observed at St. 3 inlet and outlet in winter and autumn, respectively, while the minimum values (7.22 and 7.15) were documented at St. 10 inlet and St. 5 outlet in autumn and spring, respectively.

The average value of TDS for plant inlets was 188.9 ± 28.26 mg/l, while for plant outlets it was 201.15 ± 44.64 mg/l. The results showed that the maximum values were 295 and 426 mg/l at St. 7 inlet and St. 3 outlet in winter, while the minimum values were 142 and 150 mg/l at St. 2 inlet and outlet in spring. For EC, the average value of plant inlets was 359.31±44.69 µS/cm, while it was 372.72 ± 64.7 µS/cm for the plant outlets. However, the maximum value recorded was 474 µS/cm at St. 10 inlet and St. 7 outlet in summer, while the minimum EC values of 276 µmhos/cm at St. 3 inlet and 38 µS/cm at St. 1 outlet were also recorded in summer.

The results showed that the mean chloride value for plant inlets and outlets was 24.59 ± 5.16 mg/l and 30.40 ± 6.24 mg/l, respectively. The highest value was 34 mg/l at St. 6 inlet in winter and 44 mg/l at St. 2 outlet in winter and spring, while the lowest value was 14 mg/l at St. 4 inlet and 20 mg/l at St. 4, St. 11 outlets in summer and autumn. On the other hand, plant inlets had an average alkalinity of 141.65 ± 17.57 mg/l, while the value was 129.95 ± 15.96 mg/l for plant outlets. The highest alkalinity value was 184 mg/l at St. 10 inlet in winter and 172 mg/l at St. 5 outlet in autumn, while the lowest value was 120 and 100 mg/l at St. 4 inlet and outlet in spring.

According to the data in Tables (2, 3) the mean total hardness of 162.59 ± 16.81 mg/l was reported for plant inlets and 155.77 ± 17.83 mg/l for outlets. The average calcium hardness for plant inlets was 94 ± 23.77 mg/l, while for outlets it was 93.8 ± 17.75 mg/l. The maximum value was 164 mg/l in autumn, where the minimum was 48 mg/l in spring. The magnesium hardness values for plant inlets and outlets ranged from 74 ± 2.13 mg/l to 67.45 ± 18.98 mg/l, with maximum values at St. 6 inlet and minimum values at St. 4 outlet. In addition, the average calcium content in plant inlets was 38.3 ± 10.96 mg/l and 37.96 ± 8.95 mg/l in plant outlets. The maximum value was 82 mg/l and 76 mg/l in autumn, and the minimum value was 19.2 mg/l and 28 mg/l in spring for plant inlets and outlets, respectively.

The magnesium hardness values for plant inlets and outlets ranged from 74 ± 2.13 mg/l to 67.45 ± 18.98 mg/l, with maximum values at St.6 inlet and minimum values at St.4 outlet. The highest ammonia value was 0.85 mg/l at St. 5 inlet and 0.1886 mg/l at St. 10 outlet in spring, while the lowest value was 0.001 at St. 9 inlet in autumn and non-detected (ND) at all plant outlets in most seasons. The highest sulphate value was 40 mg/l at inlets of St. 1 and St. 7, while the lowest was 20 at St. 6 outlet in winter and autumn. The average iron concentration in drinking water treatment plants was 0.04 ± 0.02 mg/l, with the highest values at St. 10 inlet in winter and St. 3 and 5 outlets in autumn and winter. The lowest values were at St. 2 outlets in spring and summer and at St. 5 outlets in winter.

The average lead concentration was 0.029 ± 0.011 mg/L, with maximum values recorded at St. 4 inlet during summer and autumn, and at St. 3 outlet in autumn. The minimum values were observed at St. 10 inlet in autumn and at St. 7 outlet in winter. However, cadmium concentrations averaged 0.006 ± 0.002 mg/L, with the highest values found at St. 4 inlet in summer and at St. 6 outlet in autumn. The lowest values were recorded at St. 7 and 11 inlets in winter and at St. 10 outlet in spring. Meanwhile, zinc concentrations were 0.14 ± 0.12 mg/L for station inlets and 0.06 ± 0.02 mg/L for station outlets, respectively. The highest values were observed at St. 2 inlets and at St. 5 outlet in autumn, while the lowest values were recorded at St. 9 inlets in winter and at Station 2 outlet in autumn.

### Drinking water treatment plants efficiency

The efficiency of drinking water treatment plant for different water quality parameters during the study period was presented in Figures (2-5). The results revealed that the plant treatment efficiency for turbidity varied from 70.7% (St.10) to 84.03 (St. 3) with an average value of 81.9%. The average treatment efficiency for TDS was -6.47%, with the lowest value of -21.28% (plant 4), and the highest value of 16.5% (plant 8). Similarly, the plant treatment efficiency for EC ranged from -20.2% at plant 4 to 23.7% at plant 7 with an average of -3.7%. In addition, the average treatment efficiency for chloride was -23.67% with a range of -45% to 0 %. On the other hand, the plant treatment efficiency for alkalinity ranged from 5.9% at plant 1 to 21.37% at plant 10 with an average of 8.26%. Moreover, the average treatment efficiency for total hardness was 4.1% with a range from -1.2% at plant 1 to 20% at plant 10.

The investigated treatment plants exhibited a calcium hardness efficiency range from -35.8% at Plant 7 to 18.6% at Plant 11, with an average value of 0.19%. In contrast, the average treatment efficiency for magnesium was 8.89%, with Plant 6 showing the highest efficiency at 50.7% and Plant 9 the lowest at -21.3%. Besides, the average treatment efficiency for ammonia was 79.45%, with the highest efficiency of 100% (plant 9) and the lowest of -131.2% at plant 11. Sulphate achieved an average treatment efficiency of -17.27%, with plant 9 having the highest value (3.9%) and plant 11 having the lowest (27.9%). In addition, the average treatment efficiency for iron was 51.16%, with maximum value of 68.4% at plant 7 and minimum value of 31.3% at plant 5. Lead had an average treatment efficiency of 65.5%, with the range of 31.8% at plant 1 and 70.2% at plant 2. The plant treatment efficiency for cadmium ranged between 75% (plant 4) and -32.1% (plant 3) with an average value of 53.12%. Meanwhile, the treatment efficiency of zinc varied between 33.6% (plant 10) and 65.5% (plant 4) with an average value of 55.17%.

## Evaluation of water quality and pollution indexes

Table (3) presents the water quality index (WQI) values for inlet and outlet water quality, evaluated for drinking purposes using the weighted arithmetic approach in water treatment plants. The analysis reveals that the average WQI value for the Nile River water at the inlet was 52.4, whereas the WQI value for treated water at the plant outlet was 45.5. These findings indicate that the water quality falls within acceptable limits for drinking after treatment.

Furthermore, the analysis of water quality parameters at both plant inlets and outlets highlights significant improvements following the treatment processes. Parameters such as turbidity, dissolved oxygen, and microbial content demonstrate marked reductions, reflecting the efficiency of the treatment protocols. The data confirm that most water quality parameters meet or exceed acceptable drinking water standards, underscoring the effectiveness of the water treatment in contaminant removal and overall enhancement of water quality. This assessment not only provides insight into the current performance of the treatment plants but also emphasizes the critical role of monitoring tools like WQI and PI in ensuring safe and sustainable water management practices.

The pollution index (PI) was calculated to assess water contamination by specific heavy metals, including iron ($Fe^{2+}$), lead ($Pb^{2+}$), zinc ($Zn^{2+}$), and cadmium ($Cd^{2+}$). The results presented in Table (4) indicate that the Nile River water at the inlet had a PI of 1.3, while the treated plant outflow water exhibited a significantly reduced PI of 0.523. This reduction demonstrates the effectiveness of the treatment processes in mitigating heavy metal pollution. The data also reveal that iron and zinc concentrations remain within

**Table (2):** Physicochemical characterization of water quality parameters from plant inlets (raw water) and outlets (treated water) in comparison with standard limits based on WHO guidelines (2017).

| **Parameters** | **Sample source** | | | | | | | | **Standard limits**$^{\dagger}$ |
|---|---|---|---|---|---|---|---|---|---|
| | **Plant inlets** | | | | **Plant outlet** | | | | |
| | **Min** | **Max** | **Mean** | **SD** | **Min** | **Max** | **Mean** | **SD** | |
| **Turbidity (**NTU) | 1.80 | 7.0 | 3.37 | 1.146 | 0.25 | 1.00 | 0.61 | 0.23 | 5.0 |
| **pH** | 7.22 | 8.5 | 8.046 | 0.258 | 7.15 | 8.30 | 7.51 | 0.23 | 6.5-8.5 |
| **Temperature** ($^{o}$C**)** | 16.0 | 33.1 | 25.89 | 5.047 | 16 | 32.00 | 25.86 | 4.7 | ≥ 15 |
| **TDS** (mg/L) | 142.0 | 295 | 188.93 | 28.27 | 150 | 426.0 | 201.16 | 44.6 | 500 |
| **EC** (µS/cm) | 276.0 | 474.0 | 359.32 | 44.7 | 38 | 474.0 | 372.73 | 64.7 | 1600 |
| **Alkalinity** (mg/L) | 120.0 | 184.0 | 141.66 | 17.57 | 100 | 172.0 | 129.95 | 15.9 | <200 |
| **Total Hardness** (mg/L) | 128.0 | 212.0 | 162.59 | 16.82 | 120 | 204.0 | 155.77 | 17.8 | 500 |
| **Calcium Hardness** (mg/L) | 48.0 | 164.0 | 94.0 | 23.77 | 72 | 160.0 | 93.82 | 17.8 | 350 |
| **Magnesium Hardness** | 28.0 | 120.0 | 74.0 | 21.32 | 28 | 120.0 | 67.45 | 18.9 | 150 |
| **Cation ions (mg/L)** | | | | | | | | | |
| **Calcium ($Ca^{2+}$)** | 19.2 | 82 | 38.26 | 10.96 | 28.0 | 76.00 | 37.96 | 8.90 | 75.0 |
| **Magnesium ($Mg^{2+}$)** | 6.72 | 38.4 | 18.45 | 6.29 | 6.72 | 35.20 | 16.81 | 5.90 | 50.0 |
| **Ammonia ($NH_4^+$)** | 0.001 | 0.85 | 0.073 | 0.128 | 0.0 | 0.1886 | 0.015 | 0.037 | 1.50 |
| **Anion ions (mg/L)** | | | | | | | | | |
| **Chloride ($Cl^-$)** | 14 | 34 | 24.59 | 5.16 | 38.0 | 474 | 372.73 | 64.70 | 250 |
| **Sulphate ($SO_4^{2-}$)** | 18 | 40 | 28.48 | 6.95 | 20.0 | 48.0 | 33.4 | 7.140 | 250 |
| **Heavy metals** (mg/L) | | | | | | | | | |
| **Iron** | 0.02 | 0.1 | 0.043 | 0.022 | 0.000 | 0.06 | 0.021 | 0.015 | 0.30 |
| **Lead** | 0.01 | 0.05 | 0.029 | 0.012 | 0.005 | 0.032 | 0.01 | 0.005 | 0.01 |
| **Cadmium** | 0.003 | 0.01 | 0.0064 | 0.002 | 0.001 | 0.03 | 0.003 | 0.004 | 0.003 |
| **Zinc** | 0.02 | 0.9 | 0.145 | 0.128 | 0.003 | 0.13 | 0.065 | 0.027 | 3.00 |

SD: Standard Deviation (all parameters were measured in triplicate); Min: Minimum Value; Max: Maximum value; Mean average value. $^{\dagger}$Standard limits based on WHO (2017).

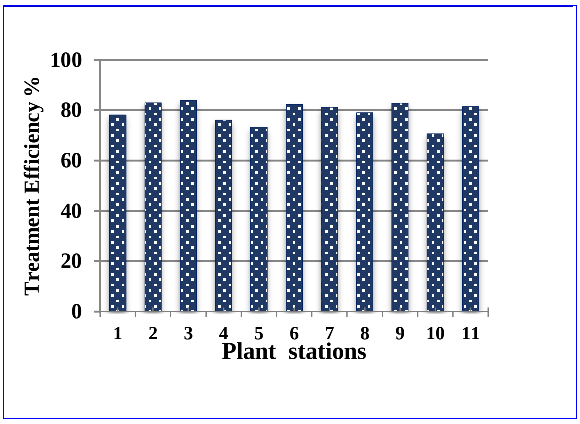


**Figure (2):** Treatment efficiency (%) of turbidity level at water treatment plant station.

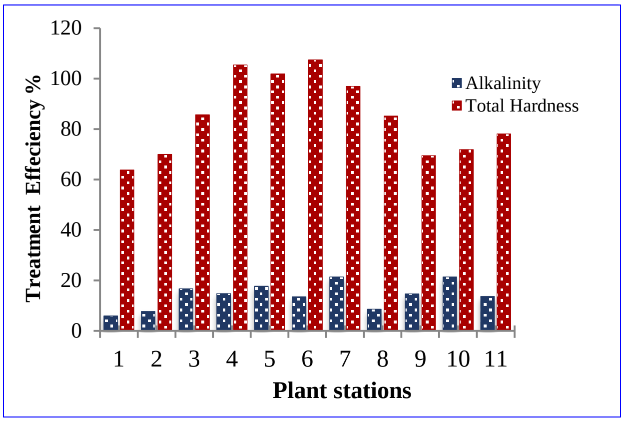


**Figure (3):** Treatment efficiency (%) of alkalinity and total hardness levels at water treatment plant stations.

both before and after treatment, reflecting their lower environmental and health risks in this context. However, lead and cadmium levels at the inlet are remarkably concerning, as their concentrations exceed permissible thresholds and pose significant risks to human health due to their toxicity and potential for bioaccumulation.

The substantial decrease in the PI after treatment highlights the capability of the water treatment plant to address these contaminants effectively. Nonetheless, the presence of elevated lead and cadmium levels at the inlet underscores the need for continuous monitoring and potential upstream interventions to control sources of these heavy metals. This study emphasizes the importance of rigorous water quality management to ensure public safety and environmental sustainability. It may be beneficial to explore additional treatment options or technologies specifically targeting these heavy metals to ensure compliance with safety standards. Generally, the treatment process appears effective in reducing heavy metal concentrations; however, further efforts are needed to adequately address the levels of lead and cadmium.

### Evaluation of relationships among various water quality parameters

*Pearson matrix of water quality indicators*

Tables (5) and (6) illustrate the construction of Pearson's correlation matrix for the evaluated variables, which include turbidity, temperature, magnesium, ammonia, sulfate, total hardness, iron, lead, cadmium, zinc, alkalinity, and total dissolved solids (TDS). The analysis revealed a strong positive correlation between total hardness, calcium, and magnesium, with a correlation coefficient (r) of 0.902. Excluding ammonia, iron, lead, and zinc, the remaining variables demonstrated weak positive correlations with the water quality index (WQI). Additionally, a moderately strong positive correlation was observed between turbidity and temperature, with a correlation coefficient of 0.637. Highly significant association between magnesium and magnesium hardness was also recorded (r = 0.999). Calcium was strongly correlated with chloride (r = 0.994), total hardness (r = 0.994), and calcium hardness (r = 0.993).

For the raw water parameters (Table 5), a strong positive association was observed among temperature, pH, and total dissolved solids (r = 0.903). Additionally,

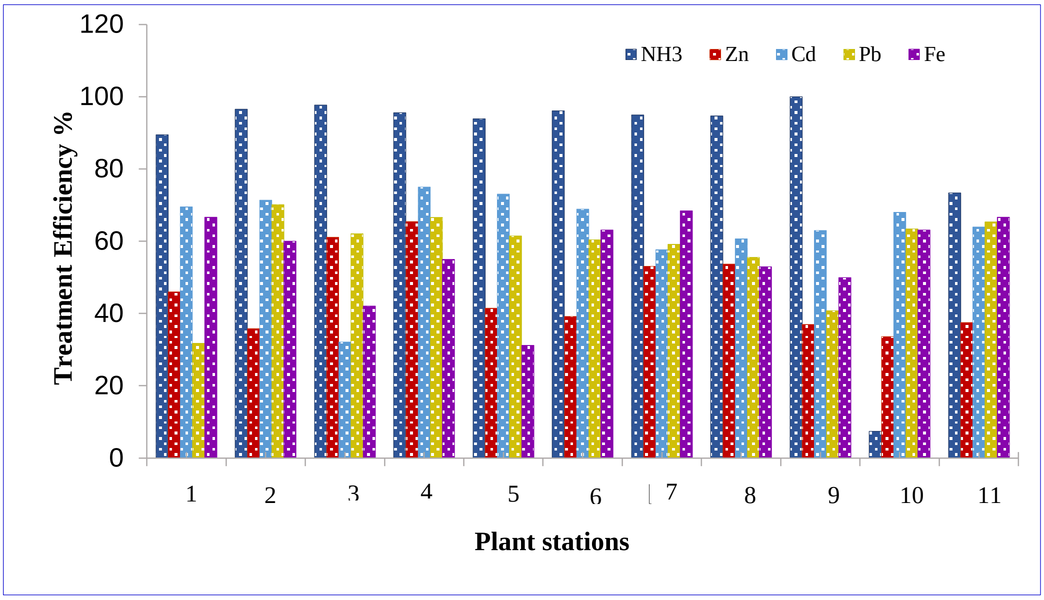


**Figure (4):** Treatment efficiency (%) of Amonia ($NH_3$), Zinc ($Zn^{2+}$), Cadmium ($Cd^{2}$+) and total hardness levels at water treatment plant stations.

most of the remaining metrics exhibited predominantly moderate to strong positive correlations with the water quality index (WQI), with the exceptions of alkalinity, zinc, and lead. Furthermore, a relatively strong positive correlation (r = 0.688) was recorded between turbidity and pH.

The presence of calcium, as determined through the calcium hardness test, showed a very strong positive correlation (r = 0.995). In contrast, ammonia exhibited a negative correlation with magnesium (r = -0.523), while there was no significant correlation with magnesium hardness (r = -0.102).

*Assessing the efficiency of water treatment plants*

The evaluation of water treatment plants concerning heavy metal content and physicochemical parameters using a one-way ANOVA test revealed significant differences among various groups of plant effluents during the treatment process under different conditions. This analysis encompassed several parameters, including turbidity, temperature, pH, electrical conductivity (EC), total hardness, total dissolved solids (TDS), chlorides, sulfate, calcium, magnesium, iron, lead, cadmium, and zinc. The statistical results indicated a significant effect with $p$=0.011.

*Inlet parameters analysis*

For the inlet parameters analyzed, the results suggest no statistically significant differences ($p \leq 0.05$) between group means. This indicates that the factors being tested do not significantly affect the studied parameters at the inlet stage.

*Outlet parameters analysis*

Conversely, for the outlet measured parameters, the results indicate significant variability between groups. This suggests that the tested factors may have a expressive the impact on these parameters during the treatment process. The observed differences in outlet parameters highlight the effectiveness of the treatment processes in removing heavy metals and improving water quality.

In conclusion, the inlet parameters showed consistency across different treatment conditions, while, undr the same conditions the outlet parameters exhibited significant variability, emphasizing the influence of treatment processes on effluent quality. Further investigation, into these specific functioning conditions and their effects on treatment efficiency, is in need to provide insights for optimizing wastewater management practices.

## DISCUSSION

**Table (3):** Evaluation of inlet and outlet water quality: A comprehensive overview of parameters before and after treatment.

| **Measured Parameters** | **Evaluation WQI** | |
|---|---|---|
| | **for Plant inlets** | **for Plant outlets** |
| **Turbidity** | ☆ 67.4 | ⇧ 12.2 |
| **pH** | ☆ 94.6 | ☆ 88.4 |
| **TDS** | ⇧ 37.8 | ⇧ 40 |
| **EC** | ⇧ 24.7 | ⇧ 23.3 |
| **Chlorides** | ⇧ 9.8 | ⇧ 12.2 |
| **Alkalinity** | ☆ 70.8 | ☆ 65 |
| **Total Hardness** | ⇧ 32.5 | ⇧ 31.2 |
| **Calcium Hardness** | ⇧ 26.9 | ⇧ 26.8 |
| **Magnesium Hardness** | ⇧ 49.3 | ⇧ 45 |
| **Calcium** | ☆ 51 | ☆ 50.2 |
| **Magnesium** | ⇧ 36.9 | ⇧ 33.6 |
| **Ammonia** | ⇧ 4.9 | ⇧ 1 |
| **Sulphate** | ⇧ 11.4 | ⇧ 13.4 |
| **$\mathrm{WQI} = \Sigma_{\mathrm{qi}\ i=1}$** | ⇧ 733.8 | ⇧ 637.1 |
| **AWQI = Σ qi/n** | ☆ 52.4 | ⇧ 45.5 |

⇧, Excellent performance; ☆, Good performance.

The average value of temperature at plant inlets was 25.88 ± 5.046 ºC which is higher than that recorded (27.4ºC) by Gad *et al.*, (2022) and lower than that obtained (29.05± 5.17) by Shrestha *et al.*, (2023) and this can be justified due to climate change and temperature patterns in recent years (Elemam and Eldeeb, 2023). The plant outlet average temperature (25.85± 4.70 ºC) was higher than that recorded (20.94 ºC) by Shawkey *et al.*, (2021). The observed variation may be associated with sampling time and the prevailed conditions during sampling collection where, the variability of surface water temperature is influenced by several factors, including seasonal changes, climatic conditions, and unique properties of the aquatic environment such as humidity, wind intensity, and turbidity (Hasaballah *et al.*, 2019).

The turbidity value of 3.36 ± 1.145 NTU, recorded at the source water (plant inlets) was lower than the value documented by Smysem *et al.* (2020), which reported 6.35 ± 1.3 NTU, and higher than the 2.76 NTU reported by Gad *et al.* (2022). Conversely, the turbidity value of 0.61 ± 0.229 NTU for the treated water sample (plant outlets) was higher than the values obtained by Abdel-Shafy *et al.* (2018) and Shawkey *et al.* (2021), which were recorded at 0.63 ± 0.13 NTU and 0.29 NTU, respectively. Increased turbidity in source water has a significant negative impact on aquatic life because it reduces light penetration, which is necessary for photosynthesis. However, for the value of pH at plant

**Table (4):** Pollution index (PI) for heavy metals in the studied drinking water plants (inlets and outlets).

| | **Parameters** | **Average ±SD** | **(Ci/Si)/ Nm** | **Standard limits** |
|---|---|---|---|---|
| **Inlets** | **Iron** | 0.043±0.02 | 0.035 | 0.3 |
| | **Lead** | 0.029±0.10 | 0.725 | 0.01 |
| | **Cadmium** | 0.006±0.00 | 0.530 | 0.003 |
| | **Zinc** | 0.145±0.13 | 0.012 | 3 |
| | **PI=∑(Ci/Si)/Nm** | **1.3** | | |
| **Outlets** | **Iron** | 0.021±0.02 | 0.018 | 0.3 |
| | **Lead** | 0.010±0.01 | 0.250 | 0.01 |
| | **Cadmium** | 0.003±0.01 | 0.250 | 0.003 |
| | **Zinc** | 0.065±0.03 | 0.005 | 3 |
| | **PI=∑(Ci/Si)/Nm** | **0. 523** | | |

**Table (5):** Correlation matrix analysis of Drinking water parameters (outlets).

| Measured parameters | Zinc | Cadmium | Lead | Iron | Sulphate | Ammonia | Magnesium | Calcium | Mg- H | Ca -H | Total H | Alkalinity | Chlorides | WQI | TDS | C° | pH | Turbi-dity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Turbidity** | 0.213 | $0.557^{*}$ | -0.154 | 0.034 | -0.17 | -0.458 | -0.237 | 0.054 | -0.422 | -0.176 | -0.374 | $-0.542^{*}$ | $-0.565^{*}$ | $0.825^{***}$ | -0.210 | $0.637^{*}$ | -0.026 | 1 |
| **pH** | $0.607^{*}$ | -0.242 | -0.083 | 0.304 | -0.15 | 0.425 | -0.523 | $0.635^{*}$ | -0.096 | 0.054 | -0.278 | 0.360 | -0.378 | $0.552^{*}$ | 0.476 | 0.271 | 1 | |
| **T C°** | -0.269 | 0.363 | -0.24 | -0.042 | 0.367 | -0.495 | $0.902^{***}$ | $0.993^{***}$ | $0.866^{***}$ | -0.035 | -0.003 | 0.450 | 0.033 | $0.798^{**}$ | 0.281 | 1 | | |
| **TDS** | 0.037 | 0.224 | $0.635^{*}$ | 0.331 | 0.368 | 0.027 | -0.214 | 0.188 | 0.528 | 0.197 | 0.392 | 0.360 | 0.480 | $0.758^{**}$ | 1 | | | |
| **WQI** | 0.489 | $0.652^{*}$ | 0.198 | 0.592 | 0.749* | $0.805^{***}$ | $0.674^{*}$ | $0.675^{*}$ | $0.542^{*}$ | $0.621^{*}$ | $0.542^{*}$ | 0.372 | $0.512^{*}$ | 1 | | | | |
| **Chlorides** | -0.269 | 0.363 | -0.240 | 0.0424 | 0.367 | -0.495 | $0.902^{****}$ | $0.993^{****}$ | $0.866^{****}$ | -0.035 | -0.003 | 0.406 | 1 | | | | | |
| **Alkalinity** | 0.394 | 0.182 | -0.292 | 0.285 | 0.034 | -0.128 | 0.154 | -0.368 | 0.325 | -0.035 | $0.593^{*}$ | 1 | | | | | | |
| **Total H** | -0.269 | 0.363 | -0.240 | -0.042 | 0.367 | -0.495 | $0.902^{****}$ | $0.993^{***}$ | $0.866^{****}$ | -0.354 | 1 | | | | | | | |
| **Calcium -H** | 0.394 | 0.182 | -0.292 | 0.285 | 0.034 | -0.128 | 0.154 | $0.993^{****}$ | -0.244 | 1 | | | | | | | | |
| **Magnesium- H** | -0.269 | 0.363 | -0.240 | -0.042 | 0.367 | -0.495 | $0.902^{***}$ | 0.206 | 1 | | | | | | | | | |
| **Calcium** | 0.394 | 0.182 | -0.292 | 0.285 | 0.034 | -0.495 | -0.495 | 1 | | | | | | | | | | |
| **Magnesium** | -0.242 | -0.083 | 0.304 | -0.15 | 0.425 | -0.260 | 1 | | | | | | | | | | | |
| **Ammonia** | -0.269 | 0.363 | -0.240 | -0.042 | -0.187 | 1 | | | | | | | | | | | | |
| **Sulphate** | -0.242 | 0.182 | -0.240 | -0.096 | 1 | | | | | | | | | | | | | |
| **Iron** | -0.269 | 0.363 | -0.367 | 1 | | | | | | | | | | | | | | |
| **Lead** | -0.289 | -0.122 | 1 | | | | | | | | | | | | | | | |
| **Cadmium** | -0.289 | 1 | | | | | | | | | | | | | | | | |
| **Zinc** | 1 | | | | | | | | | | | | | | | | | |

**Table (6):** Correlation matrix analysis of drinking water parameters (Inlets).

| Measured Parameters | Zinc | Cadmium | Lead | Iron | Sulphate | Ammonia | Magnesium | Calcium | Mg- H | Ca -H | Total H | Alkalinity | Chlorides | WQI | TDS | Temp. | pH | Turbidity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Turbidity** | 0.141 | 0.423 | $0.601^{*}$ | 0.359 | 0.335 | 0.451 | -0.411 | 0.2568 | -0.411 | 0.292 | -0.356 | 0.287 | 0.210 | $0.895^{***}$ | $0.547^{*}$ | 0.222 | $0.688^{*}$ | 1 |
| **pH** | 0.453 | -0.021 | $-0.509^{*}$ | 0.223 | 0.736 | -0.373 | -0.306 | -0.01 | 0.0916 | -0.383 | -0.150 | 0.109 | 0.160 | $0.540^{*}$ | $0.760^{**}$ | 0.330 | 1 | |
| **Temp.** | $0.789^{**}$ | 0.190 | 0.382 | -0.38 | 0.327 | -0.101 | $-0.734^{**}$ | $-0.734^{*}$ | $-0.714^{**}$ | -0.262 | $0.580^{*}$ | $0.871^{***}$ | -0.497 | $0.809^{***}$ | $0.754^{**}$ | 1 | | |
| **TDS** | -0.081 | 0.014 | $0.736^{**}$ | 0.18 | 0.194 | -0.285 | -0.306 | -0.182 | -0.306 | -0.139 | $-0.523^{*}$ | -0.100 | -0.305 | $0.702^{**}$ | 1 | | | |
| **WQI** | 0.579 | $0.751^{*}$ | 0.051 | $0.652^{*}$ | $0.850^{***}$ | 0.795 | $0.714^{**}$ | $0.693^{*}$ | $0.597^{*}$ | $0.661^{**}$ | $0.597^{*}$ | $0.512^{*}$ | 0.420 | 1 | | | | |
| **Chlorides** | 0.488 | 0.438 | -0.45 | 0.583 | 0.38 | 0.455 | $0.863^{***}$ | 0.297 | 0.489 | 0.062 | $0.719^{**}$ | $0.871^{***}$ | 1 | | | | | |
| **Alkalinity** | 0.177 | $0.651^{*}$ | 0.001 | -.457 | -0.263 | -0.101 | -0.714 | -0.293 | 0.234 | 0.356 | $0.580^{*}$ | 1 | | | | | | |
| **Total H** | 0.488 | 0.438 | -0.45 | 0.583 | 0.38 | 0.455 | $0.863^{***}$ | -0.293 | $0.863^{***}$ | -0.262 | 1 | | | | | | | |
| **Calcium-H** | 0.177 | $0.651^{*}$ | 0.001 | -.457 | -0.263 | -0.101 | -0.714 | $0.995^{***}$ | $-0.714^{**}$ | 1 | | | | | | | | |
| **Mg- Hardness** | 0.488 | 0.438 | -0.45 | $0.583^{*}$ | 0.380 | -0.101 | $0.999^{***}$ | $-0.734^{*}$ | 1 | | | | | | | | | |
| **Calcium** | 0.453 | -0.082 | 0.104 | $0.583^{*}$ | -0.260 | 0.444 | $-0.734^{**}$ | 1 | | | | | | | | | | |
| **Magnesium** | 0.488 | 0.438 | -0.45 | -.457 | 0.380 | -0.101 | 1 | | | | | | | | | | | |
| **Ammonia** | 0.042 | 0.066 | 0.028 | 0.013 | 0.327 | 1 | | | | | | | | | | | | |
| **Sulphate** | 0.177 | $0.651^{*}$ | 0.028 | -.383 | 1 | | | | | | | | | | | | | |
| **Iron** | 0.177 | 0.066 | 0.382 | 1 | | | | | | | | | | | | | | |
| **Lead** | 0.042 | 0.190 | 1 | | | | | | | | | | | | | | | |
| **Cadmium** | $0.789^{***}$ | 1 | | | | | | | | | | | | | | | | |
| **Zinc** | 1 | | | | | | | | | | | | | | | | | |

TH, Total Hardness; Calcium-H, Calcium-Hardness; Magnesium-H, Magnesium-Hardness; $^{***}$, Highly positive/-negative correlation; $^{**}$, moderate to weak positive/-negative correlation.

inlets was higher than that recorded (7.89) by Gad *et al*. (2022) and lower than that reported by Shrestha *et al*. (2023) and Smysem *et al.,* (2020) and recorded 5.67± 3.79 and 8.09 ±0.44, respectively. However, pH plant outlet value (7.5 ± 0.23) was higher than that obtained (7.2±0.09) by Shawkey *et al*., (2021) and was consistent with that measured (7.55 ± 0.13) by Abdel-Shafy *et al*., (2018). The pH level serves as the primary determinant of water's acidity and alkalinity (Dutt and Sharma, 2022), and it indirectly influences the quality of water and its acceptability for consumption (El-Alfy *et al*., 2024).

The value of TDS at plant inlets (188.9 ± 28.26 mg/l) was lower than that recorded (246.63 mg/l) by Gad *et al*., (2022) and higher than that documented (159.17± 36.02 and 223.52±45.2 mg/l) by Shrestha *et al*., (2023) and Smysem *et al*., (2020). Low TDS values may be related to the elevation rate of water drainage from rain precipitation in addition to slow water evaporation rate in winter. On the other hand, increase of TDS values in the outlet is thought to be affected by the treatment method applied in the plants, as small amount of coagulant ($Al_2(SO_4)_3$) may dissolve in water depending on pH value and result in rise of sulfate and consequently the TDS value (Alver, 2019). It was found that the average value (359.31±44.69 µmohs/cm) of electrical conductivity (EC) at plant inlets was lower than that of other studies, while at plant outlets (372.72± 64.7 µmohs/cm) was higher than that reported (Abdel-Shafy *et al*., 2018; Hasaballah *et al*., 2019; Gad *et al*., 2022; Shrestha *et al*., 2023). The existence of inorganic dissolved solids, which are very sensitive to changes in total dissolved solids, could be an explanation. This difference can be attributed to the reduction in water level and volume, as mentioned by Adjovu *et al*., (2023). These findings emphasize the significance of considering the entirety of the surrounding circumstances and influence when designing and executing water management systems.

Chloride readings offer insights into physical phenomena such as evaporation during recharging and time-dependent flow (Hardy *et al*., 2023; Li *et al*., 2023). Alkalinity is crucial for alum's reaction with water in the treatment plant's coagulation process and decreases in alkalinity lead to increased water corrosivity (García-Ávila *et al*., 2022).

The rise in the overall hardness value resulted in a decrease in water corrosiveness, as the presence of $Ca^{2+}$ facilitated the creation of a protective film on the pipe's surface, hence reducing corrosion (Brossia, 2018). The total hardness values range from low to moderate (≤250), which have an impact on the occurrence of corrosion in the distribution network (García-Ávila *et al*., 2022). Based on a comprehensive analysis of prior research, the values obtained from the present study surpass those previously recorded (Abdel-Shafy *et al*., 2018; Ezzat *et al*., 2018; Hasaballah *et al*., 2019; El-Emam, 2020; El Sayed *et al*., 2020; Azzam *et al*., 2020; Afify *et al*., 2021; Elhadad *et al*., 2021).

Moreover, the average calcium value was higher than that obtained (28.06 mg/l) by Gad *et al*. (2022) and significantly higher than that reported by Shrestha *et al*. (2023). The two main cations in river water, magnesium and calcium, are primarily responsible for the hardness of the water. Calcite, dolomite, and aragonite are examples of carbonate minerals that can be dissolved to produce calcium (Raidla *et al*., 2015). The highest value of magnesium was 18.45 ± 6.29 mg/l in plant inlets, which was higher than the recorded value (12.15 mg/l) by Gad *et al*., (2022) and significantly higher than that documented by Shrestha *et al*., (2023). This discrepancy is attributed to climate variations, specifically the observed rise in temperatures leading to increased rates of evaporation. Additionally, the treatment procedures employed at the stations, which involve the introduction of certain chemicals during a specific stage, may contribute to this disparity (Brossia, 2018; Alver, 2019).

The average values of ammonia and sulphate were also determined in plant inlets and outlets. The ammonia value was found to be higher than that recorded by Smysem *et al*., (2020), but lower than that documented by Abdel-Shafy *et al*., (2018) and Shawkey *et al*., (2021). The existence of ammonia in raw water may lead to drinking water including nitrite as a result of catalytic action or unintentional colonization of filters by ammonium-oxidizing bacteria. Additionally, as nitrification uses too much oxygen and produces moldy, earthy-tasting water presence may interfere with the performance of manganese-removal filters (Ezzat *et al*., 2017). Organic waste breakdown and the hydrolysis of urea from dead fish in water are the main sources of ammonia production. (Smysem *et al*., 2020).

The sulphate value was higher than recorded by Shrestha *et al*., (2023) and Gad *et al*., (2022), but lower than obtained by Abdel-Shafy *et al*., (2018). The aggregate sulphate level along the Damietta Branch's investigated section is under the Egyptian Ministry of Health's recommended safe drinking limit of 250 mg/l. The majority of it leached from the nearby soils and bottom sediments rich in clay, as well as from the fertilizers used in the nearby farmed areas that were rich in sulphate (El-Rayes *et al*., 2018).

Overall, heavy metals (iron, lead, cadmium, and zinc) levels varied significantly in drinking water treatment plants. The amount and type of wastewater discharged in the studied area are believed to be the factors influencing this variability (Abd El-Azim *et al*., 2018). More importantly, there have been claims that the COVID-19 epidemic had considered impact on water supplies and wastewater treatment plants. However, over the past two years, there has been an increase in the amount of certain persistent compounds in wastewater, which can be linked to the higher usage of antibiotics, disinfectants, and sanitizers (Moustafa and Mansour, 2022).

It is clear from the obtained results (Figures 2, 3, 4 and 5) that the study area was characterized by various levels of drinking water treatment efficiency for the addressed parameters. The average drinking water treatment efficiency for turbidity was 81.9%. Turbidity serves as an indicator of the cleanliness of water based on its visual appearance, specifically its transparency and absence of suspended particles, as reported by Kreisel (2019). Similarly, ammonia represents good efficiency with an average of 79.45%. On the other hand, the negative efficiency value of sulphate in municipal drinking water supplies may be due to the addition of alum as a coagulant by the treatment process and the formation of alkali metal dissolved sulphate salts (FAO, 2023). In addition, the drinking water treatment effectiveness of Electrical conductivity (EC) in most plants was found to be negative, indicating an elevation in conductivity levels in the outputs compared to the inlets. While elevated levels of electrical conductivity (EC) may not have a direct influence on health, they do result in a significant concentration of dissolved particles, leading to water hardness and causing discontent among consumers. The average drinking water treatment efficiency of alkalinity, TDS, and total hardness was found to be 8.26%, -6.47 % and 4.1%, respectively. Moreover, the occurrence of negative chloride values can be attributed to the simultaneous presence of station modernization activities and seasonal fluctuations throughout the summer months, characterized by elevated temperatures and increased solar radiation exposure, which can cause alterations in water composition. In addition, drought periods result in reduced water levels due to evaporation and changes in water composition. Another plausible cause is the potential intrusion from adjacent sources during maintenance operations at the drinking water treatment facility (Bărbulescu and Barbeș, 2023).

Assessment of water quality of plant inlets and outlets for the addressed water treatment plants according to drinking purposes was carried out using the weighted arithmetic method of WQI. As shown in Table (3), the values of WQI of the inlets and outlets displayed that the water is of excellent quality for drinking purposes, which agreed with Swelam *et al*., (2022). While the results reported (Hasaballah *et al*., 2019; Gad *et al*., 2022; Shrestha *et al*., 2023) for raw water indicated medium quality. Furthermore, the present study was expanded to evaluate water pollution caused by heavy metals, specifically iron ($Fe^{+2}$), lead ($Pb^{+2}$), zinc ($Zn^{+2}$), and cadmium ($Cd^{+2}$). This assessment was conducted by calculating the pollution index (PI). The findings presented in Table (4) demonstrate a lack of significant impact of metals on plant outlets, which contradicts that reported by Gad *et al*., (2022).

The construction of Pearson's correlation matrix was undertaken to understand the linear association between WQI and various water quality indicators. The correlation coefficient is a numerical measure that ranges from +1 to -1; a value of ±1 indicates a perfect linear relationship (direct and inverse proportional) between the two variables, while a value of 0 suggests a nonlinear relationship. The three variables under consideration are turbidity, temperature, and magnesium. It was found that there was a strong positive link between hardness, calcium, and magnesium and WQI. Other than ammonia, iron, lead, and zinc, the remaining metrics have a weak positive connection with the WQI. In addition, a relatively strong positive correlation was observed between turbidity and temperature, with a coefficient value of 0.637. Calcium was discovered using chloride (correlation coefficient, r = 0.994), total hardness (r = 0.994), and calcium hardness (0.993). A significant association was recorded between magnesium and chloride (r = 0.903), as well as overall hardness and Mg hardness. In contrast, there was a week negative correlation between calcium and magnesium (r = −0.496), calcium, EC, and alkalinity (r = −0.368). The phenomenon of magnesium ions displacing calcium ions in river water flow is attributed to the cation exchange mechanism (Kawo and Karuppannan, 2018).

Table (6) represents the correlation matrix between several characteristics of the plant inlet water parameter and the Water Quality Index (WQI). It is clear from Table (6) that there is a strong positive association between EC, turbidity, pH, TDS, and WQI. Moreover, the remaining metrics have a predominantly positive connection with WQI, except calcium, magnesium, ammonia, iron, and lead. There was a relatively strong positive link (0.689) between turbidity and pH. The presence of calcium was determined using the calcium hardness test, which exhibited a strong positive correlation (r = 0.9964). A highly significant association between magnesium and magnesium hardness was observed (r = 0.999). Ammonia exhibits a negative connection (r = -0.523) with magnesium (r = -0.102), overall hardness, and TDS (Aralu *et al*., 2022).

The study examined the efficiency performance of water treatment plants using a one-way analysis of variance (ANOVA) with a between-subjects design. The evaluation was based on the concentration of heavy metals and physicochemical parameters of both raw and treated water. Different groups of plant outlets treated in different settings showed statistically significant variations. The Least Significant Difference (LSD) test was used for the post hoc test, and significant differences were reported for various factors such as temperature, pH, EC, total hardness, TDS, chlorides, sulphate, calcium, magnesium, iron, lead, cadmium, and zinc (F = 2.37, $p$ = 0.011). The findings revealed that the physicochemical properties of plants (St. 4 and St. 10) were significantly different. The reported results are highly unlikely to have occurred randomly, as indicated by the statistical significance level, which is $p \leq 0.05$. The p-value being higher than 0.05 suggests that none of the categories of plant outlets differed significantly from one another. It was found that there was a statistically significant correlation between group means within homogeneous subgroups when examining the performance of drinking water treatment plants in treating raw water. Although, the present study successfully investigated the performance efficiency of some drinking water treatment plants in Damietta Governorate, there were some limitations, the first was that this study was conducted for a limited area in the Damietta governorate and did not extend to include all regions along the Damietta branch. However, this wouldn't significantly affect the results and it would be an important guide for future studies. Another limitation was that no study has been performed to determine how climate change affected and related to the subject area, which leaves a gap in the literature. Finally, it is important to follow up and monitor changes in a long-term study for managing drinking water treatment plants and combat the literature gap.

## CONCLUSION

It is compulsory to maintain regular monitoring and management protocols for water quality in aquatic environments in order to ensure the safety and integrity of these essential resources. Catchment management and source water protection play a crucial role in safeguarding the quality of surface water, serving as the initial line of defense. Improving the efficiency of water treatment plants is of utmost importance in the context of sustainable water management and public health. This is because it serves to decrease operational expenses, mitigate environmental consequences, and optimize the utilization of resources in order to provide clean drinking water. This study evaluated the performance efficiency of eleven drinking water treatment plants in Damietta Governorate, Egypt, through analyzing some physicochemical parameters and heavy metals. The results showed that all the addressed physicochemical parameters and heavy metals were within permissible limits of WHO standards for drinking water, except for lead and cadmium, which were slightly exceeded in the plant inlets. According to WQI, the assessment of the Nile River waters revealed good quality, while the treated water was excellent. In summary, the research findings indicate that the drinking water treatment facilities in Damietta Governorate are effectively functioning to provide the local community with safe and sanitary drinking water. In order to prevent waterborne illnesses and maintain the public's health, the study recommends continuous monitoring and auditing of the quality of drinking water. This should begin at the source intake (the River Nile and its branches) and continue through treatment facilities, purification stages like filtration and disinfection, transformation, and distributed pipes to the consumers' homes as a final product to ensure safe and sustainable water. It is also recommended to conduct a regular temporal and spatial evaluation of the Nile River at consistent intervals to reduce potential effects and maintain the main source of drinking water. This research supports the third and sixth goals of the sustainable development goals.

## ACKNOWLEDGEMENTS

The authors would like to thank Dr. Rasha M. Abou Samra from the Environmental Sciences Department at Damietta University for mapping the study area. The authors also gratefully acknowledge the comments of the anonymous reviewers.

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# تقييم جودة مياه الشرب والتلوث بالمعادن الثقيلة في محطات المعالجة بمحافظة دمياط، مصر

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## الملخص العربي

تعتبر إدارة المياه السطحية بشكل آمن أمراً بالغ الأهمية لتلبية معايير مياه الشرب العالمية. لذا، تم إجراء هذه الدراسة لتقييم جودة المياه في بعض محطات معالجة مياه الشرب في محافظة دمياط، بما في ذلك مياه النهر العذبة الواردة من نهر النيل ومياه الشرب الخارجة. لذللك تم تجمع عينات المياه من 11 محطة معالجة تقع على نهر النيل، وتم تحليل الخصائص الفيزيائية والكيميائية بالإضافة إلى بعض المعادن الثقيلة بشكل موسمي خلال عام 2022. استخدمت مؤشرات جودة المياه ومؤشرات تلوث المعادن الثقيلة لتقييم حالة جودة المياه. كما تم تطبيق تحليل التباين الأحادي (One-way ANOVA) لمقارنة التباين المكاني والزمني لمؤشر جودة المياه.(WQI) .أظهرت النتائج أن المتوسط العام لقيم العكارة، الأس الهيدروجيني(pH) ، التوصيلية الكهربائية(EC) ، العسر الكلي، والمواد الصلبة الذائبة الكلية (TDS) في مداخل المحطات بلغ NTU3.37 ، 8.05، 359.3 ميكروموز/سم، 162.6، و188.9 ملغم/لتر على التوالي. كما كانت تركيزات الكلوريد، الكبريتات، الكالسيوم، المغنيسيوم، الحديد، الرصاص، الكادميوم والزنك 24.6، 28.5، 10.9، 6.2، 0.04، 0.029، 0.006، و0.15 ملغم/لتر على التوالي. أما نتائج المياه الصادرة من المحطات فقد أشارت إلى أن المتوسط العام لقيم العكارة، الأس الهيدروجيني(pH) ، التوصيلية الكهربائية (EC) ، المواد الصلبة الذائبة الكلية (TDS) ، والعسر الكلي بلغ NTU0.61 ، 7.51، 372.7 ميكروموز/سم، 155.8، و201.2 ملغم/لتر على التوالي. وبلغت تركيزات الكلوريد، الكبريتات، الكالسيوم، المغنيسيوم، الحديد، الرصاص، الكادميوم، والزنك 30.4، 33.4، 37.9، 16.8، 0.02، 0.01، 0.003، و0.065 ملغم/لتر على التوالي.في الختام، كانت جميع المعايير التي تمت دراستها ضمن الحدود المسموح بها وفقًا لمنظمة الصحة العالمية (2017)، باستثناء الرصاص والكادميوم في مداخل المحطات، حيث تجاوزت القيم الحدود القياسية بشكل طفيف. وأكدت قيم متوسط مؤشر جودة المياه أن جودة مياه نهر النيل كانت جيدة (52.4)، في حين أن جودة مياه الشرب الصادرة كانت ممتازة (45.5).