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Influence of Physicochemical Factors and Heavy Metals on Water Quality Index in Fragile Aquatic Habitats at Nile Delta, Egypt

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Abstract: A survey has been done and a detailed account has been given of the impact of physicochemical parameters of water on the biodiversity of monogenean parasites in *Clarias gariepinus* Burchell, 1822 from degraded aquatic ecosystems located in the Nile Delta, north Egypt between summer (2021) and spring (2022). The thermal regime of the investigated habitats is close to one another. Surface water temperature ranged between 24.00 and 25.13°C. The depth of water in the investigated habitats ranged between 0.672m and 1.60m. Transparency of water fluctuated between 27.5 and 45.00cm. All explored habitats are classified on the alkaline scale (pH: 8.69- 9.09). The electrical conductivity (EC) scored 0.48-0.77 µmhos/cm, whereas total dissolved solids recorded 305.59-494.40 mg/L. The water body of MAS-1 was more oxygenated than other habitats. Oxygen dissolved in water ranged between 5.33 and 7.18 mg/L. Water sampled from Amlak Drain stored the greatest quantities of HCO_3^- and SO_4^{-2} (45.63±13.95 mg/L and 72.58±12.39 mg/L, respectively). Mean chlorides in water from Amlak Drain, Nezam Drain, MAS-1 and MAS-2 were 376.20±26.02, 346.00± 57.75, 248.52±158.70 and 318.77±79.91 mg/L, respectively. Surface water from all explored habitats contained significant quantities of nitrogen, but scanty quantities of phosphorus. The greatest quantities of Ca^{++}, Mg^{++} and Na^+ were measured at Amlak Drain (23.48±4.39, 12.72±2.72 and 450.80±25.571 mg/L, respectively). The highest amount of K^+ was recorded at MAS-1 habitat (7.88±2.29 mg/L). With a few exceptions, Fe, Al, Cu, Hg, Zn, Cr, Cd, Pb, Ni and Co in water exceeded the guideline limits of WHO. All explored habitats included poor water quality (CCME WQI= 0-44). The relationship between water features and possible impacts of pollutants on human health and ecosystem equilibrium are discussed in detail.

keywords: Fragile aquatic habitats, physicochemical factors, heavy metals, *Clarias gariepinus*.

1.Introduction

The upset of the quality of water and modification of the aquatic life as a consequence of improper dissemination of waste effluents from industrial, agricultural and domestic origin are an ongoing environmental challenge facing human around the globe [1 – 5]. Dreadfully, in response to the development of industrialization and urbanization, the biosphere is facing more difficulties: water pollution is becoming progressively grave, posing thoughtful dangers to public health safety and the economy [6]. According to Mishra *et al*. [7], most of the aquatic habitats are progressively becoming degraded. Growing industrial affairs, progressive urban lifestyle along with inadequate environmental management strategies are the primary drivers of extreme pollution episodes in fragile aquatic ecosystems which are loaded with undesirable substances rather than heavy metals, organic compounds, pesticides and fertilizers.

In aquatic ecosystems, metals are typically found in the form of free metal ions frequently attached to mud. They can appear as either colloidal particles or suspended solids. In these states, metals may be present as oxides, hydroxides, silicates, or sulphides, or as metal complexes with organic matter. The solubility of metals in water is affected by various factors including pH, concentration of ligands, oxidation state, and redox potential. Metals in the dissolved phase are more toxic to aquatic organisms. Surface runoff plays a significant role in the contamination of water sources. Definite heavy metals such as copper, iron, and zinc are important in trace amounts for the proper functioning of the human body, however elevated levels of these metals can pose great health risks to human and animals. For example, an excess of copper has been linked to anemia and damage to the liver and kidneys. The Minamata mercury poisoning event in Japan stands out as a severe example of environmental pollution, affecting individuals through the consumption of contaminated fish from the Yatsushiro Sea and the Agano River.

Due to their durability in the environment and their tendency to increase in concentration as they ascend the food chain, heavy metals have grown increasingly important. Metals tend to accumulate in sediments, concentrate in water, leading to impairment of aquatic ecosystems. This accumulation primarily occurs through the food chain and the interactions between predators and their prey. As they progress up the food chain, metals tend to become more concentrated, reaching their peak levels at the top. Lead is a dangerous pollutant that significantly impacts various body systems due to its high toxicity [8]. Although lead can enter the body through the skin, it primarily affects the respiratory and digestive systems. Exposure to lead can lead to a range of health issues, including neurological, respiratory, urinary, and heart conditions, through its effects on the immune system, oxidative processes, and inflammation [9 – 11]. Lead is extremely harmful and negatively affects the neurological, biological, and cognitive functions within the body. Chromium (Cr) is present in the Earth’s crust and the ocean, and it is a naturally occurring heavy metal used in various industrial processes [12]. Chromium exists in several oxidation states, with the trivalent and hexavalent states being the most stable [13]. Chromium can lead to a variety of health issues through its accumulation in the body, for example skin, kidney, nervous system, gastrointestinal, and several types of cancer, including those of the lungs, larynx, bladder, kidneys, testicles, bones, and thyroid [14].

Cadmium (Cd), though not very common, occurs naturally in soil, minerals as well as in water. Elevated levels of Cd in water, air, and soil can happen after industrial activities. The presence of Cd in contaminated water can disrupt the body’s normal functions, potentially causing short-term or long-term health issues [15, 16]. The Itai-itai disease outbreak in Japan was due to widespread contamination of food and water with Cd. Those affected experienced severe bone diseases, kidney failure, and diseases of digestive and respiratory systems [17]. Arsenic, a dangerous heavy metal, poses a significant threat to public health. People can be exposed to arsenic by consuming contaminated food and water [18]. It has a long history of use, both as a chemical element and in medicine. Both acute and chronic exposure to arsenic can lead to the malfunction of many essential enzymes and can block the pyruvate dehydrogenase enzyme, which is crucial for the Krebs cycle and oxidative phosphorylation, leading to a decrease in ATP production and cell damage [19]. Moreover, arsenic can damage the lining of blood vessels, making them more permeable, which can cause vasodilation and a drop in blood pressure [20].

Toxic metals can produce free radicals, primarily reactive oxygen species and reactive nitrogen species, which can lead to oxidative stress. Exposure to lead significantly lowers the levels of antioxidant enzymes, while at the same time, it increases the levels of oxidative stress markers [21]. The production of reactive oxygen species and reactive nitrogen species by chromium (VI) depletes the body’s antioxidant defenses, leading to oxidative stress and subsequent damage to DNA, lipids, and proteins [22]. Cadmium might indirectly produce radicals, which could overwhelm the body’s antioxidant defense systems [23]. It is hypothesized that the harmful effects of mercury on the central nervous system and the cardiovascular system are linked to the increase in reactive oxygen species production. The toxic effects of lead and mercury on the central nervous system and cardiovascular system are thought to be due to the increase in reactive oxygen species (ROS) production. However, cadmium is believed to produce ROS indirectly. This could be attributed to the replacement of iron and copper by cadmium in cellular proteins. Consequently, the oxidative stress is caused by an excess accumulation of iron and copper. Moreover, the replacement of essential minerals disrupts the metabolism of living cells. Alternatively, cadmium might disrupt the antioxidant glutathione, leading to oxidative stress [24]. The mechanisms heavy metals cause cancer are not fully understood and is complex. It is believed that some heavy metals may cause cancer by attaching to proteins that play a role in controlling the cell cycle, DNA replication and repair, and programmed cell death [25]. Research has shown that Cd can cause prostate cancer by increasing the resistance to apoptosis, which is a normal process of cell death. Changes in the expression of genes involved in apoptosis and DNA repair are suggested as a reason for this resistance to apoptosis caused by Cr^{6+} [25].

The primary goal of this study was to assess the influence of physicochemical features and heavy metals of water on water quality index in depreciated aquatic habitats in the Nile Delta, north Egypt.

2. Materials and methods

2.1. Area of Investigation

The study region is located in the north range of the Nile Delta in Dakahlia Governorate, Egypt (Fig. 1). The present study was conducted over 4 consecutive seasons (from summer 2021 to spring 2022). Four varying water quality habitats were explored, namely Nezam Drain (a typical agricultural drain), Amlak Drain (multisource polluted drain), two minor agricultural drains (MAS-1 connected to Amlak Drain and MAS-2 connected to Nezam Drain). Amlak Drain joins Nezam Drain and flows northwards to dump huge quantities of murky water into the southern sector of Manzala Lake (Fig. 1), one of the highly productive ecosystems and animal protein sources in Nile Delta. MAS-1 terminates close to Amlak Drain and receives its outflow through a pumping unit. MAS-2 terminates close to Nezam Drain and receives its outflow through a pumping unit.

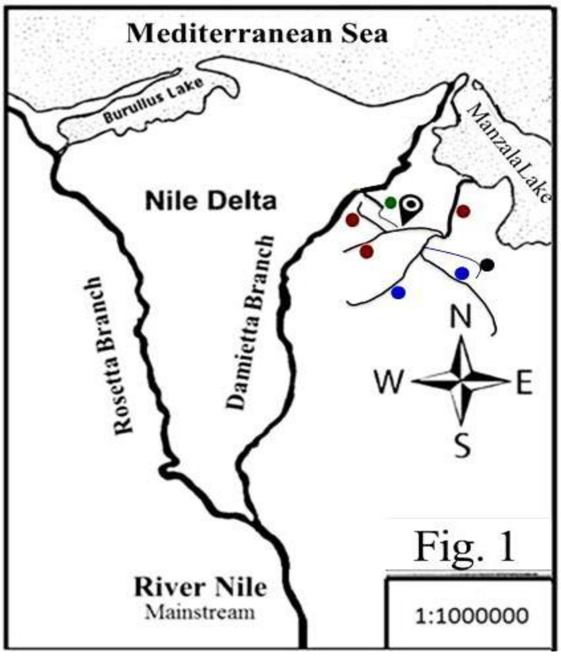

Fig. (1). Map showing the divergence of mainstream of the River Nile into Damietta and Rosetta Branches across Nile Delta, Lower Egypt. A network of murky drains flow over the eastern side of the Damietta Branch. Two minor streams, namely MAS-1 (green solid circle) and MAS-2 (black solid circle), and two major drains, namely Amlak Drain (red solid circles) and Nezam Drain (blue solid circles). Note directions on the compass. The connection between MAS-1 and Amlak Drain is indicated by 📍 .

2.2. Sampling protocol and analysis of physicochemical parameters

The subsurface water samples were collected on monthly basis from each locality at 50 cm in 1L polyethylene bottles to characterize the physical and chemical environmental parameters (abiotic factors). The hydrogen ion concentration (pH), water temperature (T), electrical conductivity (EC), and dissolved oxygen (DO) were detected by Multi–parameter Analyzer model YK-22DO and a numerical pH-meter (Orion Research Model PTI20).

Each water sample was allocated into two fragments: the first was was preserved in refrigerant at 8°C for future analysis of physicochemical environmental parameters which comprised total dissolved solids (TDS), bicarbonates (HCO^{3-}), chlorides (Cl^-), sulphates ($SO4^{2-}$), calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^+), potassium (K^+), nitrogen (N) and phosphorous (P). The trials were accomplished according to Piper [26], Hesse [27], Olsen and Sommers [28] and APHA [29]. The second fragment was kept in glass bottle and adding 3ml Nitric acid (for preservation of concentration of heavy metals) and taken for heavy metal analysis.

Chloride level was estimated as described by the American Public Health Association [29] (Mener method). Water sulphates were assessed by a gravimetric method using 5% barium chloride solution ($BaCl_2$) according to Piper [26]. Carbonates and Bicarbonates were determined by titration using 0.1N Hydrochloric acid with phenolphthalein and methyl orange as indicators for carbonate and bicarbonate anions, respectively [26]. Nitrogen in each collected water sample was estimated by a photometric method using (VARIAN 240 F.S.) flame photometer. Estimation of sodium and potassium cations of each collected water sample were carried out photometerically by using (VARIAN 240 F.S. model) flame photometer.

Calcium and magnesium were estimated by Versinate titration using ammonium purpurate as an indicator for calcium ions and Eriochrome Black T (EBT) as an indicator for both ions (calcium and magnesium) [30]. Total dissolved phosphorus was determined by digestion and followed by direct stannous chloride method as described in American Public Health Association [26].

In accordance with Bush *et al*. [31], the ecoparasitological indices of prevalence, mean intensity, and abundance of the helminth parasite species of the catfish and the Nile tilapia were computed. As a statistical concept, prevalence (% of infection) refers to the number of people in a given population who are infected with a parasite species at any given moment. Mean intensity (MI) is the total number of worms of a particular parasite species divided by the number of hosts infected with that parasite; prevalence (P%) is the number of host individuals infected/infested by one or more individuals of that parasite species divided by the number of hosts examined for that parasite species; and the total number of individuals of a specific parasite species divided by the total number of hosts (both infected and non-infected) of that species under examination is known as abundance (A).

2.3. Water Quality Index (WQI)

Water Quality Index was introduced to the water management sector in order to summarize a plenty of physicochemical measurements into brief and concise terms to gauge the validity of water for specific purposes by employing relevant guidelines of the water quality as benchmarks or key performance indicators [32, 33]. The scores of the water quality index were categorized according to the following scheme: excellent (95-100), good (80-94), fair (65-79), marginal (45-64) and poor (0-44). The scheme encompassing guideline values of irrigation water was adopted [34].

F1 (Scope) characterizes the proportion of variables that do not meet their goals at least once during the time period under consideration (i.e. unsuccessful variables), relative to the total number of variables determined:

$$F1 = \left[\frac{\text{Number of failed variables}}{\text{Number of total variables}} \right] \times 100$$

F2 (Frequency) signifies the proportion of individual tests that do not meet objectives (i.e. unsuccessful tests):

$$F2 = \left[\frac{\text{Number of failed tests}}{\text{Number of total tests}} \right] \times 100$$

F3 (Amplitude) denotes the amount by which failed test values do not meet their purposes. F3 is calculated in three steps.

$$F3 = \left[\frac{nse}{0.01\, nse + 001} \right]$$

$$nse = \left[\frac{\sum \text{Excursion}}{\text{total number of tests}} \right]$$

nse = normalized sum of excursions

$$\text{Excursion} = \left[\frac{\text{Failed test value}}{\text{Guideline value}} \right] - 1$$

$$CCMEWQI = 100 - \left[\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732} \right]$$

2.4. Statistical Analysis

All statistical procedures were performed online via Statistics Kingdom website (https://www.statskingdom.com/) which automatically analyzes and confirms assumptions, interprets outcomes and outputs graphs and histograms. Kruskal-Wallis One-Way ANOVA test calculator was chosen to test for differences of the water parameters among the four investigated habitats. Significant results were further monitored by Tukey HSD/Tukey Kramer test to detect the source of differences among a pool of variables. Probability values of the statistical outputs were categorized as follows: significant $P \leq 0.05$, high significant $P \leq 0.01$, and very high significant $P \leq 0.001$. P values > 0.05, however, were regarded as non-significant.

3. Results

3.1. Physicochemical Parameters:

3.1.1. Water temperature

Data recorded in Table (1), indicate that the thermal regime of the investigated habitats is close to one another. The mean values of surface water temperature of Nezam Drain, MAS-2, Amlak Drain and MAS-1 are 25.13±5.24°C, 24.75±7.31°C, 24.00±5.25°C and 24.83±6.17°C, respectively. On Seasonal basis, the highest water temperature was obtained in summer, while the lowest was determined in winter for all investigated ecosystems. One-Way ANOVA Test indicated non-significant differences in water temperature among the four explored aquatic habitats (P>0.05).

3.1.2. Hydrogen ion concentration (PH)

Measurements documented in Table (1) indicates that water sampled from all explored habitat is categorized on the alkaline scale, with the maximum mean pH value was determined in MAS-1 (9.09±0.31) which receives out flow from Amlak Drain. However, the lowest mean pH value was determined in MAS-2 (8.69±0.19). On seasonal basis, no remarkable differences could be recognized from one season to another at each habitat or from one habitat type to another. One-Way ANOVA Test indicated non-significant differences in water pH among the four explored aquatic habitats (P>0.05).

3.1.3. Electrical Conductivity (EC)

As recorded in Table (1), the highest electrical conductivity (EC) was measured in surface water sampled from Amlak Drain (0.77±0.05 umhos/cm), followed by Nezam Drain (0.70±0.10 µmhos/cm). However, the least conductive water body was MAS-1 (0.48±0.26 µmhos/cm). From Table (1), it can be noticed that EC attained an obviously high level (0.86 µmhos/cm) than any other season in MAS-1. Other habitats showed no definite pattern of increase of decrease of EC from season to another.

One-Way ANOVA Test indicated significant differences in EC among the four investigated habitats (F-ratio=3.6239, F-probability = 0.04). Post Hoc options (Tukey HSD/Tukey Kramer) detected significant variations in EC levels between Amlak Drain and MAS-1 (P=0.04) as well as between Amlak Drain and MAS-2 (P=0.05).

3.1.4. Total dissolved Solids (TDS)

Table (1) shows that the highest total dissolved solids was determined in water sampled from Amlak Drain (494.40±29.74 mg/L), while the lowest TDS was measured at MAS-1 habitat (305.59±165.38 mg/L). It is worth noting that Nezam Drain and MAS-2 accommodated relatively high quantities of TDS (421.40±109.30 mg/L and 405.61±92.35 mg/L, respectively). It can be noticed that summer value of TDS in water from MAS-1 is considerably higher than corresponding values in any other season. It can be also noticed that autumn levels of TDS in water from Nezam Drain, MAS-1 and MAS-2 are considerably lower than corresponding levels in the remainder of the seasons.

One-Way ANOVA Test indicated significant differences in TDS among the four investigated habitats (F-ratio=3.7036, F-probability = 0.04). Post Hoc options (Tukey HSD/Tukey Kramer) detected significant variations in TDS levels between Amlak Drain and MAS-1 (P=0.01) as well as between Amlak Drain and MAS-2 (P=0.05).

3.1.5. Water Transparency

As shown in Table (2), the maximum transparency of water was obtained for MAS-1 (45.00±17.32cm), followed by MAS-2 (38.75±15.48cm), Amlak Drain (36.25±7.5cm) and the least transparency was recorded for Nezam Drain (27.5±6.45cm). One-Way ANOVA Test indicated non-significant differences in water transparency among the studied aquatic habitats (P>0.05).

3.1.6. Water Depth

As shown in Table (2), the depth of water in the investigated habitats ranged between 0.672m and 1.60m. The highest water depth was obtained for Amlak Drain (1.60±0.16cm), followed by Nezam Drain (1.175±0.38m) and MAS-1 (0.975±0.51cm). The least transparency was recorded for MAS-2 (0.675±0.19cm). One-Way ANOVA Test indicated significant differences in water depth among the four investigated habitats (F-ratio=5.2468, F-probability = 0.015). PostHoc options (Tukey HSD/Tukey Kramer) detected significant variations in water depth between Amlak Drain and MAS-2 (P=0.01).

3.1.7. Nitrogen and phosphorous

Data documented in Table (2) indicate that surface water from all studied habitats contains considerable amounts of nitrogen, but scanty amounts of phosphorus. Water from MAS-2 incorporated the greatest amount of the micronutrient nitrogen (mean = 9.45±3.88 mg/L), followed by MAS-1 (mean = 8.66±3.93 mg/L). However, the lowest level of this micronutrient was detected in water from Amlak Drain (6.77±3.96 mg/L). Table (2) shows that summer amounts of nitrogen in all explored aquatic habitats are obviously higher than corresponding amounts determined in other seasons. From Table , it can also be observed that this element gradually increased before increasing again in spring from summer to winter. Other habitats are stochastic, with no definite pattern of increase or decrease across the four Seasons. On the other hand, the highest amount of phosphorous was detected in water from MAS-1 (0.36±0.11 mg/L), followed by Amlak Drain (0.33±0.10 mg/L). However, the lowest level of this micronutrient was determined at Nezam Drain (0.27±0.07 mg/L). On seasonal basis, no definite seasonal distribution pattern could be figured out. One-Way ANOVA Test indicated non-significant differences in nitrogen and phosphorous among the four explored aquatic habitats (P>0.05).

3.1.8. Dissolved Oxygen (DO_2)

Data recorded in Table (3) reveal that the water body of MAS-1 is more oxygenated (7.18±0.94 mg/L) than other water bodies explored in the present Study. It is worth noting the MAS-2, Nezam Drain and Amlak Drain received considerable amounts of dissolved oxygen (5.73±0.79 mg/L, 5.33±1.89 mg/L and 5.40±1.42 mg/L, respectively). As illustrated in Figure (), at Nezam Drain, the amount of oxygen dissolved in water is elevated gradually from summer to winter, before declining markedly during spring (5.10 mg/L). A similar trend could be recognized in the seasonal cycle of dissolved oxygen at MAS-2 locality, however winter and spring showed identical values (6.40 mg/L). One-Way ANOVA Test indicated non-significant differences in dissolved oxygen among the four explored aquatic habitats (P>0.05).

3.1.9. Bicarbonates (HCO_3^-) and Sulphates (SO_4^{-2})

Similar to the trend illustrated for EC and TDS, water sampled from Amlak Drain stored the greatest quantities of HCO_3^- and SO_4^{-2} (45.63±13.95 mg/L and 72.58±12.39 mg/L, respectively). The lowest amounts of HCO_3^- and SO_4^{+2} (23.58±2.59 mg/L and 33.49±6.15 mg/L, respectively) were determined at MAS-1 (Table 3). Regarding seasonal cycle of HCO_3^- in surface water, this physicochemical parameter showed a common trend at Amlak Drain, Nezam Drain and MAS-2 habitats, with gradual increase from summer to winter, followed by a remarkable decline during Spring. On the other hand, this physicochemical parameter exhibited a stochastic pattern of elevation and decline throughout the year round at MAS-1 locality (Table). Concerning the seasonal cycle of SO_4^{-2} in surface water, this physicochemical parameter exhibited a similar seasonal cycle to HCO_3^- at Amlak Drain, Nezam Drain and MAS-2 habitats. Also, a stochastic distribution pattern could be recognized for this abiotic element at MAS-1 all over the study period (Table 3).

One-Way ANOVA Test indicated significant differences in HCO_3^- among the four investigated habitats (F-ratio=3.6531, F-probability = 0.04). Post Hoc options (Tukey HSD/Tukey Kramer) detected significant variations in HCO_3^- levels between Amlak Drain and MAS-1 (P=0.01) as well as between Amlak Drain and MAS-2 (P=0.05). Similarly, One-Way ANOVA Test indicated significant differences in SO_4^{-2} among the four investigated habitats (F-ratio=3.6028, F-probability = 0.04). Post Hoc options (Tukey HSD/Tukey Kramer) detected significant variations in SO_4^{-2} levels between Amlak Drain and MAS-1 (P=0.03).

3.1.10. Chloride ions (Cl^-)

The water bodies of Amak Drain, Nezam Drain, MAS-1 and MAS-2 are loaded with considerable quantities of chloride ions (Figure , Table). The mean values determined for this physicochemical factor are 376.20±26.02, 346.00±57.75, 248.52±158.70 and 318.77±79.91 mg/L, respectively. The lowest mean value of chloride ions was determined at MAS-1 (248.52±158.70 mg/L). Table (3) shows that summer chloride levels in surface water from all habitats are higher than corresponding levels in other seasons of the year round. One-Way ANOVA Test indicated non-significant differences in chlorides among the four explored aquatic habitats (P>0.05).

3.1.11. Essential Minerals (Na^+, K^+, Ca^{++} and Mg^{++})

Table (4) illustrates the levels of the essential minerals Na^+, K^+, Ca^{++} and Mg^{++} over the study period in surface water of Amlak Drain, Nezam Drain, MAS-1 and MAS-2 ecosystems. The maximum amounts of Ca^{++}, Mg^{++} and Na^+ were determined at Amlak Drain (23.48±4.39, 12.72±2.72 and 450.80±25.571 mg/L, respectively). The highest amount of K^+ was estimated at MAS-1 habitat (7.88±2.29 mg/L). In contrast, the lowest amounts of Ca^{++}, Mg^{++} and Na^+ were obtained from surface water at MAS-1 (14.08±5.16, 6.85±5.20 and 276.78±154.74 mg/L, respectively). The lowest amount of K^+ was measured at Nezam Drain (7.25±1.26 mg/L). As represented in Table (4), the seasonal distribution pattern of Na^+ attained a gradual increase from summer to winter, followed by a decline in spring at Amlak Drain. However, the seasonal distribution pattern of Na^+ in the remainder of the habitat was random. It is obvious from Figure () there is no clear seasonal distribution pattern for K^+ in all studied habitats. As represented in Figure (), a definite seasonal distribution pattern could be recognized For Ca^{++} which increases gradually from summer to winter, and dropped in spring at three localities, namely Amlak Drain, Nezam Drain and MAS-2. In contrast, no definite seasonal distribution pattern could be noticed for this mineral at MAS-1 locality. Table () shows that Mg^{++} decreases from a peak value in summer to a minimum in winter (14.46 and 3.11 mg/L, respectively), followed by an obvious increase in spring (5.90 mg/L).

One-Way ANOVA Test indicated non-significant differences in calcium, magnesium and potassium among the four explored aquatic habitats (P>0.05). However, One-Way ANOVA Test indicated significant differences in sodium among the four investigated habitats (F-ratio=3.7162, F-probability = 0.04). PostHoc options (Tukey HSD/Tukey Kramer) detected significant variations in sodium levels between Amlak Drain and MAS-1 (P=0.05) as well as between Amlak Drain and MAS-2 (P=0.02).

3.2. Heavy Metals in water

As recorded in Table (5), Nezam Drain stored the greatest quantity of heavy metal iron (Fe) (12.513±3.743 mg/L) in its surface water, followed by MAS-1(9.183±4.671 mg/L), Amlak Drain (5.409±3.992 mg/L). The lowest amount of Fe was stored in surface water of MAS-2(4.080± 4.897 mg/L). Regarding the seasonal distribution pattern of this metal on Table (5), it could be recognized that iron was not detected in water from MAS-2 during summer and autumn. It could be also noticed that this heavy metal was not detected in water from Amlak Drain during autumn (Figure). The highest iron level at MAS-1 was estimated in summer (14.808mg/L), whereas the highest iron level at Nezam Drain was estimated in spring (17.49 mg/L).

Table (5) shows the seasonal distribution pattern of the heavy metal copper (Cu) in surface water of the aquatic habitats under investigation. MAS-2 water received the highest level of Cu (1.496±1.378 mg/L), followed by MAS-1 (0.937 ±1.084 mg/L) and Amlak Drain (0.898±0.612 mg/L). This metal was not detected in water from Nezam Drain during summer, autumn and winter (Table 5). It could be also noticed from Table (5) that copper was not detected at MAS-1 during autumn and winter. Moreover, during autumn, copper was not detected in surface water of Amlak Drain. Looking at the seasonal distribution pattern of copper, summer showed the highest level (2.99 mg/L) at MAS-2, followed by a sudden drop in autumn (0.25 mg/L), then gradually elevated in winter (0.40 mg/L) and spring (2.34 mg/L). As illustrated in

Table (5), at Amlak Drain, copper gradually increased from summer to spring apart from its absence during autumn.

As recorded in Table (5), the heavy metal aluminum (Al) is more abundant in water from Nezam Drain than in any other aquatic habitat under investigation. No clear seasonal distribution pattern could be recognized for this metal in Nezam Drain, MAS-1, MAS-2 and Amlak Drain (Figure). The highest amount of Al was detected in water sampled from Nezam Drain (719.996±525.437 mg/L), followed by MAS-1 (226.029± 128.804 mg/L), while the lowest level was measured at MAS-2 (9.937±1.168 mg/L).

Heavy metal cadmium (Cd) was not detected during autumn in surface water collected from Amlak Drain, MAS-1 and MAS-2 (Table 5). During winter, Cd was not also detected in water sampled from MAS-1. As shown in Table (5), MAS-1 received the greatest quantity of Cd (0.532±0.698 mg/L), followed by Nezam Drain (0.392±0.524 mg/L). The amount of Cd in water from MAS-2 and Amlak is comparatively lower than in water from other localities (0.165±0.130 mg/L and 0.262±0.181 mg/L, respectively). As illustrated in Table (5), Cd attained obviously high level in water from MAS-1 during summer season (1.471 mg/L) and Nezam Drain during autumn season (1.172 mg/L).

As documented in Table (6), chromium (Cr) was detected in water from Nezam Drain only during autumn (1.290 mg/L) and spring (0.504 mg/L). Also, Cr was detected in water from MAS-2 during spring only (0.085 mg/L). Additionally, Cr was detected in water from MAS-1 only during summer (0.710 mg/L). As shown in Table ( ), no regular seasonal distribution pattern could be traced for Cr in any explored habitat.

A similar distribution pattern was documented for cobalt (Co) which accumulated heavily in MAS-1 (0.484±0.655 mg/L) followed by Nezam Drain (0.359±0.473 mg /L) (Table 6). The heavy metal cobalt was not detected in water from Nezam Drain and MAS-2 during summer, from all habitats except Nezam Drain during autumn, and from MAS-1 during winter (Table,). With reference to Table (6) Co reached a peak in water From MAS-1 during summer (1.387mg/L) and exhibited a second peak in water from Nezam Drain during autumn (1.037 mg/L).

Similar to chromium and cobalt, Table (6) indicates that nickel (Ni) accumulated heavily in water from MAS-1 (0.495±0.622 mg/l), followed by Nezam Drain (0.434±0.622mg/L). As documented in Table (), Ni was not detected in water from MAS-2 during summer, autumn and winter, from Amlak Drain during summer, and from MAS-1 during autumn and winter. Figure () shows that Ni exhibited a peak value during summer in MAS-1 (1.291 mg/L) and a second peak during autumn in Nezam Drain (1.363 mg/L). It could also noticed from Table (6) that Ni attained a gradual increase from summer to spring at Amlak Drain, apart from its absence during autumn.

As documented in Table (7), lead (Pb) was not detected in water from MAS-2 during summer and spring, from Nezam Drain during spring, and from Amlak Drain during autumn. The highest level of lead was determined in water from Nezam Drain (1.422±1.377 mg/L), followed by MAS-1 (1.406±1.825 mg/L). Regarding the seasonal distribution pattern of Pb in Table (7), two remarkable peaks could be recognized for Pb: the first in water from MAS-1 during summer (4.031 mg/L); the second in water from Nezam Drain in autumn (3.225 mg/L). No clear seasonal distribution patterns could be traced for this metal in Table (7).

Table (7) shows that zinc (Zn) is accumulated at high levels in all explored habitats except for MAS-2 stream. The highest level of Zn was determined in water from MAS-1 (6.095±3. 773 mg/L), followed by Nezam Drain (5.963±3.525 mg/L) and Amlak Drain (5.908±4.820 mg/L). This heavy metal was not detected during autumn in water from MAS-2 and Amlak Drain. Following the seasonal distribution pattern of Zn in Table (7), three remarkable peaks could be recognized for Zn: the first in water from MAS-1 during summer (11.720 mg/L); the second in water from Nezam Drain in autumn (11.210 mg/L); the third from Amlak Drain during spring (11.635 mg/L). Zn showed a gradual decline autumn to spring at Nezam Drain.

As represented in Table (7), mercury (Hg) was only detected in water from MAS-1 during summer and MAS-2 during summer and spring. Mercury was only detected in Nezam Drain. This hazardous metal was not detected in water from all explored habitats during winter. Moreover, Hg was not encountered in water from Amlak Drain and MAS-1 during spring. The highest amount of Hg was determined at Nezam Drain (1.595±2.936 mg/L), followed by MAS-1 (0.893±1.785 mg/L).

3.3. Water Quality Index (WQI)

Three factorial CCME Water Quality Index (scope-F1, frequency-F2, and amplitude-F3) indicated that all explored habitats comprised poor water type (0-44). The computed values of WQI in Amlak Drain, Nezam Drain, MAS-1 and MAS-2 were 16.92, 21.01, 21.92 and 27.92, respectively as shown in Fig. (2).

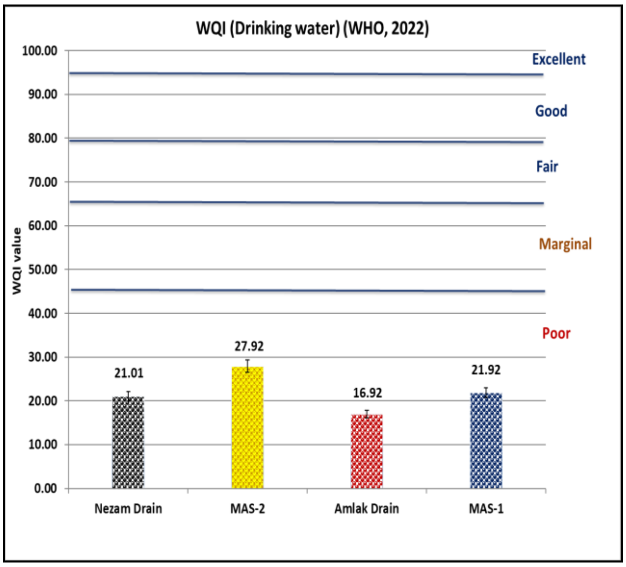

Fig. (2). Water Quality Index (WQI) in subsurface water of all studied sites.

Table 1: Seasonal fluctuations of the physicochemical parameters in subsurface water from Amlak Drain (multisource pollution drain = Black water), Nezam Drain (common agricultural drain = Grey water), MAS-1 (mix between outflow of Amlak Drain and freshwater from River Nile) and MAS-2 (mix between outflow of Nezam Drain and freshwater from Bouhyia Canal).

Season	Amlak Drain				Nezam Drain				MAS-1				MAS-2			
	T	pH	EC	TDS	T	pH	EC	TDS	T	pH	EC	TDS	T	pH	EC	TDS
Summer	30.3	8.56	0.77	490.88	31.3	8.34	0.69	444.16	32.3	8.64	0.86	551.00	33.5	8.64	0.68	437.12
Autumn	25.8	8.57	0.75	480.64	25.0	8.48	0.57	262.88	26.9	9.11	0.31	195.84	25.0	8.80	0.42	269.44
Winter	18.1	9.55	0.84	536.96	18.5	8.85	0.80	511.36	18.0	9.35	0.40	254.72	15.6	8.87	0.74	474.88
Spring	21.8	9.10	0.73	469.10	25.7	9.64	0.73	467.20	22.1	9.24	0.35	220.80	24.9	8.45	0.69	441.00
Mean	24.00	8.95	0.77	494.40	25.13	8.83	0.70	421.40	24.83	9.09	0.48	305.59	24.75	8.69	0.63	405.61
±SD	5.25	0.48	0.05	29.74	5.24	0.58	0.10	109.30	6.17	0.31	0.26	165.38	7.31	0.19	0.14	92.35

T=Temperature, pH=hydrogen ion concentration, EC=Electric conductivity, TDS=Total dissolved solids.

Table 2: Seasonal fluctuations of the physicochemical parameters in subsurface water from Amlak Drain, Nezam Drain, MAS-1 and MAS-2.

Season	Amlak Drain				Nezam Drain				MAS-1				MAS-2			
	WT	WD	N	P	WT	WD	N	P	WT	WD	N	P	WT	WD	N	P
Summer	40.00	1.80	12.60	0.42	25.00	1.65	10.71	0.26	30.00	0.40	13.86	0.50	25.00	0.70	15.12	0.33
Autumn	40.00	1.60	3.78	0.27	30.00	1.30	4.41	0.18	60.00	1.40	7.56	0.31	60.00	0.80	6.93	0.20
Winter	40.00	1.60	5.04	0.42	35.00	0.90	5.67	0.33	60.00	1.40	4.41	0.39	30.00	0.80	6.93	0.36
Spring	25.00	1.40	5.67	0.23	20.00	0.85	6.93	0.30	30.00	0.70	8.82	0.24	40.00	0.40	8.82	0.27
Mean	36.25	1.60	6.77	0.33	27.50	1.18	6.93	0.27	45.00	0.98	8.66	0.36	38.75	0.68	9.45	0.29
±SD	7.50	0.16	3.96	0.10	6.45	0.38	2.72	0.07	17.32	0.51	3.93	0.11	15.48	0.19	3.88	0.07

WT* = Water Transparency (cm), WD= Water Depth (m), N=Nitrogen, P=Phosphorous.

Table 3: Seasonal fluctuations of the physicochemical parameters in subsurface water from Amlak Drain, Nezam Drain, MAS-1 and MAS-2.

Season	Amlak Drain				Nezam Drain				MAS-1				MAS-2			
	DO_2	HCO_3^-	SO_4^{2-}	Cl^-	DO_2	HCO_3^-	SO_4^{2-}	Cl^-	DO_2	HCO_3^-	SO_4^{2-}	Cl^-	DO_2	HCO_3^-	SO_4^{2-}	Cl^-
Summer	5.90	26.88	58.22	405.78	3.20	17.08	33.88	393.20	6.30	26.64	39.45	484.90	4.90	15.11	31.75	390.26
Autumn	7.10	53.64	73.97	353.03	5.20	46.72	54.17	261.99	7.10	22.25	24.97	148.62	5.20	26.75	38.45	204.24
Winter	4.80	58.44	88.23	390.30	7.80	56.92	85.44	369.00	6.80	24.66	35.75	194.31	6.40	54.17	81.42	339.29
Spring	3.80	43.57	69.88	355.70	5.10	40.63	66.78	359.80	8.50	20.77	33.77	166.26	6.40	36.88	62.87	341.30
Mean	5.40	45.63	72.58	376.20	5.33	40.34	60.07	346.00	7.18	23.58	33.49	248.52	5.73	33.23	53.62	318.77
±SD	1.42	13.95	12.39	26.02	1.89	16.90	21.67	57.75	0.94	2.59	6.15	158.70	0.79	16.55	22.85	79.91

DO_2=dissolve oxygen, HCO_3=bicarbonates, Cl^-=Chlorides, SO_4=Sulphates.

Table 4: Seasonal fluctuations of the physicochemical parameters in subsurface water from Amlak Drain, Nezam Drain, MAS-1 and MAS-2.

Season	Amlak Drain				Nezam Drain				MAS-1				MAS-2			
	Na^+	K^+	Ca^{++}	Mg^{++}	Na^+	K^+	Ca^{++}	Mg^{++}	Na^+	K^+	Ca^{++}	Mg^{++}	Na^+	K^+	Ca^{++}	Mg^{++}
Summer	445.01	11.00	19.76	15.11	418.09	7.00	11.22	7.85	506.10	10.50	19.94	14.46	400.74	9.00	15.76	11.62
Autumn	446.30	4.50	20.67	9.17	331.80	7.00	17.22	6.86	175.78	6.50	9.62	3.94	246.63	6.00	11.89	4.92
Winter	486.40	6.50	29.47	14.56	463.99	9.00	26.21	12.16	232.70	9.00	9.87	3.11	433.81	7.50	23.46	10.11
Spring	425.50	7.50	24.01	12.04	429.20	6.00	22.88	9.11	192.52	5.50	16.88	5.90	404.90	7.00	20.99	8.07
Mean	450.80	7.38	23.48	12.72	410.77	7.25	19.38	9.00	276.78	7.88	14.08	6.85	371.52	7.38	18.03	8.68
±SD	25.57	2.72	4.39	2.72	56.16	1.26	6.59	2.30	154.74	2.29	5.16	5.20	84.55	1.25	5.20	2.90

Ca^{++-}= Calcium ions, Mg^{++-}= Magnesium ions, Na^+= Sodium ions, K^{+-}= Potassium ions.

Table 5: Seasonal fluctuations of selected heavy metals in subsurface water from Amlak Drain, Nezam Drain, MAS-1 and MAS-2.

Season	Amlak Drain				Nezam Drain				MAS-1				MAS-2			
	Fe	Cu	Al	Cd	Fe	Cu	Al	Cd	Fe	Cu	Al	Cd	Fe	Cu	Al	Cd
Summer	6.515	1.039	65.915	0.297	8.441	0.000	643.535	0.078	14.808	1.939	231.654	1.471	0.000	2.993	9.034	0.315
Autumn	ND	ND	8.412	ND	12.409	0.000	1264.588	1.172	3.593	0.000	51.030	0.000	0.000	0.253	8.926	0.000
Winter	9.568	1.200	100.654	0.341	11.712	0.000	29.722	0.223	10.300	0.000	359.561	0.000	9.800	0.400	11.364	0.188
Spring	5.552	1.353	9.126	0.410	17.492	0.948	942.138	0.095	8.032	1.810	261.870	0.658	6.518	2.339	10.404	0.156
Mean	5.409	0.898	46.027	0.262	12.513	0.237	719.996	0.392	9.183	0.937	226.029	0.532	4.080	1.496	9.932	0.165
±SD	3.992	0.612	45.300	0.181	3.743	0.474	525.437	0.524	4.671	1.084	128.804	0.698	4.897	1.378	1.168	0.130

Fe^-= Iron, Cu= Copper, Al= Aluminum, Cd^-= Cadmium.

Table 6: Seasonal fluctuations of selected heavy metals in subsurface water from Amlak Drain, Nezam Drain, MAS-1 and MAS-2.

Season	Amlak Drain			Nezam Drain			MAS-1			MAS-2		
	Cr	Co	Ni	Cr	Co	Ni	Cr	Co	Ni	Cr	Co	Ni
Summer	ND	0.146	0.256	ND	ND	0.099	0.710	1.387	1.291	ND	ND	ND
Autumn	ND	ND	ND	1.290	1.037	1.363	ND	ND	ND	ND	ND	ND
Winter	ND	0.214	0.381	ND	0.078	0.074	ND	ND	ND	ND	0.291	ND
Spring	ND	0.331	0.593	0.504	0.294	0.202	ND	0.551	0.688	0.085	0.125	0.250
Mean	0.000	0.173	0.307	0.449	0.352	0.434	0.178	0.484	0.495	0.021	0.104	0.063
±SD	0.000	0.138	0.248	0.609	0.473	0.622	0.355	0.655	0.622	0.043	0.138	0.125

Cr= Chromium, Co= Cobalt, Ni^-= Nickel.

Table 7: Seasonal fluctuations of selected heavy metals in subsurface water from Amlak Drain, Nezam Drain, MAS-1 and MAS-2.

Season	Amlak Drain			Nezam Drain			MAS-1			MAS-2		
	Pb	Zn	Hg	Pb	Zn	Hg	Pb	Zn	Hg	Pb	Zn	Hg
Summer	1.054	6.995	ND	0.816	4.324	0.000	4.031	11.720	3.570	0.000	0.951	2.190
Autumn	ND	ND	ND	3.225	11.210	5.990	0.014	3.852	ND	0.123	ND	ND
Winter	1.223	5.002	ND	1.646	4.677	ND	0.343	4.005	ND	0.438	4.505	ND
Spring	0.955	11.635	ND	ND	3.640	0.389	1.236	4.802	ND	ND	4.842	0.103
Mean	0.808	5.908	0.000	1.422	5.963	1.595	1.406	6.095	0.893	0.140	2.575	0.573
±SD	0.550	4.820	0.000	1.377	3.525	2.936	1.825	3.773	1.785	0.207	2.458	1.079

Pb^-= Lead, Zn= Zinc, Hg= Mercury.

4. Discussion

Temperature of surface water fluctuated between 24.00 and 25.13°C. All explored habitats are classified on the alkaline scale (pH: 8.69- 9.09). The electrical conductivity (EC) scored 0.48-0.77 µmhos/cm, whereas total dissolved solids recorded 305.59-494.40 mg/L. In comparison to other habitats, surface water in MAS-1 was oxygen-rich. Oxygen dissolved in water ranged between 5.33 and 7.18 mg/L. Water in Amlak Drain stored the greatest quantities of HCO_3^- and SO_4^{-2} (45.63±13.95 mg/L and 72.58±12.39 mg/L, respectively). Mean water chloride values in Amlak Drain, Nezam Drain, MAS-1 and MAS-2 were 376.20±26.02, 346.00± 57.75, 248.52±158.70 and 318.77±79.91 mg/L, respectively. Surface water from all studied habitats included significant amounts of nitrogen, but scanty amounts of phosphorus. The greatest quantities of Ca^{++}, Mg^{++} and Na^+ were measured at Amlak Drain (23.48±4.39, 12.72±2.72 and

450.80±25.571 mg/L, respectively). The highest amount of K^+ was recorded at MAS-1 habitat (7.88±2.29 mg/L). Water depth in explored habitats ranged between 0.672m and 1.60m. Water transparency scored 27.5-45.00cm.

The statistical analyses performed by Modu *et al*. [35] revealed a positive relationship between prevalence and mean intensity of monogenean parasites with some ingredients of water, namely ammonia, temperature, alkalinity dissolved oxygen and pH. In the present investigation,

According to the recommendations of WHO [34], the permissible levels of the heavy metals are: iron (0.30 mg/L), aluminum (0.20 mg/L), chromium (0.10 mg/L), copper (0.05 mg/L), cadmium (0.01 mg/L), lead (0.05 mg/L), zinc (3.00 mg/L), mercury (0.002 mg/L), nickel (0.01 mg/L) and cobalt (2.00 mg/L). Except for zinc and chromium in MAS-2, concentrations of the determined heavy metals in water from all explored habitats exceeded the standard levels suggested by WHO [34]. With a few exceptions, Fe, Al, Cu, Hg, Zn, Cr, Cd, Pb, Ni and Co in water exceeded the guideline limits of WHO. All explored habitats included poor water quality (CCME WQI= 0-44). The excessive application of pesticides and fertilizers, along with wastewater from both industrial and residential areas, eventually reaches the water bodies. This leads to a decline in the quality of water and contributes to the transmission of diseases like dysentery, diarrhea, and jaundice [4].

Many reports suggested that certain heavy metals have a positive association with disease-causing microorganisms, potentially aiding the development of these parasites by disrupting the natural functions of the fish they infect [36, 37]. For instance, Aluminum (Al) is known to induce oxidative stress, damage cells, affect DNA, increase inflammation, modify immune responses, alter the structure of proteins, impair the function of enzymes, cause changes in metabolic pathways, damage cell membranes, interfere with the growth of microtubules, disrupt the balance of iron in the body, contribute to the formation of amyloid fibers, cause programmed cell death, lead to cell death through other mechanisms, and promote the development of abnormal cell growth [38]. Additionally, ATSDR [39] and Turner *et al*. [36] have reported that Aluminum is toxic to the brain and primarily targets the central nervous system.

According to Radwan *et al*. [40], there was a significant negative relationship between prevalence levels of parasites and amounts of heavy metals in water, including Zn, Pb, and As. Also, there was a significant positive relationship between prevalence levels of parasites and amounts of Cu; however, no significant relationship was relevant with Cd and Fe. As suggested by Smriti *et al*. [41], the inverse relationship between copper levels and the number of the monogenean species from the genus *Quadriacanthus* can be linked to several reasons. Copper acts as an algaecide, so it is anticipated that it leads to a reduction in algal growth when unintentionally introduced into water. Since algae form the foundation of food chains, the quantity of algae in a water system influences the availability of food for aquatic organisms [41].

Ogundiran *et al*. [42], the gills of fish is highly responsive to fluctuations in the physical and chemical properties of water, as well as any modifications in the ambient environment. This sensitivity serves as a key sign of pollutants persisting in water. From a physiological and morphological perspective, the gill is crucial for fish survival, as it is the primary organ for exchanging gases, which includes regulating water levels, maintaining the balance of acids and bases, removal of nitrogenous waste products such as ammonia and urea [43, 44]. On the other hand, the skin surface is wet and has a slimy mucus mat of mechanical, chemical and immunological functions. Kearn [45] suggested that attachment to skin of the fish host is challenging regardless the topography of the skin as a flat surface or residence of the fish on the riverbed during the daytime. The catfish host are known to conduct sudden bursts of speed accompanied by vigorous body contractions and acrobat displays creating vortices nearby the water surface, followed by immediate sinking to deeper water layers [46]. It is worth noting that the skin epidermis of the catfish, *C. gariepinus* has a plenty of epithelial cells which are regarded as the primary food resources for monogeneans which are assorted as epidermal browsers [47].

The results of the study implies that continuous monitoring has to be carried out to ascertain the long-term impact of anthropogenic inputs in order to take remedial measures so as to ensure the performance of aquatic organisms and equilibrium of the ecosystem as a whole.

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