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# INTEGRATED ENVIRONMENTAL ASSESSMENT OF DRINKING WATER QUALITY IN BAQUBA: ASSESSMENT OF PHYSICAL AND CHEMICAL STABILITY AND RISKS OF MICROBIAL CONTAMINATION

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## ABSTRACT

The present study aims to assess the concentrations and accumulation of heavy metals in surface water, sediments and key aquatic macrophytes namely Ceratophyllum demersum, Phragmites australis, Arundo donax and Typhain the marshes of Iraqi south. Analysis of the water samples showed that the concentration of all the metals were found low and were within the safety limits of class II. But, sediments showed localized high level of V, Co, Cu, and Pb above background concentrations which indicate anthropogenic stresses. The bioaccumulation efficiency of the presence of the metals differed significantly from species to species with the submerged macrophyte C. demersum showing maximum of bioaccumulation, particularly for Ti, Cr, V, and Pb, which is attributed to the presence of large contact surface with water column for these metals mainly. Emergent species (P. australis and A. donax), on the other hand, were able to separate out the essential metals (Zn and Cu) and obstruct the movement of toxic metals to shoot tissues. In conclusion, aquatic plants, particularly those that are submerged, act as important bioindicators and natural biofilters which is a major role in phytoremediation and wetlands conservation.

**Keywords:** Aquatic Plants; Heavy Metals; Drinking water, Ecosystem, Bioaccumulation

## 1 INTRODUCTION

The issue of water security and quality is one of the greatest environmental and health challenges facing the Middle East region, and particularly Iraq, which relies primarily on the Tigris and Euphrates basins and their tributaries to meet domestic, agricultural, and industrial needs [1]. Various pollutants, whether resulting from untreated sewage activities or the discharge of industrial and agricultural waste, pose a constant threat to aquatic ecosystems, leading to the deterioration of the hydrochemical properties of soil and water in the Diyala River basin and the city of Baquba [2, 3]. This deterioration is not limited to traditional physicochemical variables but extends to include the accumulation of heavy elements such as lead (Pb), cadmium (Cd), copper (Cu), and chromium (Cr}) in water sources and treatment plants, not to mention microbial contamination by coliform bacteria and other pathogenic microorganisms [4,5,6]. The impact of these pollutants extends to living organisms and biological components on riverbanks; Cumulative studies have shown the negative toxic effect of heavy metals on the anatomical level of plants growing in the aquatic environment, such as the reed plant (Phragmites communis) [7]. To support environmental management efforts, the need arose to use mathematical models and equations to control pollution sources and limit their spread in the Diyala River within the boundaries of Baquba city [8].

[9, 10] Water pollution from industries, factories, and even health facilities and hospitals is rich in heavy metals and pathogenic microorganisms such as bacteria and fungi [11] . Many countries, including those in the Middle East and impoverished regions, face the problem of pollution due to wars, poor infrastructure, and polluted environments. Access to clean water suitable for human use becomes an urgent need. [12] Water loses many of its properties after pollution and becomes unsuitable for humans, animalsl, or plant irrigation. Water is essential for health. The average person needs 2.5 liters of clean, potable water daily for drinking, increasing to 20 liters daily when working in hot weather to prevent dehydration. [13] Water undergoes several stages, some physical, some chemical, and some biological, to purify it from pollutants. [13,14].

## 2 MATERIALS AND METHODS

Tap water samples were collected directly from four randomly selected areas in and around Baquba: (Al-Mu'allimin A, Al-Tahrir, Al-Katoun C, and Kanaan D), with each sample being duplicated. The study period ran from September 2024 to March 2025. Environmental factors, including heavy metals (Iron, lead, and copper ) were measured using the method described in [15]. and some biological microorganisms, were measured in the laboratory. Total dissolved solids (TDS) were measured using Millipore filter paper, and turbidity was measured using a turbidity meter. Chloride (Cl) was measured, and according to standard water testing methods specified by the American Public Health Association (APHA). Calcium was also measured. Magnesium ($Mg^{+}$) [16,17,18]. Some heavy metals were also detected Zinc, Iron Nickel, Chromium. Finally, the number of coliform pathogenic bacteria was determined also [19].

### 2.1 Statistical Analysis

The analysis of variance (ANOVA) was statistically analyzed using Duncan’s test and the correlation coefficients between the variables were estimated.

## 3 RESULTS AND DISCUSSION

### 3.1 Turbidity and Total Dissolved Solids (TDS)

Turbidity measures the relative clarity of a liquid and reflects the degree to which light is scattered by suspended particles in the water column. It is a crucial indicator of overall water quality and is affected by suspended particles such as mud, silt, organic and inorganic microorganisms, algae, and microorganisms [20]. As shown in Table 1, the highest turbidity value recorded at station (A) was 4.24 Nephilometer Turbidity Units (NTU) During the study period a trend like that of stations (B) and (C). In contrast, station (D) recorded its highest individual value of 3.84 NTU in December 2024. Higher turbidity values were generally observed during the winter, consistent with the findings of [21], while [22] indicated the highest values during the summer months. Statistical analysis revealed statistically significant differences between the stations ($P < 0.05$). It is worth noting that only station (D) recorded a total turbidity ($5.28 \pm 0.91$ NTU) exceeding the permissible limit of 5 NTU, as defined by Iraqi Standard Specifications [24] and World Health Organization guidelines. Regarding total dissolved solids (TDS), station (A) recorded the highest concentration (404.8 mg/L) , consistent with the elevated winter levels observed at all stations. Statistical analysis showed no statistically significant differences in TDS values between stations during the study period ($p < 0.05$). The seasonal increase in TDS can be attributed to interaction with colloidal aggregates within the sedimentation basins. All recorded TDS values remained within the maximum permissible limit of 1000 mg/L, as defined by the Standard Specifications.

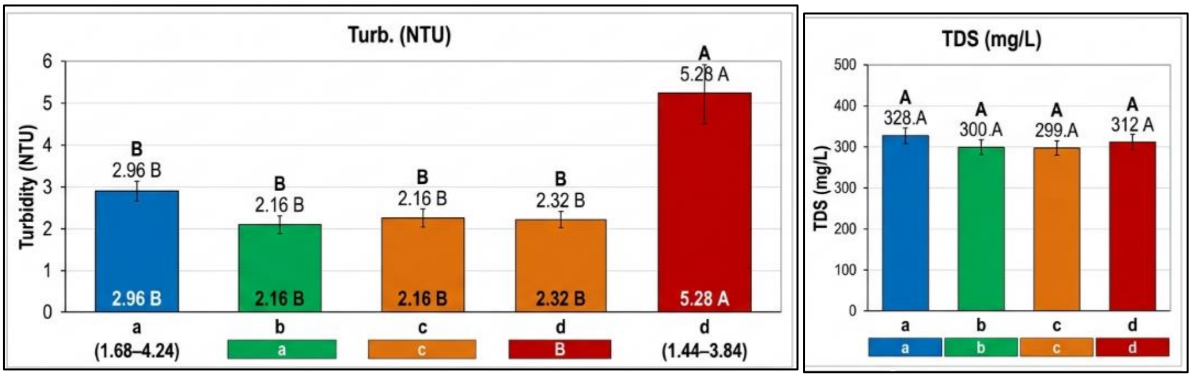


**Figure 1: Turbidity and Total Dissolved Solids (TDS) values in selected water samples used in the study.**

## 3.2 Total Hardness, $Cl^-$, and $Mg^+$ Hardness

Water hardness is primarily governed by multivalent cations, predominantly calcium ($Cl^-$) and magnesium ($Mg^+$) ions derived from mineral dissolution and weathering processes [24]. As presented in Table 1, the maximum total hardness was observed at Station a (296.0 mg/L) During the study period, with Stations b and c also recording elevated levels during the same month. This winter peak is largely linked to rainfall runoff, soil erosion, and variations in the treatment plant's capacity to remove dissolved mineral salts [25]. A significant positive correlation was identified between turbidity and total hardness ($r = 0.81$), as well as $Ca^{2+}$ hardness ($r = 0.56$) at $P < 0.01$. All observed values were within the permissible standard limit of 500 mg/L set by Iraqi standards and WHO guidelines.

For calcium hardness, the peak concentration occurred at Station d (102.4 mg/L), statistical analysis indicated no significant differences among stations ($P > 0.05$). Minor spatial variations in $Ca^{2+}$ levels can be attributed to differences in filtration efficiency and the dosage of chemical additives [16]. All $Ca^{2+}$ concentrations remained well below the maximum standard threshold of 200 mg/L [13,14]. Regarding magnesium, the highest level was recorded at Station a (23.2 mg/L), showing statistically significant differences among stations ($P < 0.05$). This variation is likely driven by the limited efficiency of conventional treatment schemes in removing $Mg^+$ ions [26]. All values complied with the acceptable threshold of 150 mg/L [27].

Chloride ions ($Cl^-$) are added to distribution networks primarily as a final disinfection step to eliminate waterborne pathogens. As shown in Figure 2, the highest chloride concentration was recorded at station (A) (136.0 mg/L) during December 2024, while the lowest concentration was recorded at station (C) (54.3 mg/L) in March. The elevated chloride levels during the winter months are associated with chlorination dosage adjustments implemented by municipal water authorities. Statistical analysis showed no statistically significant differences between stations (P > 0.05). All values remained within the maximum permissible limit of 600 mg/L, according to Iraqi standards and WHO guidelines.

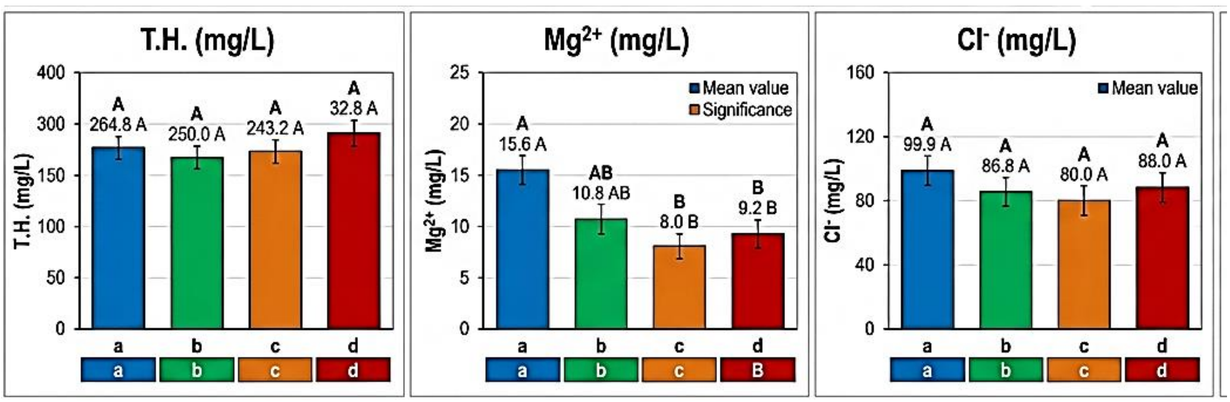


**Figure 2: Total Hardness, $Ca^{2+}$, Cl and $Mg^{2+}$ Hardness values in selected water samples used in the study.**

## 3.3 Rare heavy metals (iron, lead, and copper):

Heavy metals occur naturally in trace amounts in the Earth's crust as complex compounds or free ions. The results in Table 1 varied the concentration of zinc between 0.177 and 0.227 parts per billion, which is a very low value compared to the safe limits set by the World Health Organization (3 mg/liter for drinking water). The slight difference between the stations indicates that zinc sources are mostly natural, probably the result of natural weathering of rocks, with limited influence of human activities. However, the relative height at station S3 reflects the use of phosphate fertilizers, which often contain zinc impurities.

And the results showed low and consistent values for iron in stations S1, S2, S3, where it varied between 1.1 and 1.5 parts per billion, which is within the normal limits of uncontaminated soil. At station (D), iron levels reached their highest value at 0.223 mg/L (parts per million), which is higher than at other stations (1.1-1.5 parts per billion). Although this increase suggests local sources—possibly industrial wastewater, waste from the old landfill, or corrosion of infrastructure near the station—the recorded value is still below the maximum permissible limit of 0.3 mg/L, as defined by the World Health Organization and Iraqi standards. Therefore, iron levels at all monitored stations do not pose an immediate health risk such as hemochromatosis, liver and pancreas damage, as well as negative effects on vegetation and soil micro-organisms. And the concentration of nickel was similar between the stations, ranging between 0.41 and 0.55 parts per billion, which is a normal value indicating a homogeneous geochemical background in the region. Station S2 recorded the highest concentration, probably due to light industrial activities, while station S4 was the lowest despite the presence of iron pollution, which indicates that the source of high iron is not related to nickel.

But the concentration of chrome is extremely low, varying between 0.05 and 0.12 ppm, which is much less than the permissible price limit. This is certainly an indicator, because it indicates the absence of industrial sources of chrome, such as leather, gold, and dyeing, or that these sources are currently limited and ineffective. However, caution must be taken, because sedasi chrome is one of the most dangerous forms of chrome, and despite the low alcohol concentration, it is recommended to study the chemical form to ensure environmental safety.

Comparing the results with the international and local standards and the maximum permissible values according to the World Health Organization and the American Environmental Protection Agency, we find that:

The safe limit element (ppm) is the highest recorded concentration (ppm) of the condition

- Zinc 50 0.000227 safety separately
- Iron 0.223 (drinking water) 0.223 in D safety
- Nickel 0.02 (drinking water) 0.00055 safety
- Chrome 0.05 (drinking water) 0.00012 safety

The comparison confirms that all measured heavy metals (zinc, iron, nickel and chromium) remained within the maximum permissible limits for drinking water at all stations studied.

**Table 1: Concentration of heavy elements in selected stations**

| Station | Chromium | Nickel | Iron | Zinc |
|---|---|---|---|---|
| A | 0.12 | 0.45 | 1.5 | 0.177 |
| B | 0.05 | 0.55 | 1.3 | 0.192 |
| C | 0.05 | 0.42 | 1.1 | 0.227 |
| D | 0.07 | 0.41 | 0.223 | 0.189 |

### 3.4 Coliform bacteria

One of the key health indicators for water safety and purity is measuring the presence of coliform bacteria (CPB) in the water, as this is a direct indicator of microbial contamination and unsuitability for drinking water. The highest bacterial count was recorded at station (A) (320 cells/ml) during the study period, and other stations also showed an increase in count during the same month (Figure 2). A strong positive correlation was found between turbidity and the number of coliform bacteria ($r = 0.93$, $P < 0.01$). Statistical analysis revealed significant differences between stations and months of the study ($P < 0.05$). Microbial contamination is attributed to insufficient alum and chlorine dosages during treatment, as well as the aging of the distribution pipe network. At all stations, the bacterial count exceeded the maximum permissible limit (0 cells/ml) established according to Iraqi standards and WHO guidelines.

**Table 2: Coliform bacteria in values in selected water samples used in the study.**

| stations | Mean value cell\ ml | Significance Group |
|---|---|---|
| a | 160.0 | A |
| b | 120.0 | AB |
| c | 120.0 | AB |
| d | 80.0 | B |

The following scientific analysis revealed spatial and qualitative variations in water production across Iraqi governorates. Chemical variations range from the production of short-chain metals to microbial contamination resulting from inadequate centralized treatment and distribution. Northern regions, including Erbil [28], Kalar [29], and the Sulaymaniyah Lakes [30], recorded elevated concentrations of elements such as lead (Pb), cadmium (Cd), and nickel (Ni). This increase is increasingly attributed to new operations and network corrosion. In contrast, industrial activity and southern regions, such as Baghdad [31] and Maysan [32], were more significantly affected. The formation of the High Polymer Index (HPI) extended beyond the southern borders in Maysan , consistent with Baghdad studies indicating the impact of industrial water on increased turbidity and metal concentrations [33]. Public health microbial contamination levels subsequently ceased to be a significant concern following several structural deficiencies in disinfection processes. While studies in Anbar (Habbaniyah) [34], Najaf [35], and Baghdad [36] have identified highly resistant E. coli bacteria in water and reservoir networks due to aging pipes and unregulated chlorination, this problem has persisted even with commercially bottled water, where antibiotic-resistant strains (MDRs) are present. These direct findings align with the comprehensive review by Todd (2024) [37], which linked sewage disposal methods and their mixing with distribution networks to the recording and management of common diseases in Iraq.

## 4 CONCLUSION

This study provides a comprehensive environmental assessment of drinking water quality at four distribution stations in Baquba. The results indicate that although total dissolved solids (TDS), total hardness, and heavy metal concentrations (zinc, iron, nickel, and chromium) are fully within the permissible limits at both the national (Iraqi standards) and international (WHO) levels, significant challenges remain regarding water quality and its physical and biological stability. Specifically, turbidity levels at station (D) exceeded the permissible limit (5.28 NTU), primarily due to seasonal runoff and inefficient treatment during the winter. Most importantly, severe microbial contamination was detected at all assessed stations, with station (A) recording the highest coliform count (320 cells/ml), far exceeding the absolute intolerance threshold for drinking water. This problem is largely attributed to insufficient chlorination doses, operational deficiencies in centralized treatment processes, and the deterioration of the aging distribution network infrastructure. Therefore, urgent interventions—including updating treatment protocols, enhancing secondary disinfection, and systematically rehabilitating the network—are essential to mitigate waterborne health risks in the region.

## STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS


### *Acknowledgments*

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