

Research Paper



Evaluation of the drinking water quality index in Dibis district, Kirkuk

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ABSTRACT

In this study, a weighted arithmetic water quality index (WQI) model was used to evaluate the quality of water from the water treatment plant in Dibis district, Kirkuk. The assessment was conducted at five sites from October 2023 to April 2024. The water samples were analysed for physical properties (turbidity, total suspended solids, total dissolved solids, and electrical conductivity), chemical properties (pH, total alkalinity, total hardness, calcium hardness, magnesium hardness, chloride, total nitrogen, and available phosphorus), and bacterial properties (total bacterial count, coliform bacteria, and faecal coliform bacteria). The sites were the raw water intake from the Lower Zab River, the water pumping area, and the Dur Al-Naft, Diyarbakir, and Kolan neighbourhoods. The results showed poor water quality at the raw water intake (WQI = 197.78), whereas the treated water at sites 2, 3, 4, and 5 was of excellent quality, with WQI values of 18.10, 17.61, 47.96, and 30.40, respectively. These findings indicate that the treatment plant effectively produces water suitable for drinking and domestic use.

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1. INTRODUCTION

Water plays an important role in human development, survival, and economic activity; despite its importance, water resources are often inadequately exploited and protected, and approximately 95–97% of the Earth's water is saline water in the seas and oceans [1]. Although governments and institutions worldwide apply regulations and controls to ensure the availability and quality of water resources, many water sources remain vulnerable to pollution [2]. Water pollution poses great risks to human health and can cause significant economic losses, and preserving water resources of adequate and usable quality is a major challenge [3]. Water quality is affected naturally by the properties of the river basin and artificially by human activities within it [4]. The concept of quality is closely related to the intended use of water, with different requirements for domestic use and irrigation, and water pollution occurs when foreign substances are introduced, often as a result of human activity [5].

The physical and chemical properties of water are of great importance in determining its quality: they indicate the organic and inorganic compounds and elements it contains, reveal the level of pollution and the true chemistry of the water, and allow sound decisions to improve water quality [6]. They also support the growth of phytoplankton through temperature, light, and the supply of nutrients, salts, dissolved chemicals, and dissolved oxygen, and contribute to the diversity of aquatic communities [7]. Water is considered undrinkable when it contains waterborne pathogenic microbes, which reach water through excreta and cause many diseases transmissible to humans; a large proportion of human health problems are therefore directly due to water pollution [8]. Animals are an important reservoir of waterborne pathogens, especially through excreta deposited in water or soil, increasing the numbers of pathogenic bacteria such as *Escherichia coli* and *Salmonella* spp. in the environment [9]. Effective assessment of water quality and accurate identification of pollution sources are essential for the sustainable use of water resources, and although water quality index (WQI) models have proven applicable to surface water assessment, they still have potential for further development [10]. The aim of this study was to evaluate the quality of the drinking water produced for Dibis district and its suitability for domestic use.

2. RELATED WORK

Deidan and AbdelQader [11] assessed the quality of water produced by the Hawija district treatment plant in Kirkuk and found that it produces high-quality water suitable for various human uses, including drinking, and another study [12] showed that drinking water stations in Kirkuk produce water with physical and chemical properties within the acceptable range for domestic use. Al-Safawi and Al-Assaf [13] examined the effect of the effluents of Wadi Al-Danafi on the physical and chemical properties of Tigris River water in Mosul, and Lafta [14] reported a significant decrease in the bacterial content of water at all sites after purification at a treatment plant in Baghdad Governorate, indicating the effectiveness of the treatment process.

3. METHODOLOGY

3.1 Study Area

The study area is located in Dibis district, Kirkuk Governorate, north of Baghdad (35°28' N, 44°23' E), about 240 km from Baghdad and 40 km from Kirkuk. The Lower Zab River is the water source for the treatment plant, whose pumps withdraw water from the river to supply all areas of the district. The study sites were: site 1, raw water from the intake channel; site 2, the water pumping area; site 3, the Dur Al-Naft neighbourhood, 1 km from the plant; site 4, the Diyarbakir neighbourhood, 2.7 km from the plant; and site 5, the Kolan neighbourhood, 3 km from the plant.

3.2 Sample Collection

Water samples were collected from the five sites for physical, chemical, and biological analyses from October 2023 to April 2024. Samples were collected in polyethylene bottles in the early morning to ensure their arrival at the laboratory within the specified time; tap samples were collected after letting the water run for about 10 minutes to obtain water free of scale and pipe debris. Samples were transported to the laboratory in an ice-cooled container.

3.3 Measurement of Physical, Chemical, and Biological Parameters

The parameters were analysed according to the standard methods of APHA [15] in the laboratories of the Department of Biology, College of Education for Pure Sciences, University of Kirkuk, the Kirkuk Directorate of Agriculture, and the Department of Irrigation.

3.4 Water Quality Index

The weighted arithmetic water quality index model, used by many researchers [16], [17], [18], [19], [20], was applied to estimate the water quality of the treatment plant. First, the relative weight (W_i) of each parameter was determined (Equation 1); second, the quality rating (q_i) of each parameter was calculated (Equation 2); third, the sub-index (SI_i) of each parameter was calculated (Equation 3); and finally, the WQI was obtained as the sum of the sub-indices (Equation 4):

$$W_i = w_i / \sum w_i \quad (1)$$

$$q_i = (C_i / S_i) \times 100 \quad (2)$$

$$SI_i = W_i \times q_i \quad (3)$$

$$WQI = \sum SI_i \quad (4)$$

Where w_i is the weight assigned to parameter i , C_i is the measured value of the parameter, and S_i is its standard (permissible) value. Water quality was classified according to the WQI values in Table 1.

Table 1. Classification of Water Quality by WQI Values [11]

Water Quality	WQI
Excellent	< 50
Good	50–100
Poor	100–200
Very poor	200–300
Unsuitable	> 300

4. RESULTS AND DISCUSSION

The water quality of the Dibis district treatment plant was assessed using the weighted arithmetic model [11], [17], [18], [19], [20], applied to 15 parameters—turbidity, total suspended solids (TSS), total dissolved solids (TDS), electrical conductivity (EC), pH, total alkalinity (TAlk), total hardness (TH), calcium hardness (CaH), magnesium hardness (MgH), chloride (Cl), total nitrogen (TN), total phosphorus (TP), total plate count (TPC), coliform bacteria (MPN), and *E. coli* (MPN)—as shown in Table 2, to evaluate the water produced for drinking and domestic use.

Table 2. Mean Values (with Ranges) of the Studied Parameters at the Five Sites

Parameter (Unit)	Site 1	Site 2	Site 3	Site 4	Site 5
Turbidity (NTU)	0.162a (0–0.77)	0.089a (0–0.026)	0.074a (0–0.22)	0.071a (0.004–0.332)	0.62a (0–0.11)
TSS (ppm)	0.77a (0.5–1.02)	0.71a (0.22–1.04)	0.803a (0.5–1.04)	0.83a (0.6–1.42)	0.666a (0.3–1)

Parameter (Unit)	Site 1	Site 2	Site 3	Site 4	Site 5
TDS (ppm)	0.123a (0–0.24)	0.096a (0–0.16)	0.136a (0–0.18)	0.233a (0.2–0.76)	0.47a (0.2–1.98)
EC ($\mu\text{S}/\text{cm}$)	358.666a (285–441)	368a (265–472)	395a (294–543)	351.5a (264–427)	366.333a (274–443)
pH	7.183a (6.5–7.5)	7.183a (6.6–7.6)	7.15a (6.4–7.7)	6.983a (6.2–7.5)	7.233a (6.7–7.6)
TAlk (ppm)	122.333a (100–140)	121a (112–136)	127.22a (112–140)	121a (108–140)	121.667a (108–140)
TH (ppm)	152.5a (120–190)	154.166a (120–190)	167.5a (135–230)	152.5a (120–180)	154.166a (120–180)
CaH (ppm)	105.833a (95–125)	110.833a (85–130)	120.625a (98.75–165)	108.333a (85–125)	108.333a (85–125)
MgH (ppm)	46.666a (25–65)	43.333a (30–60)	46.875a (30–65)	44.166a (30–55)	45.833a (30–65)
Cl (ppm)	8.756a (5.68–11.36)	9.23a (5.68–11.36)	14.97c (8.5–31.24)	9.94b (8.52–11.36)	9.94b (8.52–11.36)
TN (%)	0.15a (0.1–0.2)	0.133a (0.1–0.2)	0.15a (0.1–0.2)	0.15a (0.1–0.2)	0.15a (0.1–0.2)
TP (ppm)	0.0081a (0–0.033)	0.006a (0–0.022)	0.0058a (0–0.011)	0.004167a (0–0.011)	0.006a (0–0.011)
TPC (cells/100 mL)	215.5b (163–250)	10a (0–60)	0a (0–0)	31.5a (0–189)	33.33a (0–125)
Coliforms (MPN/100 mL)	16b (16–16)	0a (0–0)	0a (0–0)	0a (0–16)	0.85a (0–5.1)
E. coli (MPN/100 mL)	13.333b (0–16)	0a (0–0)	0a (0–0)	2.666a (0–16)	0.85a (0–5.1)

Note: Values are means with ranges in parentheses; means in the same row followed by different letters differ significantly (Duncan's test, $P \leq 0.05$).

Total dissolved solids ranged from undetectable levels at the first, second, and third sites in October 2023 to a peak of 1.98 ppm at the fifth site in December 2023, and mean TDS did not differ significantly among sites ($P \leq 0.05$). The variation in TDS could reflect the absence of residential sewage systems and industrial facilities, as water characteristics are predominantly reflected in supply networks [21]. A significant correlation ($P \leq 0.05$) was observed between TDS and magnesium hardness ($r = 0.365$), and variations in TDS in the neighbourhood networks were associated with winter and spring rainfall, which increases soil erosion and salt content, particularly in water from agricultural areas [22]. These results were compared with a previous study [11], in which TDS ranged from 244 to 310 mg/L, and differed from a study of the Lower Zab River in Hawija district, Kirkuk [23], in which TSS ranged from 823 to 1600 mg/L.

Electrical conductivity ranged from 264 to 543 $\mu\text{S}/\text{cm}$, with the lowest value in January 2024 at the fourth site and the highest in March at the third site. Analysis of variance and Duncan's test revealed significant differences ($P \leq 0.05$) among monthly means but not among sites. These variations may be attributed to suspended materials, clays, and organic substances carried by the river, which contribute unequally to conductivity, since EC is influenced by the concentration of dissolved salts [24]. The results agreed with studies [25], [26] showing that this parameter is not strongly affected by month, owing to the geology of the region, the salt content of the soil, and the chemicals added at treatment plants to purify the water and reduce turbidity. EC was positively correlated with pH ($r = 0.501$, $P \leq 0.01$), possibly because an increase in pH raises the concentration of hydroxide ions, which contribute to conductivity. The results were not consistent with study [12], in which EC values ranged from 380 to 430 $\mu\text{S}/\text{cm}$.

pH values ranged from 6.2 at the fourth site in December 2023 to 7.7 at the third site in November 2023, with no significant differences among sites ($P \leq 0.05$); these values comply with the Iraqi standard specifications and fall within the limits set by the World Health Organization. pH was negatively correlated with TSS ($r = -0.414$, $P \leq 0.05$) and positively correlated with EC ($r = 0.501$, $P \leq 0.01$) and total alkalinity ($r = 0.458$, $P \leq 0.05$), and negatively correlated with magnesium hardness ($r = -0.404$). The pH values were lower than those reported for the Tigris River at Al-Ishaqi, Salah Al-Din Governorate, which ranged from 6.6 to 8.5 [27].

Total alkalinity was lowest at the first site in January and highest at the first, third, fourth, and fifth sites in March 2024, with no significant differences among sites ($P \leq 0.05$) but significant differences among sampling dates. These results differed from a previous study reporting an alkalinity range of 145–240 mg/L for the Tigris River in Mosul [28], a difference attributed to the high concentration of organic matter decomposed aerobically by microorganisms, producing carbon dioxide that forms carbonic acid, bicarbonate, and carbonate ions and increases total alkalinity.

Total hardness ranged from 120 mg/L at sites 1, 2, 4, and 5 in November 2023 to 230 mg/L at site 3 in 2024. Mean total hardness did not differ significantly among sites ($P \geq 0.05$) but differed significantly among sampling dates. The higher hardness at some sampling times may be because the Zab River was affected by rainfall, as the upper Zab catchment receives large amounts of rain. Total hardness was significantly correlated with total alkalinity ($r = 0.527$), calcium hardness ($r = 0.579$), and magnesium hardness ($r = 0.834$) ($P \leq 0.01$). The high levels of total hardness can be attributed to calcium and magnesium ions derived from the calcareous soils of the river basin [29], [30]. Total hardness was positively correlated with chloride ($r = 0.711$) and negatively correlated with total nitrogen ($r = -0.655$) ($P \leq 0.01$). These results differed from a previous study reporting total hardness values of 160–184 mg/L [22]. Total alkalinity was also significantly correlated with EC ($r = 0.589$), total hardness ($r = 0.527$), calcium hardness ($r = 0.579$), and chloride ($r = 0.565$) ($P \leq 0.01$), and with turbidity ($r = 0.362$) and pH ($r = 0.458$) ($P \leq 0.05$), and negatively with total nitrogen ($r = -0.386$).

The total bacterial count ranged from 0 to 250 cells/100 mL. Analysis of variance and Duncan's test revealed significant differences ($P \leq 0.05$) among sites but not among sampling dates; the first site differed significantly from all other sites because chlorine is added to the water only after that point. The total bacterial count was strongly correlated with faecal coliform bacteria ($r = 0.959$), coliform bacteria ($r = 0.900$), and the water quality index ($r = 0.987$) ($P \leq 0.01$). *E. coli* and coliform bacteria are clear indicators of recent faecal contamination of water. Their counts ranged from 0 to 16 cells/100 mL, with the highest value (16 cells/100 mL) observed consistently at the first site throughout the study and at the fourth site in January, whereas sites 2–5 had undetectable levels except in January. Coliform and *E. coli* counts were significantly correlated ($P \leq 0.01$) with the total bacterial count and the water quality index, consistent with a previous study [11].

4.1 Drinking Water Quality Index

Table 3. Drinking Water Quality Index Values at the Sampling Sites

Site	WQI Value	Water Quality Class
1	197.784	Poor
2	18.109	Excellent
3	17.614	Excellent
4	47.969	Excellent
5	30.408	Excellent

The WQI of the Dibis district treatment plant, based on 15 parameters (Table 3), showed poor water quality at the first site, which represents untreated raw water, with a WQI of 197.784, indicating unsuitability for drinking, mainly because of high bacterial levels. Sites 2–5 represent water treated at the plant and were classified as excellent, indicating that the plant operates efficiently. The higher WQI values at the fourth and fifth sites, the most distant from the plant, may be due to the age of the distribution

networks and pipes, estimated at about 60 years. These findings agree with those of [31]: raw water is unsuitable for consumption, whereas treated water is of excellent quality.

5. CONCLUSION

The drinking water quality index divided the study sites into two groups. The first group, the raw Lower Zab River water at site 1, was unsuitable for drinking; the second group, the treated water at sites 2, 3, 4, and 5, was of excellent quality, with the best water quality at the third, second, and fifth sites.

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Authors Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Omar Taha Mahmoud Al-Taay	✓	✓	✓		✓	✓		✓	✓		✓		✓	
Rushdi Sabah Abdulqader	✓			✓			✓			✓		✓		✓

C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

Conflict of Interest Statement

No conflict of interest.

Informed Consent

Not Applicable.

Ethical Approval

Not Applicable.

Data Availability

This study draws on publicly available data. No new datasets were created.

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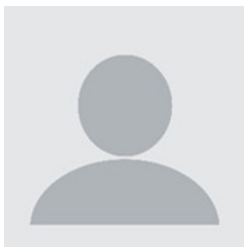
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