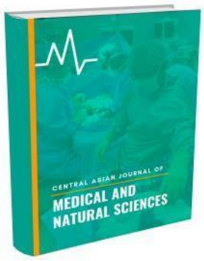

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Article

Stable Water Quality Amid Seasonal Fluctuations in Iraqi Lake

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Abstract: This study investigates the physical, chemical, and biological properties of Darbandikhan Lake and the Sirwan River in Sulaymaniyah province, focusing on five locations from September 2023 to February 2024. Chemical parameters measured included pH, BOD, total alkalinity, total hardness, sulfates, nitrates, chloride ions, calcium and magnesium hardness, and sodium and potassium ions. pH values ranged from 6.2 to 8.88, total alkalinity from 80 to 182 mg/L, and total hardness from 92 to 450 mg/L, all within permissible limits. Calcium hardness ranged from 11.6 to 151.4 mg/L, and magnesium hardness from 3.22 to 45.49 mg/L. Chloride, sodium, and nitrate levels were within acceptable ranges, with sulfate concentrations expectedly low. Statistical analysis using ANOVA, Duncan Test, and Pearson Correlation identified significant spatial differences in pH values but no temporal differences. The findings suggest that the lake's water quality is stable but underscore the need for ongoing monitoring and pollution prevention due to potential anthropogenic impacts. This research highlights the importance of continuous water quality assessment to safeguard public health and the environment.

Keywords: Darbandikhan Lake, Sirwan River, Water Quality, Chemical Properties, Environmental Monitoring.

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1. Introduction

Studying water resources and understanding their quality characteristics are crucial due to their direct connection to agricultural, industrial, residential, environmental, and even tourism activities. Water quality is influenced by surface water sources, groundwater movement, and the nature of the water-bearing rock layer, essential for determining water suitability for various uses.

The decrease in water levels in rivers and lakes negatively affects their qualitative properties, impacting their uses for various purposes ,Natural inputs negatively affect agricultural, industrial, and drinking water development [1].

The development of societies, agricultural and industrial progress, and population growth have significantly contributed to increasing environmental pollution in various forms [2] Sources of surface water pollution include human activities, heavy sewage, and industrial waste [3]. Despite the importance of water for living organisms, it can sometimes cause death when contaminated by various pollutants. This leads to undesirable changes in the physical, chemical, or biological properties of water.

Study Objectives

Identify the chemical properties of water in Darbandikhan Lake within the study area and conduct a spatial and monthly comparison of the studied factors.

Water Pollution

Pollution is defined as any negative change or impact on water quality, resulting in water becoming unsuitable for aquatic life such as fish and birds that rely on water for survival. Any alteration in water composition or state is considered pollution.

Chemical pollution directly and indirectly affects water quality, negatively impacting uses such as irrigation, construction, and industry, and affecting individuals, families, and communities [4]. Types of pollution include:

Chemical Pollution: This type of pollution is among the most dangerous and widespread, primarily due to industrial development, especially in developed countries. It renders water toxic due to the presence of chemical elements such as agricultural waste, pesticides, or oil pollution. It also includes heavy metals like lead, cadmium, mercury, and organic fertilizers used in agriculture and pesticides, which reach surface water through sewage, as well as household cleaning agents entering rivers and lakes with wastewater. These elements support the growth of harmful algae and bacteria such as coliform and fecal bacteria, and algae, which rapidly proliferate and affect dissolved oxygen levels, leading to the death of crustaceans and microorganisms, as observed in the polluted Tangro River from Sulaymaniyah, carrying wastewater and industrial water before merging with Darbandikhan Lake.

Physical, Chemical, and Ionic Properties of Water

The chemical properties of water are essential for determining its quality and suitability, containing various organic and inorganic elements and compounds. Lakes contain a set of physical, chemical, and biological properties that reflect their life-supporting capacity. The chemical properties are influenced by several factors, leading to variations over different periods. Human activities and the management of lake water levels also play significant roles. The aquatic environment of the lake is influenced by rocks, soil, vegetation, and the surrounding land, as well as the volume and quality of water entering the lake, its elevation above sea level, climatic conditions, and evaporation rates, which affect dissolved salt levels and water properties [5].

Chemical Properties of Water

Knowing the chemical properties helps determine the various uses of water, including:

1. **pH:** This measures hydrogen ion activity or the degree of acidity or alkalinity, indicated by a number (7). pH is crucial for controlling coagulation, removing iron and manganese ions, and managing taste and rust [6]. pH significantly impacts different organisms, affecting the ecosystem's nature [7].
2. **Total Alkalinity (TA):** This refers to the amount of dissolved negative ions in water that resist pH changes and is a measure of water's acid-neutralizing capacity. Natural sources of water alkalinity include limestone and dolomite rocks, forming bicarbonates, carbonates, calcium, sodium, and magnesium).
3. **Total Hardness (T.H):** This is the total concentration of calcium (Ca^{2+}) and magnesium (Mg^{2+}) and bicarbonates (HCO_3^-) dissolved in water. These ions represent the majority of total dissolved solids.
4. **Sulfates (SO_4^{2-}):** These are stable compounds in water, composed of sulfur and oxygen atoms [8].
5. **Nitrates (NO_3^-):** These are negative ions produced from various sources, including agricultural activities, industrial waste, sewage, and decaying plants. Rainwater also carries atmospheric nitrogen, and nitrates are a vital nutrient for plants and alga. High concentrations can become toxic to humans and fish.
6. **Total Dissolved Solids (TDS):** This includes the total amount of organic and inorganic substances dissolved in water, expressed as Total Dissolved Solids, encompassing molecular, ionic, and particulate matter.

2. Materials and Methods

Description of Study Area: The research was conducted at the University of Tikrit, College of Education for Women, in the laboratories of the Department of Life Sciences, to study the physical, chemical, and biological properties of water in Darbandikhan Lake, Sulaymaniyah province, from September 2023 to February 2024, with one sample collected monthly.

Sample Collection: Samples were collected from 8 am to 2 pm, from September 2023 to the end of February 2024. Bottles were rinsed with sample water several times before filling with minimal air space to preserve physical and chemical properties during transport. Polyethylene bottles (2.25 liters) were used for physical and chemical tests, rinsed three times with sample water before collection. Transparent and opaque Winkler bottles (250 ml) were used for biochemical oxygen demand measurement, and pre-sterilized glass bottles (200-250 ml) with tight caps were used for bacteriological tests, transported to the laboratory in an ice-filled plastic box to maintain sample properties until analysis. If not immediately analyzed, samples were stored at 4°C for up to 24 hours, avoiding light exposure [9]. Laboratory equipment and glassware were washed thoroughly with distilled water and dried using an electric oven. Analyses were conducted in the laboratories of the College of Engineering, Chemical and Environmental Engineering Departments, University of Tikrit, and the Department of Water and Sewerage, Quality Control Section.

Statistical Analysis

The pre-packaged statistical software SPSS (Special Program for Statistical) was used.

1. Analysis of Variance (ANOVA) The ANOVA test was used to determine the presence or absence of significant differences in the measured physical, chemical, and biological properties, both spatially across station locations and temporally across months and seasons. This analysis identifies differences in the studied variables at a significance level of $P \leq 0.05$.
2. Duncan Test The Duncan test was conducted on properties that showed significant differences between study stations according to the ANOVA results. This test identifies which stations have significant differences and which do not, at a significance level of $P \leq 0.05$.
3. Pearson Correlation Coefficient This test was used to determine the magnitude of the relationship between the studied variables based on the correlation coefficient at significance levels of $P \leq 0.05$ and $P \leq 0.01$.

3. Results

1. pH : The pH values during the study period across all sample stations ranged from 6.2 to 8.88. The lowest value of 6.2 was recorded at station St1 in September 2023, and the highest value of 8.88 at station St2 in December 2023. The statistical analysis of pH values indicated significant spatial differences at the level of $P \leq 0.05$, but no significant temporal differences were observed between the study stations. Table (1) shows the pH variations during the study period. noted that the low pH value of 6.2 at station St2 in September 2023 was due to the high production of carbon dioxide and the formation of humic acids, bacterial respiration, and the decomposition of organic materials. High temperatures also reduce photosynthetic activity, leading to carbon dioxide accumulation.

The high pH value of 8.88 at station St2 in December 2023 was attributed to heavy rainfall diluting alkaline materials or dissolving carbon dioxide. pH levels can rise during the rainy season due to waste discharge into the water. The pH value in natural waters is influenced by geological factors, the balance of carbon dioxide and bicarbonate, and the presence of carbonates and bicarbonates in the water. Water level rise, storage capacity, and increased carbon dioxide from organic material decomposition and total alkalinity can cause pH fluctuations.

The current pH values align with the highest winter pH values recorded by [9] and [10], which were 8.70 and 8.35, respectively, for Dukan Lake. The lowest value of 6.2 is consistent with [11] for Tharthar Lake, which recorded 6.7, and higher than [12] for Duhok Lake, which recorded 6-7.52. The low pH value of 6.2 recorded during the study period falls within the Iraqi standards and World Health Organization limits.

Table 1. Monthly and Site Variations in pH during the Study Period (4-4)

	Sep 2023	Oct 2023	Nov 2023	Dec 2023	Jan 2024	Feb 2024	Mean
St1	6.2	6.25	8.05	8.84	-	8.2	7.508 A
St2	6.18	6.22	8.28	8.88	-	7.8	7.472 A
St3	6.44	6.18	8.02	8.53	-	8.1	7.454 A
St4	7.01	7	8.04	8.84	-	7.84	7.746 A
St5	7.03	7.01	8.05	8.06	-	7.07	7.444 A
Mean	6.572 C	6.532 c	8.088 B	8.630 a	-	7.802 b	

2. Total Alkalinity (TA) : The total alkalinity values during the study period across all sites ranged from 80 to 182 mg/L as CaCO3. The lowest value of 80 mg/L was recorded at site St1 in September 2023, and the highest value of 182 mg/L was recorded at site St5 as CaCO3 in November 2023, as shown in Table (2). The statistical analysis of total alkalinity values indicated significant spatial and temporal differences at the level of $P \leq 0.05$. The low total alkalinity value of 80 mg/L at the study site was due to high water temperatures, causing carbonate precipitation and a decrease in alkalinity concentration. The highest value of 182 mg/L was due to increased rates of organic material decomposition by bacteria, leading to higher carbon dioxide (CO_2) concentration, which raises soil pH and reduces nutrient availability (Almuktar et al., 2020). The results were similar to [13] for Darbandikhan Lake, which recorded values between 50-170 mg/L. The values were higher than [14] for Tharthar Lake, which recorded 25-125 mg/L, and lower than [15] for Duhok Lake, which recorded values between 210-880 mg/L.

Table 2. Monthly and Site Variations in Total Alkalinity during the Study Period (5-4)

Months	Sep 2023	Oct 2023	Nov 2023	Dec 2023	Jan 2024	Feb 2024	Mean
St1	80	140	140	156	-	144	132 C
St2	120	120	141	156	-	162	140 B
St3	102	100	141	152	-	142	127 C
St4	150	150	181	180	-	164	165 A
St5	160	140	182	172	-	144	127 C
Mean	122 C	130 c	124 C	163 a	-	151	

3. **Total Hardness (TH):** Our study results in Table (3) showed that the highest value recorded was 450.8 mg/L at site St5 in December 2023, and the lowest value of 92 mg/L was recorded at site St2 in September 2023. The hardness in water is due to the geological composition of the study area and the presence of multivalent ions such as calcium and magnesium, as well as low concentrations of ions like manganese and iron [16]. The highest total hardness value of 450.8 mg/L was due to soil erosion towards the lake caused by heavy rainfall and runoff, along with the presence of pollutants from human activities and wastewater from nearby homes. The lake's water was also affected by fish farming activities, which involved removing algae and plants, adding chemicals for fish feeding, and cleaning during sample collection periods. The lowest value of 92 mg/L at site St2 in September 2023 was due to low water levels, along with algae and phytoplankton growth consuming large amounts of carbon dioxide (CO_2), reducing water hardness[17]. The differences in hardness concentrations during summer and autumn were due to evaporation and variations in dissolved salts resulting from natural and human activities [18]. The main sources of total hardness are geological, such as limestone, dolomite, and gypsum, as well as the presence of carbonates, bicarbonates, chlorides, and nitrates of calcium and magnesium [19]

The current results were higher than those obtained by [20] for Darbandikhan Lake, which ranged between 51-145 mg/L, but lower than [21] and [22], which recorded values between 226-608 mg/L for Tharthar Lake and 330.5-360.6 mg/L for Habbaniyah Lake, respectively. The total hardness values were within the World Health Organization's permissible limit of 500 mg/L for drinking water.

Table 3. Monthly and Site Variations in Total Hardness during the Study Period (6-4)

Months	Sep 2023	Oct 2023	Nov 2023	Dec 2023	Jan 2024	Feb 2024	Mean
St1	96.6	230	325.2	395.6	-	386.4	287 B
St2	92	239.2	322	391	-	391	287 B
St3	92.2	234.6	276.5	335.8	-	368	261 C
St4	184	239.2	368	386.4	-	294.4	294 A
St5	161	262	370.3	450.8	-	276	304 A
Mean	125 D	241 c	332 b	392 a	-	343 b	

4. **Sulfate (SO4) :** The results shown in Table (4) for sulfate indicate values ranging from 51 to 64.4 mg/L during the study period. The lowest value of 51 mg/L was recorded at site St5 in November 2023, and the highest value of 64.4 mg/L at site St5 in September 2023, both in the same year. Sulfate showed significant spatial differences but non-significant temporal differences during the study period at the probability level of $P \leq 0.05$. The variation in sulfate concentration between study sites may be due to the geological nature of the area, which affects sulfate ion concentration through the dissolution of gypsum and anhydrite rocks. Sulfate has limited solubility in surface waters [23].

Climate changes in the second study season, such as rainfall and soil erosion, mixed lake water with soil from surrounding lands coinciding with the planting season. Human activities and biochemical sources also directly impact sulfate concentrations [24]. Rainfall on soil and the presence of sulfate bacteria consume sulfate and release hydrogen sulfide gas (S2H), while sulfate can bind with magnesium and calcium, causing permanent water hardness and salt formation.

Our current results align with those obtained by [25] for Darbandikhan Lake, which recorded sulfate concentrations between 53-81 mg/L. Higher values were recorded for Darbandikhan and Dukan Lakes, which were 51-145 mg/L and 18-125 mg/L, respectively, within the permissible sulfate limit for Iraqi drinking water of 250 mg/L. Recorded higher values of 114-588 mg/L, exceeding the permissible limit, indicating that Tharthar Lake is unsuitable for drinking.

Table 4: Monthly and Site Variations in Sulfate during the Study Period (7-4)

Months	Sep 2023	Oct 2023	Nov 2023	Dec 2023	Jan 2024	Feb 2024	Mean
St1	56.2	63.4	55	51.57	-	58.97	57.0 A
St2	60	59.76	53	56.37	-	59.77	57.8 A
St3	55	62.36	54	51.77	-	61.97	57.0 A
St4	60.1	60	54	51.37	-	61.17	57.3 A
St5	64.4	62.4	51	52.97	-	61.77	58.5 A
Mean	59.1 A	61.6 a	45.4 c	52.8 b	-	60.7 a	

5. **Nitrate (NO3) :** Table (5) shows that nitrate values were similar across all sites during the study period, with the highest value of 4.287 μg/L recorded at site St4 in November 2023 and the lowest value of 2.436 μg/L recorded at site St5 in October 2023. The low nitrate values in October were due to nitrate reduction or loss as nitrogen gas (N2) by bacteria or the lake's self-purification processes, along with abundant algae and lichens on the lake surface, which utilize nitrate as a nutrient [26].

The high nitrate value of 4.287 mg/L in November 2023 was due to the removal of algae and aquatic plants, which consume nitrate, by the lake's management. The lake was converted into a fish pond, and runoff from agricultural lands with chemical fertilizers and wastewater from nearby villages increased nitrate concentrations. Strong currents mixed sediments with water [27].

The current results were higher than those recorded for Habbaniyah Lake, which ranged from 1.1-3.2 mg/L, within the permissible limit for Iraqi water. Lower values were recorded [28] for Mosul Lake, which ranged from 480-2090 mg/L, exceeding the permissible limit for Iraqi water. Higher values were recorded for Dukan Lake, which was 7.4 mg/L, within the global water standards for Iraq, which allow up to 50 mg/L. The current study showed similar nitrate concentrations across months, with significant temporal differences and non-significant spatial differences at the statistical level of $P \leq 0.05$.

Nitrate originates from natural processes such as plant decomposition and nitrogen fixation by bacteria, or from organic material decomposition releasing ammonia (NH3), which converts to nitrate [29]. Human activities, such as pollutant discharge near the lake and runoff with rainwater, significantly affect nitrate concentrations [30].

Table 5. Monthly and Site Variations in Nitrate during the Study Period (8-4)

Months	Sep 2023	Oct 2023	Nov 2023	Dec 2023	Jan 2024	Feb 2024	Mean
St1	3.751	3.652	3.612	3.559	-	3.872	3.69 A
St2	2.837	3.639	3.507	3.156	-	3.285	3.28 B
St3	2.947	3.543	3.266	3.019	-	3.434	3.24 B
St4	3.869	3.679	4.287	4.177	-	3.436	3.89 A
St5	2.789	2.436	2.816	2.625	-	3.856	2.90 C
Mean	3.24 A	3.39 a	3.50 a	3.31 a	-	3.58 a	

6. Total Dissolved Solids (TDS) : The TDS values varied between parts of the lake, as shown in Table (6). The TDS values showed significant spatial and temporal differences at the statistical level of $P \leq 0.05$. The values ranged between 164-270 mg/L, with the highest value of 270 mg/L recorded at site St5 in September 2023 and the lowest value of 164 mg/L recorded at site St2 in December 2023. The high TDS value in September 2023 was due to high temperatures, increased ion concentration, and waste discharge in the water, as the area is a tourist spot with resorts, leading to rapid organic material decomposition. In February 2024, high rainfall and fast surface runoff increased TDS [31]. The lowest TDS value in December 2023 was due to suspended solids settling and slow decomposition during this month.

The current results were similar to those recorded for Dukan Lake, which ranged between 126-299 mg/L, higher than those recorded for Darbandikhan Lake, which ranged between 90-180 mg/L, and lower than [32] for Duhok Lake, which ranged between 650-1240 mg/L.

TDS positively correlates with electrical conductivity [33] and is directly proportional to rainfall and runoff, as well as river discharge and current speed [34].

Table 6: Monthly and Site Variations in TDS during the Study Period (4-9)

Months	Sep 2023	Oct 2023	Nov 2023	Dec 2023	Jan 2024	Feb 2024	Mean
St1	206	189	175	166	-	269	201 B
St2	204	182	187	164	-	266	201 B
St3	177	181	169	171	-	264	192 B
St4	269	226	235	192	-	205	225 A
St5	270	216	213	202	-	213	223 A
Mean	225 B	199 c	196 c	179 d	-	243 a	

7. Total Suspended Solids (TSS) : The presence of suspended solids in water at varying concentrations during the study period was evident in Table (7). TSS variations were moderate across study sites and months. Suspended particles such as silt, clay, and fine particles are due to erosion and steep terrain [35]. Our current results showed significant spatial differences but non-significant temporal differences at the statistical level of $P \leq 0.05$. The lowest value of 0.334 mg/L was recorded at site St3 in November 2023, due to low water levels, reduced rainfall, and lake cleaning operations by the management, converting part of the lake into a fish pond. The highest value of 9.476 mg/L was recorded at site St5 in February 2024, due to high water levels, soil erosion, and heavy rainfall, which increased TSS concentrations in February [36]. Soil erosion from surrounding areas and human activities such as agriculture and construction contribute to TSS.

The current results were lower than those recorded which ranged between 26-38 mg/L and 145-1449 mg/L for Tharthar and Dukan Lakes, respectively. The current study values were within the WHO permissible limit for Iraqi water, not exceeding 50 mg/L.

Table 7: Monthly and Site Variations in TSS during the Study Period (4-10)

Months	Sep 2023	Oct 2023	Nov 2023	Dec 2023	Jan 2024	Feb 2024	Mean
St1	7.789	5.409	2.54	1.243	-	7.623	4.921 A
St2	6.695	3.293	2.499	1.457	-	8.024	4.394 A
St3	7.184	3.752	0.334	0.598	-	8.539	4.082 A
St4	8.412	5.421	1.458	1.238	-	9.287	5.163 A
St5	7.921	2.98	2.022	1.874	-	9.476	4.855 A
Mean	7.6 A	4.171 b	1.771 c	1.282 c	-	8.59 a	

8. Biological Oxygen Demand (BOD5) : BOD values are directly proportional to pollution and temperature. The current results in Table (8) showed values ranging between 2-6 mg/L. The lowest value of 2 mg/L was recorded in September, October, and November at sites St2, St4, St1, and St2, respectively, in 2023. The highest value of 6 mg/L was recorded in February 2024.

The low BOD value may be due to dilution, continuous purification, and natural self-purification of the lake water, which reduces and removes organic materials, especially with low lake levels [37]. The lake was cleaned, and chemicals were added to prepare it for fish farming, affecting microbial populations. BOD concentration is directly proportional to bacterial counts during the study months [38]. The highest value of 6 mg/L in February 2024 was due to high water levels, which washed organic materials, soil, and fertilizers from surrounding agricultural lands into the lake, consuming dissolved oxygen (DO) by microorganisms using organic materials, along with wastewater from nearby villages and tourist resorts [39].

The statistical analysis results at $P \leq 0.05$ indicated non-significant spatial and temporal differences. The study agreed, which recorded 2.07-6.45 mg/L which recorded 0.20-8.50 mg/L for Darbandikhan Lake, but lower than, which recorded 56-460 mg/L for BOD.

Table 8: Monthly and Site Variations in BOD during the Study Period (4-11)

Months	Sep 2023	Oct 2023	Nov 2023	Dec 2023	Jan 2024	Feb 2024	Mean
St1	5	4	2	3	-	5	3.8 A
St2	2	3	2	3	-	4	3.2 A
St3	4	4	3	3	-	4	3.6 A
St4	3	2	3	4	-	5	3.4 A
St5	4	3	3	3	-	6	3.8 A
Mean	3.6 b	3.2 B	2.6 b	3.2 b	-	4.8 a	

4. Conclusion

The comprehensive study of Darbandikhan Lake's physical and chemical properties revealed that all measured parameters remained within the permissible limits of Iraqi standards, despite slight natural and anthropogenic variations. Notably, salinity, nitrate, chloride, sodium, and potassium levels were stable, indicating no significant impact on water quality. Sulfate concentrations were low, consistent with expectations for freshwater bodies, and compliant with both national and international standards. Air and water temperature fluctuations highlighted seasonal effects, particularly during winter months when heavy rainfall, soil erosion, and rising water levels posed risks. Human activities such as construction and fish farming also influenced water properties. These findings underscore the need for ongoing monitoring and pollution prevention efforts. Further research should focus on identifying pollution sources and mitigating their impact while enhancing public awareness about water conservation and the consequences of water pollution. Implementing continuous testing and promoting preventive measures will be crucial for maintaining the lake's water quality and safeguarding public health.

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