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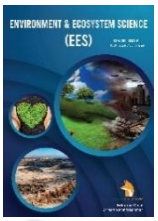

RESEARCH ARTICLE

EVALUATION OF WATER QUALITY IN DUKAN LAKE IN THE KURDISTAN REGION OF IRAQ USING THE WATER QUALITY INDEX

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ABSTRACT

Dukan Lake is a key source of drinking water for the residents of Sulaimani city in the Kurdistan Region of Iraq. Recently, concerns regarding its water quality have grown; however, there has been limited research on the lake's condition. Therefore, this study was undertaken to evaluate the water quality of Dukan Lake using the Water Quality Index (WQI). Water samples were collected from three locations in the lake during 2022 and 2023. Nine water quality parameters, namely, dissolved oxygen, biochemical oxygen demand, pH, turbidity, electrical conductivity, hardness, alkalinity, sodium, and nitrate were analyzed in the samples. It was noted that all water quality parameters, except for alkalinity and hardness, were within the permissible limits. The average WQI value was calculated to be 63, with a range between 56 and 69. All water samples fell within the "Good water" category. It is concluded that the water from Dukan Lake is safe for drinking. However, ongoing monitoring of water quality is recommended.

KEYWORDS

environmental assessment, dissolved oxygen, Dukan Lake, drinking water, environmental monitoring

1. INTRODUCTION

In order to describe how acceptable the water is for human consumption, the phrase "water quality" was created (Sajitha and Vijayamma, 2016). The physical, chemical, and biological qualities of water define its quality. Water quality monitoring is an important component of water resources management (Barzegar et al., 2020). The primary goals of water quality monitoring are to manage and reduce pollution, and supply water of adequate quality for use in a variety of applications, including irrigation and drinking water (Boyacioglu, 2006).

One of the challenges in water quality monitoring is the complexity of processing large volumes of data (Simeonov et al., 2002; Alobaidy et al., 2010). There are various methods for analyzing data on water quality, and they differ based on the goals of the study and the types of samples. One of these methods is the Water Quality Index (WQI), which condenses large amounts of data on water quality into basic terms (such as excellent, good, and bad). Hence, since the WQI was introduced, water quality science has advanced significantly.

Iraq was rich in its water resources relative to its neighboring countries. In the 1980s, the three neighboring countries Syria, Turkey, and Iran began to build dams on Euphrates and Tigris Rivers. These dams significantly lowered the flow of the two rivers and severely deteriorated the quality of the water (Abd-El-Mooty et al., 2016). Global climate change, a decline in annual precipitation rates, and inefficient water use planning inside Iraq are further factors contributing to the degradation of water quality (Hama-Aziz, 2022). Water and its management need to be prioritized by the government of Iraq and the Kurdistan Regional Government, as it is essential to alleviating poverty and hunger, ensuring environmental sustainability, and contributing to the nation's sustainable growth.

Dukan Lake serves as the main supply of drinking water for the roughly 1 million residents in the Sulaimani governorate. Complaints about the quality of the water coming from the lake have recently increased. The quality of the lake, however, has rarely been investigated. Therefore, monitoring the lake's water quality is important. As a result, this study sought to evaluate the water quality of Dukan Lake through the application of the WQI approach.

2. MATERIALS AND METHODS

2.1 Study area

The study area is Dukan (or Dokan) Lake which is the largest body of water in Iraqi Kurdistan. It is situated 76 km northwest of the city of Sulaimani. It was constructed in (1954-1959) on the lesser Zab River to serve multiple purposes including, providing water for irrigation, electric generation, fishery, recreation, and preventing flooding. The lake has a volume of 6.8 billion cubic meters and a surface area that, during high and low levels, is approximately 270 km^2 and 48 km^2, respectively. The region's geology is composed of marl, calcareous rock, and limestone. The study area's climate is an Irano-Turanian with three distinct seasons: a cold winter, a moderate spring, and a hot, dry summer (Toma, 2013).

2.2 Sample collection and analysis

Three water samples from three sites of the lake were collected in February 2022. This was repeated in March 2022, January 2023, April 2023, July 2023, and August 2023 (Figure 1). The samples were collected in this manner to investigate the spatial and temporal variability of water quality. The samples were taken in 0.5L pre-cleaned, sterilized bottles and transported to the Environmental Laboratory at Sulaimani Directorate of Environment, where they were analyzed on the same day of collection. The samples were analyzed for nine physical and chemical water parameters, including dissolved oxygen (DO), biochemical oxygen demand (BOD), pH, turbidity, conductivity, hardness, alkalinity, sodium, and nitrate. Dissolved Oxygen (DO) was measured using a YSI dissolved oxygen meter. Biochemical Oxygen Demand (BOD) was determined with a BOD analyzer BD600 from Lovibond. pH and Electrical Conductivity (EC) were measured using a multiparameter instrument. Turbidity was measured with a

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turbidity meter. Hardness was determined by titrating with a standard solution of ethylenediaminetetraacetic acid (EDTA). Sodium was measured using a flame photometer. Nitrate was determined using ultraviolet (UV) spectroscopy.

Figure 1: Map showing the locations of the sampling sites in the study area.

2.3 Calculation of Water Quality Index (WQI)

To evaluate the water quality for this study, each of the nine parameters was initially assigned a weight (AW) ranging from 1 to 4, based on expert opinions gathered from numerous prior investigations. The assigned weight of 1 was seen as the least significant and 4 as the most significant. Table 1 displays the mean values for the assigned weights of each parameter as well as the sources consulted.

Table 1: Assigned weight (AW) value adopted from the literature.

Parameters	Reference Number									Mean value
	1	2	3	4	5	6	7	8	9	
DO (mg/L)	4	4	4	4	4	4	4	4	4	4.0
BOD (mg/L)	3	3	3	2	3	3	4	3	3	3.0
pH (pH unit)	4	1	4	1	1	1	4	1	1	2.0
Turbidity (NTU)	2	2	2	-	-	4	-	2	-	2.4
Conductivity (µS/cm)	2	4	2	-	1	4	4	2	-	2.7
Hardness (mg/L)	1	1	1	-	1	1	2	1	-	1.1
Alkalinity (mg/L)	1	-	1	-	-	-	3	-	-	1.7
Na (mg/L)	-	-	-	-	-	1	-	-	-	1.0
NO_3 (µg/L)	-	2	-	3	2	2	-	2	2	2.2

1- (Dwivedi and Pathak, 2007) 2- (Pesce and Wunderlin, 2000) 3- (Pathak and Banerjee, 1992) 4- (Boyacioglu, 2007) 5- (Kannel et al., 2007) 6- (Abrahão et al., 2007) 7- (Chougule et al., 2009) 8- (Karakaya and Evrendilek, 2010) 9- (Sánchez et al., 2007)

The following equation was then used to calculate the relative weight (RW).

$$RW = \frac{AW_i}{\sum_{i=1}^{n} AW_i} \quad (1)$$

Where,

RW = the relative weight

AW = the assigned weight of each parameter

n = the number of parameters.

Table 2 lists the relative weight (RW) values and the WHO water quality standard for each parameter.

Table 2: Water quality standard, Assigned weight (AW), and Relative weight (RW) of the water quality parameters.

Parameters	Water quality standard	Assigned weight (AW)	Relative weight (RW)
DO(mg/l)	5	4.0	0.199
BOD(mg/l)	5	3.0	0.149
pH	6.5-8.5	2.0	0.1
Turbidity (NTU)	5	2.4	0.119
Conductivity(µS/cm)	250	2.7	0.134
Hardness(mg/l)	100	1.1	0.055
Alkalinity(mg/l)	100	1.7	0.085
Na(mg/l)	200	1.0	0.05
NO_3(mg/l)	50	2.2	0.109
Total		22.1	1.0

The following equation was then used to determine the quality rating scale (Q_i) for each parameter, with the exception of pH and DO.

$$Q_i = \left[\frac{c_i}{s_i}\right] \times 100 \quad (2)$$

The quality rating for pH and DO ($Q_{pH, DO}$) was calculated as follow,

$$Q_{pH,DO} = \left[\frac{c_i - v_i}{s_i - v_i}\right] \times 100 \quad (3)$$

where,

Q_i = the quality rating.

C_i = the parameter's value for water quality as measured by laboratory analysis

S_i = value of the water quality parameter determined by the Iraqi or WHO standard for the relevant parameter

V_i = the ideal value, which is 14.6 for DO and 7.0 for pH.

Finally, following the equations below, the sub-indices (SI_i) were generated for each parameter, and then used to compute the WQI.

$$SI_i = RW \times Q_i \quad (4)$$

$$WQI = \sum_{i=1}^{n} SI_i \quad (5)$$

According to Ramakrishnaiah et al. (2009), the computed WQI values were divided into five categories for human consumption, as shown in Table 3.

Table 3: Grade of water quality index (WQI) and the statue of water quality (Ramakrishnaiah et al., 2009).

Water Quality Index level	Description
Less than 50	Excellent
50 to 100	Good water
100 to 200	Poor water
200 to 300	Very poor (bad) water
More than 300	Unsuitable (unfit) for drinking

3. Results and Discussion

3.1 Water quality parameters

Dissolved oxygen (DO) is perhaps the most important parameter for water quality assessment as it was shown in Table 1 in which all references in the literature assigned a maximum weight of 4. The infiltrated water body's atmospheric oxygen serves as a source of DO, and water plants can also release DO through photosynthesis. To a human, DO should not be less than 6 mg/l, and for aquatic life such as fishes DO should not be less than 4 mg/l (Tai et al., 2011). The reported mean value of 8.4 mg/l in this study was above those levels, indicating good water quality condition (Table 4). The result of DO in study is comparable to the result of a study in which a range of 5-9.5 mg/l for DO of Dukan Lake was reported (Toma, 2013).

Table 4: Data of water quality parameters of Dukan Lake in the sampling campaigns.

Water quality parameters	February 2022			March 2022			January 2023		
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
DO (mg/l)	9.2	9.2	9.7	8.4	8.1	7.76	9.3	9.3	8.7
BOD (mg/l)	0.75	0.75	0.75	0.84	0.84	0.84	0.2	0.2	0.2
pH	7.3	7.2	7.21	7.0	7.0	7.05	8.1	8.2	8.3
Turbidity (NTU)	0.02	0.02	0.02	0	0	0	0	0	0
Conductivity (µS/cm)	285	250	235	257	212	219	311	308	302
Hardness (mg/l)	215	190	210	164	163	156	175	180	180
Alkalinity (mg/l)	280	284	268	290	270	260	120	120	120
Na (mg/l)	5	5	5	9	8	9	13	14	12
NO_3 (mg/l)	4.7	4.1	4.6	6.5	4.6	4.44	3.30	3.40	3.20

Water quality parameters	April 2023			July 2023			August 2023			Mean
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	
DO (mg/l)	8.85	9.5	9.1	6.60	6.8	6.33	7.9	7.7	8.11	8.4
BOD (mg/l)	0.9	1.3	1.11	1.15	1.2	1.1	0.6	0.6	0.5	0.8
pH	8.24	8.13	8.36	8.50	8.46	8.42	8.45	8.51	8.48	7.9
Turbidity (NTU)	0	0	0	0.00	0	0	0	0	0	0.0
Conductivity (µS/cm)	295	262	306	220	222	224	155	162	158	244
Hardness (mg/l)	180	180	160	120	120	124	105	110	110	158
Alkalinity (mg/l)	140	150	140	122	135	127	140	123	130	179
Na (mg/l)	6	6	6	6	5	5	5	6	6	7.3
NO_3 (mg/l)	10.25	10.50	10.20	12.50	13.00	12.20	4.30	4.60	4.20	6.7

The Biochemical Oxygen Demand (BOD) is also one of the most popular parameters for evaluating water quality. It shows the amount of oxygen needed by bacteria and other microbes during the aerobic decomposition of organic materials. A BOD value of less than 3 mg/l is typical for unpolluted water, but values exceeding 5 mg/l suggest potential pollution. The mean value of BOD of 0.8 mg/l recorded in this study was far below these critical values, again indicating good water quality condition. The BOD value in this study is also lower than the mean value of 3.2 mg/l measured in Dukan Lake in 2008 and 2009 by Alobaidy et al. (2010).

pH is another important parameter for water quality assessment. pH levels that are less than 8 are preferred for chlorine disinfection, however water with pH less than 6.5 is more likely to be corrosive. Hence, the range of 6.5–8.5 is ideal. In this study, the mean value of pH was 7.9 which was within the permissible range of 6.5-8.5. The mean value of turbidity was 0.0 NTU which was within the standards of 5 NTU for drinking water.

Electrical conductivity is a measure of cations in water. It can greatly affect water taste and thus can significantly impact the suitability of water for drinking (Pradeep, 1998). High conductivity can result from anthropogenic sources, such as industrial and sewage discharge, or it can result from the natural weathering of some sedimentary rocks. The current investigation indicated that the mean value of EC was 244 µS/cm which was slightly lower than the permissible level of 250 µS/cm.

Total hardness is a key indicator of water quality, regardless of whether the water is intended for drinking, industrial, or agricultural use (Alobaidy et al., 2010). It is a common way to gauge how well water reacts with soap, hard water needs significantly more soap to create lather than soft water. It is measured in milligrams of calcium carbonate per liter. The observed mean value of hardness was 158 mg/l which was above the permissible level of 100 mg/l. According to a study, Dukan lake is classified as a very hard water, perhaps due to the presence of limestone and chalk rocks

beneath and surrounding the lake (McGowan, 2000). The mean value of alkalinity was 179 mg/l which was higher than the permissible level of 100 mg/l recommended by WHO. Hence, Dukan Lake is alkaline water. This was supported by a slightly alkaline pH value (i.e. 7.9) and a high value of the total hardness. This is again likely due to the presence of limestone and chalk beneath and surrounding the lake.

Sodium (Na^+) is an essential element for the human body for a number of processes, including the health of muscles and nerves. Nonetheless, a high Na+ concentration could cause blood pressure to rise and thus accelerate the rate of kidney injury (Batool et al., 2018). The mean value of Na^+ observed in this work was 7.3 mg/l which was far below the permissible level of 200 mg/l. Another crucial factor for determining the quality of water is nitrate (NO_3). It's concentration shouldn't be high in drinking water because it can lead to a number of illnesses, including hypertension, stomach cancer, goiter, and Blue Baby Disease (Majumdar and Gupta, 2000). The mean value of NO_3 was 6.7 mg/l which is much lower than the permissible level of 50 mg/l. The findings from the tests mentioned above indicated that except for Alkalinity and Hardness, the values of all other parameters were below the permissible limit.

3.2 Water Quality Index (WQI)

The calculated WQI values for the samples collected from the three sites on different sampling dates are shown in Table 5. The WQI values at all three sites across the six sampling dates were very similar, ranging from 56 to 69, suggesting that the temporal and spatial variability in water quality was minimal. The mean value of WQI was 63. According to the WQI classification in Table 2, all the water samples were classified as good, as their WQI values fell within the range of 50–100. However, this result may not fully reflect the water quality of Dukan Lake, as the samples were collected over only six months of the year. Hence, to improve the assessment of the lake's water quality, it is recommended to collect samples across all months of the year and over multiple years for a more comprehensive study. The results of this study are comparable to those of Alobaidy et al. (2010), who reported a WQI value of 84 for Dukan Lake in 2008.

Table 5: Values of calculated Water Quality Index (WQI)

Date of sampling	Location	WQI
February 2022	Site 1	69
	Site 2	65
	Site 3	62
March 2022	Site 1	65
	Site 2	61
	Site 3	61
January 2023	Site 1	60
	Site 2	61
	Site 3	63
April 2023	Site 1	67
	Site 2	65
	Site 3	68
July 2023	Site 1	67
	Site 2	67
	Site 3	67
August 2023	Site 1	57
	Site 2	57
	Site 3	56
	Mean	63

4. Conclusions

While concerns about water quality of Dukan Lake have risen recently, there has been limited research on the lake's condition. This study was conducted to assess the water quality of Dukan Lake using the Water Quality Index (WQI). It was observed that all water quality parameters, except for alkalinity and hardness, were within the permissible limits. The calculated WQI values for the samples were similar, ranging from 56 to 69, with an average of 63. All water samples fell within the "Good water" category. It is concluded that the water of Dukan Lake is safe for drinking. However, it is recommended to regularly monitor the water quality to detect any potential changes. Additionally, the local government should implement effective protection programs, such as regulating the excessive use of pesticides and fertilizers by farmers around the lake, managing wastewater and solid waste from surrounding villages, and providing trash bins for tourists to help prevent pollution of the lake's water.

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