EQA - International Journal of Environmental Quality
ISSN 2281-4485 - Vol. 71 (2026): 132 - 140
Journal homepage: https://eqa.unibo.it/

published by

Integrating multivariate statistical analysis and canadian water quality index to assess seasonal variation in Duhok Dam, Iraq

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Article info
Received 18/9/2025; received in revised form 15/11/2025; accepted 2/12/2025
DOI: 10.60923/issn.2281-4485/22779

Abstract
The escalating demand for freshwater resources in arid and semi-arid regions necessitates comprehensive assessments of water quality to ensure sustainable use for domestic and agricultural purposes. This study evaluated the seasonal water quality of Duhok Lake by integrating multivariate statistical techniques Principal Component Analysis (PCA) and exploratory Cluster Analysis (CA) with the Canadian Water Quality Index (CCME WQI). PCA identified five principal components explaining 92.5% of the total variance, revealing the dominant influences of domestic discharge, eutrophication driven by phosphate and phytoplankton proliferation, geological contributions, agricultural runoff, and mineral ion enrichment. CA was applied in an exploratory sense only, to visualize similarity patterns among sites, seasons, and variables. The CCME WQI classified Duhok Lake's water as marginal for both drinking (55.6) and irrigation (58.5), primarily due to elevated levels of sulfate, hardness, total dissolved solids, and magnesium exceeding WHO standards. Historical comparison over two decades revealed fluctuating trends linked to variable inflows and precipitation. These findings highlight the urgent need for continuous monitoring and integrated management strategies to mitigate emerging risks and ensure the sustainable use of Duhok Lake as a vital freshwater resource.

Keywords: *Water quality, Duhok Lake, Multivariate statistical analysis, WQI.*

Introduction

Water demand has increased worldwide with the growth of the human population, as well as agriculture, commercial, industrial, and recreational activities. Natural lakes or man-made reservoirs serve as precious freshwater resources in semiarid and arid regions (Rahman et al., 2021). Both natural processes and anthropogenic activities play the main role in the deterioration of water quality in surface water (Uddin et al., 2023). Duhok Dam, located in the Duhok Governorate of northern Iraq, is a high earth-fill structure with a central clay core and gravel shell. Initially constructed to irrigate agricultural lands extending to Summel city, the dam has evolved into a multipurpose resource. Today, it provides municipal water to Duhok City and serves as a prominent recreational area (Mustafa and Noori, 2013). It is 60 m (197 ft) in height and can withhold 52 million m^3 (42,157 acre. ft) of water. Duhok dam has a bellmouth spillway with a maximum discharge of 81 m^3/s (2,860 cu ft/s) (Al-Karai and Al-Douri, 2023). Many studies have been carried out by several investigators and covered issues related to the water quality of the Duhok Dam to know the physicochemical and phycological composition (Al-Nakshbandi, 2002); microbiological constituents (Shekha et al., 2013), trace elements (Al-Mezori and Hawrami, 2013), and nutrient trophic status (Shekha et al., 2017, Darwesh et al., 2017). However, none of these studies mentioned the use of multivariate statistical methods in their works. Multivariate statistical methods, and hierarchal cluster analysis (CA) are powerful techniques that have been used widely in recent years

DOI: 10.6092/issn.2281-4485/22779

for the evaluation of environmental systems to better understand the water quality of surface water through the interpretation of a large set of complicated data and transforming it to a small set of independent variables and drawing meaningful information (Sabri et al., 2016, Kükrer and Mutlu, 2019, Nair and Naveen, 2022, Muniz and Oliveira-Filho, 2023). In the last decade, a few articles concerning using multivariate statistical techniques for water quality evaluation in different parts of Iraq were published. It could be summarized in the works conducted by (Shekha, 2008, Shekha, 2013, Shekha, 2016, Shihab and Abdul Baqi, 2010, Salah et al., 2015, Aljanabi et al., 2023, Al-Ansari et al., 2024). The water quality index (WQI) is a powerful tool that uses large numbers of water quality data sets to transform them into a single data or simply understood terms. It can be easily communicated to the general public and those working in the water sector: planners, distributors, managers, and political decision-makers (Uddin et al., 2021, Abbasi and Abbasi, 2012). In recent years, the application of (CCME) has become most universal for the assessment, management and monitoring of water quality for various water resources (Radaideh, 2022, Hyarat and Al Kuisi, 2021). Therefore, this study aims to provide a comprehensive evaluation of Duhok Lake's water quality by integrating multivariate statistical techniques (PCA, and CA) with the CCME WQI. The objectives are threefold: (1) to identify the key pollutants and their sources through dimensional reduction of 21 variables; (2) to determine the seasonal variation in water quality and its implications for drinking and irrigation purposes; and (3) to compare the current condition with historical classifications from the last two decades, highlighting emerging risks and long-term trends.

Materials and Methods

Sample collection

Samples collection was carried out for four seasons in 2024 from three sites of Duhok Dam (Table 1 and Figure 1). Collected water samples were kept at 4 °C and immediately transported to the laboratory for processing and analysis. Water quality variables were analyzed, including twenty-one parameters, according to (Rice et al., 2017, Mackerth, 1978) (Table 2).

Statistical analysis

All data interpretation and statistical calculations were done using IBM SPSS Version 26. The data sets of Duhok dam surface water were subjected to multivariate techniques, including Cluster Analysis (CA) and Principal Component Analysis (PCA), after standardization of data Log10(x+1) to meet the assumptions of normality and homogeneity of variances (Greenacre et al., 2022). The component loadings were marked as strong (PC> 0.75), moderate (0.75>PC> 0.5) and weak (PC<0.5), corresponding to absolute varifactors values (Kherif and Latypova, 2020). Principal Component Analysis (PCA) is a widely used method designed to transform an original data set into new, smaller, uncorrelated variables (called Principal Components, PCs), which are linear combinations of the original variables (Bollen et al., 2009). PCA supplied information on the most meaningful parameters , which describe the whole data set, affording data reduction with minimum loss of original information (Vega et al., 1998). Cluster analysis (CA) is a useful tool whose purpose is to assemble objects based on the characteristics they possess (Vega et al., 1998) Hierarchical agglomerative CA, is the most widely used; it provides intuitive similarity relationships between any one sample and the entire data set, and is typically illustrated by the dendrogram (Mardia et al., 2024). In the present investigation, to measure similarity, hierarchical agglomerative CA was performed on the normalized dataset using the Wards method using squared Euclidean distances. Ordination methods such as PCA and CA like Wards sum of squares, are complementary (Dalmaijer et al., 2022).

Table 1. *Represent geographical coordinates for the studied sites:*

Sites	Latitude	Longitude
S1	36°52'42.9"N	43°00'01.4"E
S2	36°52'48.4"N	43°00'18.4"E
S3	36°52'54.0"N	43°00'31.1"E

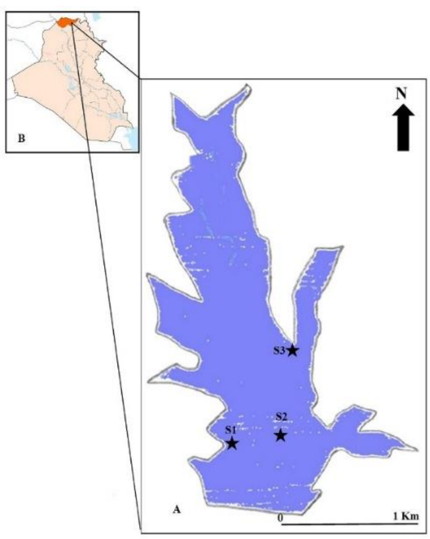

Figure 1
Map Shows:
A- Location of Duhok City in northern Iraq,
B- Duhok Lake and the studied sites.

DOI: 10.6092/issn.2281-4485/22779

Table 2
Analytical methods were used to determine water quality variables at the Duhok dam.

Water variables	Units	Analytical Procedures
pH		pH meter (Philips 9420)
Electrical conductivity	EC ($\mu S.cm^{-1}$)	EC meter (WTW D 8120)
Total dissolved solids	TDS ($mg. l^{-1}$)	EC-TDS meter
Total alkalinity	HCO_3 ($mg\ CaCO_3.l^{-1}$)	Titrant with HCl
Total hardness	($mg\ CaCO_3.l^{-1}$)	Na_2EDTA titrant
Calcium	Ca ($mg\ CaCO_3.l^{-1}$)	Na_2EDTA titrant
Magnesium	Mg ($mg\ CaCO_3.l^{-1}$)	Na_2EDTA titrant
Sodium	Na ($mg. l^{-1}$)	Flame photometer
Potassium	K ($mg. l^{-1}$)	Flame photometer
Chloride	Cl ($mg. l^{-1}$)	Argentometeric
Sulphate	SO_4 ($mg. l^{-1}$)	Titrant method
Dissolved oxygen	DO ($mg. l^{-1}$)	Winkler azide modification
Biochemical oxygen demand	BOD_5 ($mg. l^{-1}$)	Winkler azide modification
Nitrite	NO_2 ($\mu g. l^{-1}$)	Azo-dye
Ammonium	NH_4 ($\mu g. l^{-1}$)	Indophenols blue
Total dissolved nitrogen	TDN ($\mu g\ N.l^{-1}$)	Potassium persulphate digestion
Phosphate	PO_4 ($\mu g\ PO_4.l^{-1}$)	Ascorbic acid reduction
Total dissolved phosphate	TDP ($\mu g\ P.l^{-1}$)	Potassium persulphate digestion
Chlorophyll a	($\mu g. l^{-1}$)	Acetone extraction
Phytoplankton	($Cells.l^{-1}$)	Membrane filtration 0.45μm

CCMEWQI calculation

In this study, CCME WQI was applied to assess the water quality of Duhok Lake during four seasons in 2011. For the calculation of CCME WQI, the following formula was used, and a detailed description of the formula is found in the Canadian WQI 1.0 Technical Report (CCME, 2001).

$$CCME\ WQI = 100 - \frac{\sqrt{F1^2+F2^2+F3^2}}{1.732} \quad [1]$$

In which:
F1 (Scope) = the percentage of variables that does not meet the objective (failed variables).
F2 (Frequency) = Individual tests percentage that does not meet the objective (failed tests).
F3 (Amplitude) = It represents the amount of failed tests values does not meet the objective.

Results and Discussion

Water quality parameter analysis

PCA was conducted on standardized data for 21 variables across four seasons at three different sites, resulting in five factors that explained more than 92.5% of the total variance in the water quality dataset, as shown in Table 3. The first component (PC1) accounts for 42% of the total variance in the dataset, exhibiting a strong positive loading on water temperature, EC, TDS, and NH_4, and a negative moderate loading on DO and K^+. This is related to domestic discharge (Tan et al., 2018) explained that an increase in lake water temperature causes a decrease in DO content. However, it has led to an increase in EC and TDS values. The second component (PC2) accounted for 22.3% of the variance, and it was strongly weighted on phytoplankton, PO_4, pH and moderately negatively loaded to DO, SO_4, and Na^+ (Fig.1). The component reflects the influence of phytoplankton growth (eutrophication) with phosphate content in water. Duhok Lake was classified as an eutrophic lake status according to previous studies (Shekha et al., 2017, Darwesh et al., 2017) that had a relatively decreased DO content of water. Component three (PC3) is explained by 12.4% of total variance with positively strong loading to Ca^{2+}, HCO_3, moderately to Cl^-, TDN, and SO_4, and negatively loaded to BOD5. This may contribute to the geological composition of the area and fertilizer runoff from agricultural activities. Mu et al. (2015) stated that water samples rich in some ions, such as Ca^{2+}, and HCO_3, reflect chemistries naturally obtained by the dissolution of carbonate-rich sediments of the Lake. Component four (PC4) demonstrated 9.15 % of the total variance of 92.5% with positive loading of chlorophyll a, TDN (Fig. 2). This indicates the dischar-

DOI: 10.6092/issn.2281-4485/22779

ge of agricultural activities that enhanced phytoplankton growth and increased chlorophyll a content. Component five (PC5) extracted 6.5% of the variance with strong positive loading on hardness, Mg^{2+}, and TDP, representing the influence of water quality by runoff from surrounding agricultural cropland rich with hard-ness-related ions and nutrients.

Table 3. *Eigenvalue and percentage of variance are explained by each of the five principal components loading values for the water quality variables of Duhok Lake.*

Variables	PC1	PC2	PC3	PC4	PC5
Eigenvalue	8.825	4.692	2.614	1.923	1.378
% Total variance explained	42.024	22.342	12.448	9.158	6.563
% Cumulative variance	42.024	64.366	76.814	85.972	92.534
Rotated factor correlation coefficients					
Water temperature	0.895	0.189	-0.076	0.335	-0.157
pH	0.564	0.783	-0.108	-0.069	-0.129
EC	0.833	0.417	-0.245	0.214	-0.094
TDS	0.813	0.429	-0.329	0.147	-0.007
HCO_3^-	-0.455	-0.260	0.782	0.240	-0.041
Hardness	-0.115	0.119	0.131	0.001	0.964
Ca^{2+}	-0.460	-0.193	0.818	0.002	-0.178
Mg^{2+}	0.118	0.314	-0.412	-0.136	0.779
Na^+	-0.210	-0.745	0.401	0.279	0.112
K^+	-0.607	-0.087	-0.005	-0.758	0.099
Cl^-	0.421	-0.106	0.709	0.119	-0.387
SO_4^{2-}	-0.191	-0.650	0.642	-0.289	0.147
DO	-0.532	-0.559	0.583	0.095	-0.047
BOD_5	0.349	0.173	-0.705	0.276	-0.370
NO_2^-	-0.038	0.445	0.349	-0.764	-0.085
NH_4^+	0.948	-0.034	-0.101	-0.097	0.024
TDN	0.211	-0.260	0.556	0.678	-0.046
PO_4^{2-}	0.088	0.826	-0.192	-0.486	0.006
TDP	-0.075	-0.296	-0.033	-0.100	0.885
Chlorophyll a	0.015	-0.037	0.078	0.885	-0.168
Phytoplankton	0.117	0.912	-0.140	0.007	0.235

Note: Strong loading (PC> 0.75), bold font; moderate loading (0.75 >PC> 0.5), italic font and weak loading (PC<0.5) underlined font.

Cluster analysis

Sites 2 and 3 showed greater similarity, which is likely due to their shared exposure to domestic and agricultural inputs, as indicated by the dendrogram of spatial similarity (Fig. 3). It is important to note that CA was used in this study as an exploratory tool to visualize similarity patterns among sites, seasons, and variables. Formal testing of differences among predefined groups (e.g., sites or seasons) would require methods such as ANOVA or non-parametric equivalents, which may be considered in future research. In contrast, Site 1 appeared more distinct, which may be related to localized hydrological conditions. While for temporal similarity, as shown in (Fig. 4), the autumn samples were separately clustered, resulting from stronger climatic and anthropogenic influence during. this period. However, samples from the spring and summer were grouped (especially water temperature, EC, TDS, HCO_3, Na, SO_4, BOD_5 and NH_4), indicating similar water quality in warmer climates. The intermediate position of winter samples was consistent with rainfall-associated dilution. The variables similarity cluster (Fig. 5) shows more distinct groupings. The clustering of phytoplankton density highlights its significant ecological importance as a biological outcome as rather than a chemical measure. Hardness and mineral-related ions (such as Ca^{2+}, Mg^{2+}, and SO_4^{2-}) were grouped in the first subgroup of the main cluster, indicating strong geochemical control from agricultural runoff and watershed geology. The majority of the remaining variables were found in the second grouping, suggesting a complex interaction between physical factors, organic matter, and nutrients.

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DOI: 10.6092/issn.2281-4485/22779

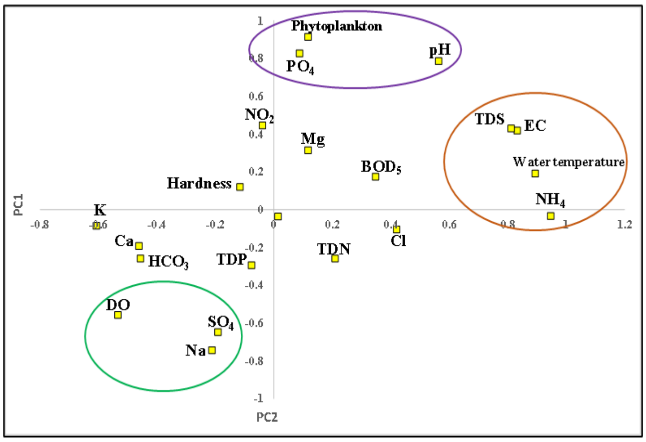

Figure 1. *Principal components scatterplot for water quality variables of Duhok Lake.*

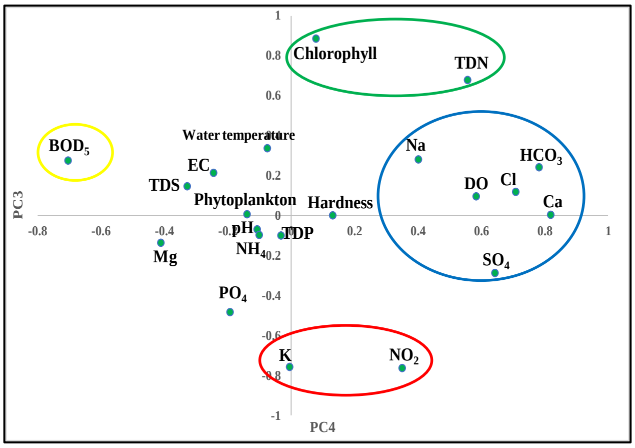

Figure 2. *Principal components scatterplot for water quality variables of Duhok Lake.*

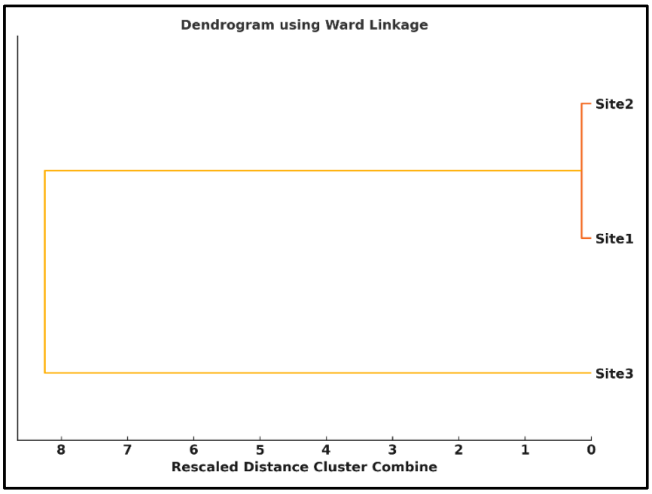

Figure 3. *Similarity dendrogram among studied sites for Duhok Lake from cluster*

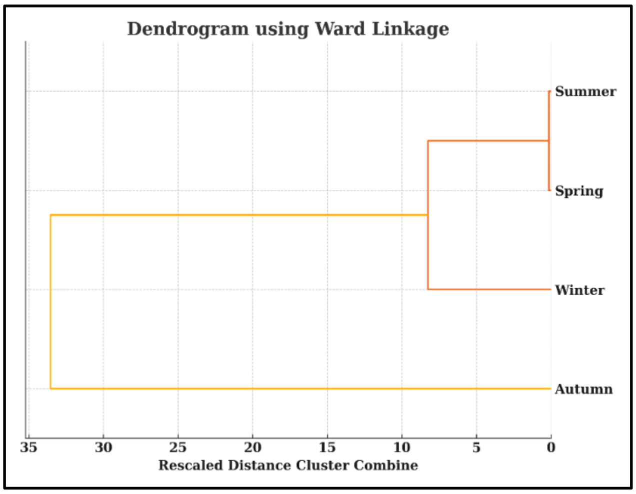

Figure 4. *Similarity dendrogram among studied seasons for Duhok Lake from cluster*

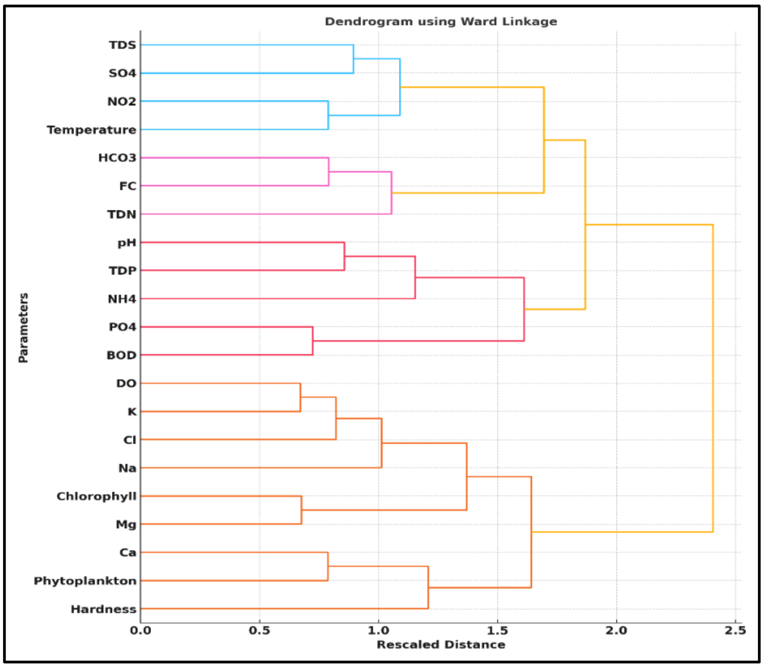

Figure 5
Similarity dendrogram among water quality variables for Duhok Lake from cluster analysis.

DOI: 10.6092/issn.2281-4485/22779

As shown in Table 4, the CCME WQI value (55.6) for Duhok Lake is ranked as a marginal type for drinking purposes: water quality is frequently threatened or impaired; conditions often deviate from desirable or natural levels. This may be attributed to many variables that exceeded the guidelines (Objective), mainly the hardness and sulphate, TDS, and magnesium ion. On the other hand, the water quality index value for irrigation purposes (58.5) (Table 5) is ranked as a marginal type, with the condition departing from natural or desirable levels (CCME, 2001). The very high level of SO_4 in Duhok Lake exceeded the objective by more than four times its natural level (Ayers and Westcot, 1985) is the main reason behind the deterioration of the water quality. (Shekha et al., 2017) during their work, the same Lake classified the water quality of Du-

Table 4. *Physical-chemical properties of Duhok Lake, with sets of standards for drinking purposes. The bold values do not meet the standard values.*

Variables	Winter	Spring	Summer	Autumn	Drinking water standards (WHO, 2022) ($mg.l^{-1}$)
pH	8.14	8.08	8.115	8.24	6.5- 8.5
EC ($\mu S.cm^{-1}$)	973.75	957	966.9	1040	1000
TDS ($mg. l^{-1}$)	639	614	614	686	500
HCO_3 ($mg\ CaCO_3.l^{-1}$)	165	158	169	159	200
Hardness ($mg\ CaCO_3.l^{-1}$)	380	398	395	385	200
Ca ($mg\ CaCO_3.l^{-1}$)	78	74	82	70	100
Mg ($mg\ CaCO_3.l^{-1}$)	51	49	49	52	30
Na ($mg. l^{-1}$)	75	78	81	77	200
K ($mg. l^{-1}$)	9.9	9.7	10.5	9	10
Cl ($mg. l^{-1}$)	35	28	37	33	250
SO_4 ($mg. l^{-1}$)	480	515	530	460	250
DO ($mg. l^{-1}$)	5.5	5.2	5.7	4.5	5
BOD_5 ($mg. l^{-1}$)	1.52	1.65	1.4	1.42	3
NO_2 ($\mu g. l^{-1}$)	0.65	0.67	0.92	0.69	2
NH_4 ($\mu g. l^{-1}$)	17.9	20	19	24	3
F1= 53.3	F2= 41.6	nse=0.58	F3= 36.7	WQI= 55.6	Marginal water Type

Table 5. *Physical-chemical properties of Duhok Lake, with sets of standards for irrigation purposes. The bold values do not meet the standard values.*

Variables	Winter	Spring	Summer	Autumn	(Ayers and Westcot, 1985), Irrigation standards ($mg. l^{-1}$)
pH	8.14	8.08	8.115	8.24	6.5- 8.4
EC ($\mu S.cm^{-1}$)	973.75	957	966.9	1040	750-3000
TDS ($mg. l^{-1}$)	639	614	614	686	450- 2000
HCO_3 ($mg\ CaCO_3.l^{-1}$)	165	158	169	159	120- 180
Ca ($mg\ CaCO_3.l^{-1}$)	78	74	82	70	100-200
Mg ($mg\ CaCO_3.l^{-1}$)	51	49	49	52	30-60
Na ($mg. l^{-1}$)	75	78	81	77	70-180
K ($mg. l^{-1}$)	9.9	9.7	10.5	9	5.00-20.00
Cl ($mg. l^{-1}$)	35	28	37	33	140
SO_4 ($mg. l^{-1}$)	480	515	530	460	30-90
NO_2 ($\mu g. l^{-1}$)	0.65	0.67	0.92	0.69	<5
NH_4 ($\mu g. l^{-1}$)	17.9	20	19	24	<5
TDN ($\mu g. l^{-1}$)	36.55	43	33.5	46.77	1.00-10.00
TDP ($\mu g. l^{-1}$)	3.5	7.1	3.52	3.7	0.1-0.4
F1= 28.57	F2=28.57	nse=1.47	F3= 59.5	WQI= 58.5	Marginal water Type

DOI: 10.6092/issn.2281-4485/22779

hok Lake as an excellent type for irrigation purposes by using the irrigated water quality index proposed by (Maia and Rodrigues, 2012). This variation in water quality classification may be attributed to the nature of the used index. IWQI depends mainly on EC values to be used as a reference to calculate IWQI for the temporal and spatial variation of water sources. Table 6 shows the water quality in the Dohuk Dam for drinking and irrigation purposes. The water quality index was measured according to the Canadian index. The data were taken from previous research over 25 years, where clear changes in the lake's water quality were observed. This is due to several factors, including the quality of the water entering the dam and the variations in the amount of precipitation, which affect the water's physico-chemical characteristics, reflecting the water quality changes.

Table 6. *Represent values for water quality for the Duhok dam for more than two decades for drinking and irrigation purposes, depending on the CCMEWQI calculation.*

	Duhoki (1997)	Toma (2012)	Kheder (2014)	Mohammed and Bamarni (2019)	Qaseem et al. (2022)
Drinking	57	53	71	46	76
Category	Marginal	Marginal	Fair	Marginal	Fair
Irrigation	64	72	90	64	77
Category	Marginal	Fair	Good	Marginal	Fair

Conclusions

This study assessed the seasonal water quality of Duhok Lake using a combined approach of multivariate statistical techniques and the Canadian Water Quality Index (CCME WQI). The analysis of 21 physicochemical and biological variables across four seasons revealed that water quality is significantly influenced by both anthropogenic and natural sources, including domestic sewage, agricultural runoff, and the local geological composition. Principal Component and Cluster Analysis identified sulfate, TDS, hardness, and nutrients (particularly phosphate and ammonium) as key contributors to water quality deterioration. The CCME WQI values (55.6 for drinking and 58.5 for irrigation) indicated a marginal classification, revealing that the lake water frequently fails to meet established standards. Compared to earlier studies that used other indices, such as IWQI and reported better water quality, our findings reflect a decline, most likely due to increased pollutant load and expanding human activities in the watershed. These results demonstrated the urgent need for improved monitoring programs, enforcement of water quality regulations, and investment in treatment technologies. Future studies should expand the scope of assessment by including microbial and emerging contaminants, as well as modeling the long-term effects of climate variability and land use on water quality trends.

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