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Original Article

Water Quality Assessment of Dewana and Darbandikhan Reservoirs for Drinking Purposes

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ABSTRACT

People living in Darbandikhan city have lacked access to basic drinking water services since many years. This research aimed to examine water quality of the Dewana and Darbandikhan Reservoirs in Darbandikhan city for drinking purposes, since there are no studies assessing both water reservoirs in this city. The samples were taken from various points in each of the reservoir with three replications each month during 2023. The evaluation of water quality depended on utilizing three indices which are: the water quality index (WQI), Heavy metal pollution index (HPI), and Metal pollution index (MI). The WQI index calculated using physicchemical parameters including (pH, turbidity, Electric conductivity, Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, HCO_3^{-}, SO_4^{2-}, and Cl^{-}). Also, the HPI and MI models calculated using several heavy metals (Co, Ni, Cr, Mn, Zn, Al, Fe, and Pb) which analyzed by using ICP. The obtained results of WQI for both reservoirs' water found to be unsuitable for drinking purposes. Based on the HPI model, the results showed that water in Dewana Reservoir is proper for drinking, and the quality of water fall under the (Low polluted) class; while, the Darbandikhan Reservoir water is unsuitable for drinking purposes, and falls under the (High polluted) category. The scenario is the same for the MI model; all the water samples in Dewana Reservoir were of purified quality; however, all the water samples in Darbandikhan Reservoir were strongly affected by the heavy metals.

Keywords: Dewana Reservoir, Darbandikhan Reservoir, Drinking purposes, Metal index MI, Heavy Metal Pollution Index IP.

1 Introduction

Generally, water quality defined by its physical characteristics (odour, colour, and taste), chemical characteristics (EC, pH, total hardness, turbidity, presence of heavy metals) and biological characteristics. Many forms of WQI have been proposed to represent the quality of water sources based on physicchemical and biological parameters [1]. Based on the data of water quality in the evaluation of drinking water, decision-making is a crucial issue. In the past, the professionals of water resources were communicated their decision on the status of water quality for drinking purposes by comparing and contrasting the guideline values with the individual parameters. In contrast, this decision does not provide accurate picture of the quality of drinking water [2,3]. The WQ index is a mathematical instrument that converts complex data on water quality into an individual value that describes the status of general water quality [4-7]. Water quality indices not only used for predicting the presence of contaminants in water, but they also compare water quality from various sources and then decide the suitable usage of each water source [8,9]. The drinking water quality must meet the criteria of physicochemical contaminants and should be free of pathogens to save people's health [10-12].

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Water considered as crucial need for human life, and its quality is a concern as it links to public health directly. Therefore, monitoring water quality is a significant and the most important issue in water management which helps to identify the issues regarding contamination [13,14]. Dam reservoirs utilized for supplying water requirement for drinking, irrigation, production of energy, fish [15]. Artificial activities including the entry of wastewater, industrial effluent, livestock, residues of pesticides and fertilizers contaminate reservoir water. Also, the entry of nutrients, metals, and pollutants into water lead to cause significant issues for public health [16,17].

The Kurdistan Region in Iraq, like other parts of Iraq, suffers from a lack of water management. Although there are two dams on either side of Darbandikhan city; however, the residents still suffer from limited of clean water. The lack of good water quality in Darbandikhan District has threatened the people’s health since there are high incidences of cancer and other health issues among the residents of the studied area [18,19]. Darbandikhan reservoir is the second most prominent lake in Kurdistan Region, Northern Iraq, and currently, it is heavily polluted by municipal wastes, sewage, and solid waste; the authorities in Kurdistan Region have failed to construct a water purification project to provide the people with clean water. To protest against the lack of clean drinking water, the residents have poured out into the streets in January this year.

Recently, the majority of the studies done in Iraq to assess the drinking WQ have focused on comparing the value of parameters to the permissible limits of WQ standards. At the same time, the application of WQ indices has been barely used. Since there are little or no studies combined among the WQI, HPI and MI for this reason, this study aims to assess water quality in both dams Dewana and Darbandikhan using water quality parameters to choose the most useful source for drinking purposes in Darbandikhan District. This research adopts WQI, HPI, and MI which are widely used for assessing WQ for drinking purposes.

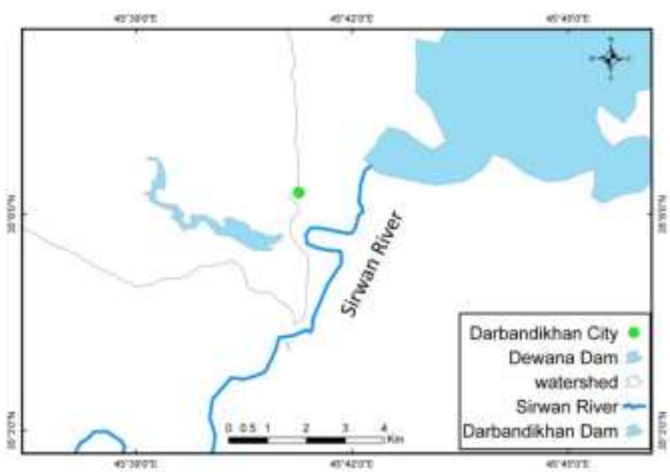

Figure 1: The study area.

2 Methods and Materials

2.1 Study Area

Darbandikhan city is 60 kilometers southeast of Sulaymaniyah city and located between (45°41'32.88"E, 35° 6'4.62"N) Southwest and (45° 39' 6.12"E, 35° 7'24.74"N) Northeast, Figure 1. The city is suffering from shortage of healthy drinking water, although it is one of the wealthiest cities in Iraq with water resources. On both sides of the city there are two dams: The Darbandikhan Dam, which constructed in 1961, and the Dewana Dam, which constructed in 2022. Darbandikhan reservoir is heavily contaminated by heavy metals and it is non-potable for drinking. The Tanjero River runs from Sulaymaniyah City. It pours into the Darbandikhan Lake, and it is the main reason for the lake's pollution as the river carries large amounts of chemical wastes from factories, hospitals, oil refineries and others.

2.2 Samples Collection and Analysis

Three samples with three replications each month from each reservoir were collected during January to December 2023; the data also were divided each three months to facilitate calculations and comparison processes. Polyethylene bottles were used for collecting the samples; also, were washed, dried, and rinsed with water in site before the process of sample collection. Then, the collected samples were stored in an ice box at 4 °C and were taken to the laboratory of University of Garmian for further analysis. Physicochemical parameters, including: pH, turbidity, Electric conductivity, Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, HCO_3^{-}, SO_4^{2-}, and Cl^{-} have been analyzed. Also, some of HM were analyzed including Co, Ni, Cr, Mn, Zn, Al, Fe, and Pb. In order to prevent the heavy metals from precipitating, samples for heavy metals were maintained separately by adding 1.0 ml concentrated nitric acid. Electrical conductivity, pH, and turbidity were estimated directly on-site using (EUTECH Instruments CD650, pH 610, and EUTECH TN 100) respectively. Bicarbonates were determined by the acid titration method. Sulfate and Chloride were determined using Ion Chromatography. Sodium, Potassium, Calcium, and Magnesium and the studied heavy metals were analyzed by (ICP). One of quality ranging methods and pollution evaluation of water resources is using some quality indices that show compound effect of physicochemical parameters. There follows an explanation of some water quality indices applied in this research.

2.3 Water Quality Index (WQI)

One of the main advantages of the WQI is finding one value that represents the interference between a large numbers of data for the studied parameters; also, it is easy to be understood by all. There are some steps of calculating drinking water quality index DWQI, which are given in the following steps:

1- Calculating the rating quality sub-index (Q_n) regarding parameters (n^{th})

$$Qn = 100\left[\frac{Vn-Vio}{Sn-Vio}\right] \tag{1}$$

Where: V_n= is each parameter’s estimated value at each station, S_n= is each parameter’s standard limit, V_{io}= is the ideal values of the parameters. For all the parameters zero (0) was taken as ideal value except for the pH parameter (7) where set as an ideal value.

2- Calculating the weight’s unit (W_n) for the monitored parameters, this is inversely proportional to the standard values (Sn).

$$Wn = K / Sn \quad (2)$$

Where: K is constant.

3- Calculating WQI from the following Equation:

$$DWQI = \sum Qn * Wn / \sum Wn \quad (3)$$

Based on its values, the WQI was classified into five classes as which are: unsuitable (≥100), Very poor (76-100), Poor (51-75), Good (26-50), and Excellent (≤25) [20].

2.4 Heavy Metal Pollution Index (HPI)

This index is utilized to evaluate WQ based on the concentrations of HMs, and was set by Mohan et al. [21]:

$$HPI = \sum_{i=1}^{n} WiQi \quad (4)$$

Where: Wi= is the weight factor for each studied parameter, it is calculated by utilizing Equation (5). Q_i= is each heavy metal's individual quality rating (i^{th}), and it is calculated by utilizing Equation (6). (n)= represents the number of studied parameters.

$$Wi = wi \, l \sum_{i=1}^{n} wi \quad (5)$$

$$Qi = \frac{[Mi - Ii]}{Si - Ii} * 100 \quad (6)$$

Where: (w_i)= is the unit weight factor for each of the studied HMs (i^{th}), and it is inversely proportional to the limit value of (S_i) as shown in Equation (7). (Mi) is each parameter's monitored value in the samples; (I_i) and (S_i) represent the limit and desirable value of (i^{th}) parameters, respectively, based on (WHO 2011) [22].

$$wi \propto = \frac{1}{Si} = \frac{K}{Si} = \frac{1}{Si} \quad (7)$$

Where: k= is the proportionality factor which is equal to (1) for all the HMs [23].

Based on its values, the HPI for drinking purposes is divided into three classes, which are: High (30≥), Medium (15-30), and Low (≤15).

2.5 Metal Index (MI)

This index is commonly used by utilizing the maximum allowed concentration (MAC), shown in Equation (5) [24].

$$MI = \sum_{i=1}^{n} Mi/MACi \quad (8)$$

WQ based on the MI value can be classified into six classes which are: seriously affected (>6), strongly affected (4–6), moderately or reasonably affected (2–4), slightly affected (1–2), purified (0.3–1), and very pure (<0.3) [25]. By evaluating the measured qualitative parameters, it could be possible to comment on the current state of both reservoirs.

3 Results and Discussions

3.1 WQ assessment using physiochemical parameters

Ten parameters have been considered in the present study in order to evaluate water quality for drinking usage. These parameters in the water samples in both reservoirs have been evaluated and compared with the permissible values of (WHO) standards, Table 1. The results illustrated that the average values of pH in Dewana and Darbandikhan reservoirs are 8.14 and 8.44, respectively. All the samples from Dewana reservoir are within the permissible limit; however, only one sample from Darbandikhan reservoir shows higher value compared with the permissible limit. The highest allowable limit of pH in drinking water is 8.5 [9]. Discharging of pollutants from various sources into the Tanjaro River and then accumulation in the Darbandikhan reservoir is one of the main reasons for pH value fluctuations.

Increasing the concentrations of the dissolved salts leads to increase the water's electrical conductivity. The average values of electrical conductivity in Dewana and Darbandikhan reservoirs were found to be 722.6 and 764.4 µS/cm, respectively. Both reservoirs show that the EC values are slightly higher than the permissible limit (600 µS/cm), which may be a result of natural geological activities [26]. Turbidity is considered the easiest way to determine water quality for human consumption. There are many factors that affect the turbidity of water, such as (algae, silt, clay, and organic and inorganic matter). The average values of turbidity in Dewana and Darbandikhan Reservoirs were 4 and 8.74 NTU, respectively; which indicates a considerable difference between both reservoirs. The values of Cl^- and SO_4^{2-} show considerable difference between both reservoirs. The average values of Cl^- were 26.72 and 101.7 mg/l in The Dewana and Darbandikhan reservoirs, respectively. Also, the average values of SO_4^{2-} were 44.56 and 76.1 mg/l in Dewana and Darbandikhan reservoirs, respectively. The concentrations of Cl^- and SO_4^{2-} ions are within the permissible limit. Moreover, the average values of HCO_3^- were 95.29 mg/l and 190.8 mg/l in Dewana and Darbandikhan reservoirs, respectively.

The average concentrations of Ca^{2+}, Mg^{2+}, K^+, and Na^+ were 52.99, 13.64, 3.22 and 19.92 mg/l in Dewana reservoir; however, they were 65.35, 27.9, 3.75 and 147.8 mg/l in Darbandikhan reservoir. Although there are crucial differences between both reservoirs in terms of these actions, their concentrations are within the permissible limit [27]. The WQI is regarded as the most effective way to communicate water quality as it presents the overall water quality results, rather than the results for each separate parameter [28].

Table 1: The results of physiochemical parameters in both reservoirs.

Parameters-Units		Dewana					Darbandikhan				
		Dates of samples collection					Dates of samples collection				
		Jan.-Mar.	Apr.-Jun.	Jul.-Sep.	Oct.-Dec.	Ave.	Jan.-Mar.	Apr.-Jun.	Jul.-Sep.	Oct.-Dec.	Ave.
pH		8.15	7.9	8.2	8.31	8.14	8.44	8.33	8.49	8.51	8.44
Turbidity (NTU)		4.49	4.24	4.16	3.12	4	9.19	9.37	9.43	6.97	8.74
EC (µS/cm)		734.1	700.3	730.	726	722.6	768.2	771.1	756.3	762	764.4
Ca^{2+}	mg/l	53.8	47.77	55.7	54.7	52.99	66.03	69.22	67	59.15	65.35
Mg^{2+}		14.98	13.76	13.22	12.61	13.64	29.3	26.3	26	30	27.9
K^+		2.49	2.61	3.93	3.85	3.22	3.72	3.74	3.86	3.68	3.75
Na^+		20.75	20.85	18.88	19.2	19.92	154.1	145.08	141.02	151	147.8
HCO_3^-		99.9	92.88	93.41	94.97	95.29	201.73	196.62	182.96	181.9	190.8
SO_4^{2-}		41.55	44.6	43.4	48.7	44.56	90	82.31	67.05	65.04	76.1
Cl^-		30.1	27.32	24.33	25.12	26.72	101.3	106.77	103.3	95.43	101.7

Table 2: The WQ relative parameters for calculating the WQI index.

Parameters	Unit	WHO Standard	Weight of parameter
pH		8.5	0.40874
Turbidity	NTU	10	0.347429
EC	µS/cm	600	0.00579
Ca^{2+}	mg/l	75	0.046324
Mg^{2+}		50	0.069486
K^+		55	0.063169
Na^+		200	0.017371
HCO_3^-		250	0.013897
SO_4^{2-}		250	0.013897
Cl^-		250	0.013897
Total			1

3.2 WQ assessment using WQI index

WQI is a quick way to assess the overall WQ in any water body, and its relative parameters are illustrated in Table 2.

From most of the durations, the Dewana water samples indicate (Poor) water quality; however only during the duration of (April-June) Dewana water samples had (Good) water quality with a value of (43.79). While, the Darbandikhan water samples had (Very poor) water quality along the study duration. The average value of WQI in Dewana reservoir water is (51.9), this is classified under the (Poor) category; however, the average value of WQI in Darbandikhan reservoir water is (81.03), and is classified under the (Very poor) category, as illustrated in Table 3.

The results indicate that water in both reservoirs is unfit for drinking reasons without treatment, and it is strongly recommended that water in both reservoirs must be treated before use. On the other hand, the process of treating the water of the Dewana Reservoir will be easier than treating the water of the Darbandikhan Reservoir.

Table 3: Results and status of WQI.

Sample	WQI			
	Dewana	Status	Darbandikhan	Status
Jan.-March	54.07	Poor	82.94	Very poor
April-June	45.79	Good	80.25	Very poor
July-Sep.	54.27	Poor	84.53	Very poor
Oct.-Dec.	53.5	Poor	76.39	Very poor
Ave.	51.9	Poor	81.03	Very poor

Table 4: Results of HMs concentrations in the study area.

Metal	MAC/WHO (mg/l)	Dewana				Darbandikhan			
		Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Co	0.01	0.001	0.001	0.00102	0.000045	0.001	0.003	0.0016	0.00088
Ni	0.02	0.002	0.003	0.00274	0.00037	0.0028	0.005	0.0035	0.0009
Cr	0.003	0.011	0.015	0.013	0.00158	0.021	0.05	0.034	0.0147
Mn	0.02	0.005	0.008	0.0068	0.0013	0.038	0.046	0.0426	0.0034
Zn	3	0.002	0.003	0.0025	0.00048	0.01	0.013	0.0122	0.0013
Al	0.2	0.006	0.007	0.00666	0.00042	0.33	0.54	0.432	0.09
Fe	0.3	0.01	0.024	0.0144	0.0055	0.031	0.28	0.1882	0.093
Pb	0.01	0.001	0.001	0.001	0	0.003	0.014	0.01	0.0042

3.3 Heavy Metals Behavior

Eight heavy metals (Co, Ni, Cr, Mn, Zn, Al, Fe, and Pb) have been considered in this study in order to evaluate WQ for drinking usage. These HMs in water samples have been analyzed and compared to the standard values of WHO [27], Table 4.

A number of previous studies indicated that the concentrations of many heavy metals including Al, Pb, Ni, Co, Fe and Cr in Darbandikhan reservoir cross the highest permitted value for drinking purpose which set by ISQ and WHO [29,30,19,31]. Usually, high levels of those metals can be found in water resources that are closed to industrialized areas. However, there are no studies regarding the assessment of Dewana reservoir water quality.

Regarding the present study, the HMs concentrations in the Dewana Reservoir water were within the permissible limit based on (WHO) standards for drinking uses [32]. While, some metals showed high concentrations in the Darbandikhan Reservoir water. The Fe concentration in one sampling station exceeded the maximum allowable concentration (MAC) 0.3 mg/l which set by WHO [22]. Fe is considered one of the natural elements of the earth's crust, and it is presented in water bodies as a result of weathering of the rocks that contain high quantities of iron [3334]. The concentrations of manganese in all samples of the Darbandikhan Reservoir were slightly high, although their concentrations did not exceed the permissible limits. Landfill leachate, Industrial effluent, and sewage are contributing to the increase in manganese in water bodies [33-35]. Also, the concentrations of Zn in all the sampling stations in Darbandikhan Reservoir were below the MAC. Two out of five samples in the Darbandikhan water have chromium concentrations equal to MAC; however, all of the sampling stations have Co and Ni levels below the MAC in in Darbandikhan Reservoir. On the contrary, all the sample stations have aluminum concentration over the MAC. The primary source of aluminum in the surface waters are leaching from soils and weathering of rocks [36-38]. Anthropogenic activities are regarded as the major sources of aluminum existence in water. Most of the production processes, mining, motor vehicle exhaust, and waste burning are all contribute to the increase of aluminum concentration in the environment [39-41].

3.4 Calculation of HPI and MI Indices

These two models have been applied to eight heavy metal ions: Co, Ni, Cr, Mn, Zn, Al, Fe, and Pb. As shown in Table 5, the values of HPI illustrate that all the water samples in the Dewana Reservoir are proper for drinking. The values of HPI ranged between 11.58 and 12.64, with a mean value of 11.98 which fall under the (Low) class. While, all the water samples in the Darbandikhan reservoir are unsuitable for drinking. The values of HPI ranged between 38.22 and 66.77, with a mean value of 54.15 which fall under the (High) class.

Table 5: Comparison and results of WQ based on HPI and MI.

Sample	Dewana		Darbandikhan	
	HPI	MI	HPI	MI
Jan.-March	11.86	0.805	38.22	5.46
April-June	12.64	0.91	52.95	4.99
Jul.-Sep.	11.58	0.8	58.65	5.7
Oct.-Dec.	11.85	0.804	66.77	5.86
Min.	11.58	0.8	38.22	4.99
Max.	12.64	0.91	66.77	5.86
Ave.	11.98	0.83	54.15	5.5

The classification of WQ based on the MI index suggests that all the water samples in Dewana Reservoir are of purified quality. In contrast, all the water samples in Darbandikhan Reservoir are of strongly affected quality by the heavy metals. All the Municipal Solid and liquid wastes are deposited in the Tanjero River Basin that contains high levels of inorganic, organic compounds, and some heavy metals which then pours into the Darbandikhan Reservoir [42].

In this study, WQI, HPI and MI provided realistic results in comparison to the raw data. Therefore, they are the best approach for the evaluation of the reservoir water quality in Darbandikhan city. In general, it can be said that according to the results of the present study and their comparison, water of the Dewana reservoir was better than the Darbandikhan reservoir in terms of quality; however, both of them have not capacity of being used directly for human consumption. The water of Dewana reservoir is also threatened to be polluted in next few years due to the dumping of approximately 60% of the wastewater that are generated from the city. Therefore, precise and continuous evaluation of water quality in both reservoirs is necessary.

Conclusion

In this paper, some WQ indices have been investigated in order to evaluate the suitability of Dewana and Darbandikhan Reservoirs' water for drinking purposes. The three conclusions are mentioned in the following:

1- Water samples according to WQI index revealed that water in both reservoirs is non-proper for drinking purposes.

2- The HPI index showed that water in the Dewana Reservoir is proper for drinking and falls under the (Low polluted) class. On the other hand, the Darbandikhan Reservoir water is unsuitable for drinking purposes, and fall under the (High polluted) category.

3- Based on metal pollution index, the results revealed that Dewana Reservoir water is pure and proper for drinking; however, Darbandikhan Reservoir water is strongly affected by heavy metals and non-proper for drinking.

This study suggests establishing a treatment plant to treat wastewater and sewage that flows into the Dewana Reservoir. Based on the results obtained, this study also recommends establishing a water treatment plant on the Dewana reservoir for drinking purposes.

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Conflict of interests

No conflict of interest.

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