Water quality monitoring of Duhok Dam (Kurdistan Region of Iraq)

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ABSTRACT

Surface water quality is a crucial factor that contributes for drinking water demand and agriculture use. In the light of progressive depletion of water quality of the Duhok dam, an investigation of major dissolved ions was performed. The main objectives were to detect the water quality condition for drinking and agriculture purposes and temporal variations of studied parameters. The water quality analysis of Duhok Dam was assessed based on 14 water quality parameters (turbidity, total dissolved solids, pH, electrical conductivity, total alkalinity, total hardness, calcium, magnesium, potassium, sodium, bicarbonate, sulfate, chloride, nitrate) which were collected monthly from two locations (91 samples from each location) for a period of 8 years between 2009 and 2017. The water quality analysis of Duhok Dam was assessed based on 14 water quality parameters. The water of study area was found to be characterized by the dominance ion of calcium and sulfate based on Piper trilinear diagram. The observed results indicated to high concentrations of electrical conductivity and total dissolved solids, sulfate and total hardness in all water samples and some concentrations exceed the guidelines prescribed by WHO in 2008. In addition, temporal variations of most parameters were observed. The quality of water is believed to be controlled by both geological formation and anthropogenic activities around the dam.

1. INTRODUCTION

Dams are one of the most significant human interventions in the water cycle which supply large amount of water for variety of human uses including drinking water supply, agriculture and recreation. They also considerably decrease the risk of floods and droughts (Odhiambo et al., 2015). However, increasing population, agricultural activities, urbanization expansion and industrialization have made water quality deterioration a serious problem and have shortened the accessibility of drinking water. Water quality is also affected by the natural contributions such as precipitation rate, weathering processes and soil erosion (Khatri and Tyagi, 2015; Issaka and Ashraf, 2017). Consequently, it is challenging to preserve water quality at an acceptable level for various purposes, primarily potability (Venkatesharaj et al., 2010).

Duhok dam is an earth-fill embankment dam built in 1988 on Duhok River with main
purpose of providing water for irrigation of agricultural land in Duhok city and area around it. Nowadays, the dam is providing water supply for drinking purposes and recreational activities (Mustafa and Noori, 2013). Water quality in Duhok Dam has suffered from remarkable stress in terms of quantity (due to drought periods and overexploitation) and quality which certainly affected by quantity and quality of supplies coming from different sources (Toma, 2013). Water quality in the dams, therefore, needs to be monitored periodically and continuously. Water quality monitoring has obtained its significance for sustainable development and appropriate management of this valuable natural resource. Assessment of physical, chemical and biological water contamination is essential for the freshwater pollution reduction.

The aims of the present study are to determine the hydrochemistry of Duhok dam and to find out the quality status of the water with reference to drinking water quality as well as irrigational purpose. Furthermore, observe the temporal variations of selected water parameters and identify the pollution sources, if obtained, at this dam.

2. MATERIALS AND METHODS

2.1. Study area

The study has been conducted in Dohuk dam situated about 2 km north of the city of Dohuk between latitudes 36°52′35″ and 36°54′21″N, and longitudes 42°59′51″ and 43°00′40″E (Fig. 1). The dam is actually a reservoir created by an earth-fill embankment dam on the Dohuk River and was completed in 1988 with the primary purpose of providing water for irrigation and for the city of Dohuk but recently used for recreational activities as well. The dam is 60 m high with the capacity of holding 52 million cubic meter of water and has a maximum discharge of 81 m$^3$. The reservoir is about 4 km long and 1.7 km wide, the total catchment area is 135 km$^2$ (Shekha et al., 2013). There are several mineral springs (Sulphur springs) that appear on the limit in the tail of the reservoir and their discharges vary seasonally and decrease considerably during dry summer period. The geological structure of catchment consists mainly of dolomite, limestone, siltstone, clay marls, and gypsum from Eocene deposits (Mohammed, 2010).

The climate of the study area is considered semi-arid which is comparable to the Mediterranean climatic condition (hot and dry summer and rainy cold winter) and partly to the Iranian climate with an influence of the relatively high altitude of the surrounding high mountains. The mean annual precipitation was approximately 587 mm for the period 2009 to the end of 2016. Rainfall storms occur between October and May, with maximum during January, February each year whereas the other months of the year are relatively dry. Another feature characterized the precipitation in the study area is its irregular yearly distribution. The temperature during winter season is at minimum (less than 1°C), whereas the maximum temperature is about 43°C during summer, with the average annual temperature of about 19.2°C (Mohammed, 2010).

2.2. Data collection

The water samples were taken at the depth of 0.2 m (to avoid scums and to give accurate results) from two locations at monthly intervals for a period of eight years from 2009 to the end of 2016. A total of 182 samples were collected from both locations and each sample kept in a 1L sterilized polyethylene bottle and stored in cold ice box at 4 °C and delivered on the same day to laboratory for analysis. The geographical location of the sampling locations is shown in Fig. 1.
The samples were analysed for 14 parameters including turbidity (TU), total dissolved solids (TDS), pH, electrical conductivity (EC), total alkalinity (TA), total hardness (TH), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), bicarbonate (HCO₃⁻), sulphate (SO₄²⁻), chloride (Cl), nitrate (NO₃⁻). Electrical conductivity (µS/cm), pH, and total dissolved solids were measured in the field with a portable multi-meter (Trans ISO 9002). All other parameters were determined in the laboratory following standard protocols. Alkalinity was determined using titration with sulfuric acid carried out in the laboratory of the Directorate of Environment of Dohuk city. Other chemical analyses were carried out using spectrophotometer and flame atomic absorption spectrometer. Precipitation samples were collected based on daily interval from fixed Dohuk dam meteorological station and water level of the dam was also measured daily during study period in order to compare with temporal variations of water quality parameters. Aquacham software, Diagramme software, and Microsoft excel and word had been used to obtain tables and figures.

3. RESULTS AND DISCUSSION

3.1. Hydrochemical characteristics and temporal variation

The pH value of aquatic system is an important indicator of the water quality and the extent pollution in the watershed area. It is a measure of the acidity intensity or alkalinity conditions of a water body (Kadhem, 2013). The pH values of water samples varied from 7.68 to 8.41 with average value of 8.1 in location 1 and from 7.7 to 8.46 with average value of 8.2 in location 2. All of the water samples are alkaline due to presence high concentration of carbonates and bicarbonates and found within the limit (6.5 – 8.5) for drinking prescribed by WHO (2008).

Electrical conductivity (EC) and total dissolved solids (TDS) are two important parameters in determining salinity hazards and suitability of water for any purposes. EC values
were in the range of 814 to 1291 μS/cm with average value of 981.7 μS/cm, and 823 to 1321 μS/cm with average value of 983.7 μS/cm for sampling location 1 and 2, respectively. TDS values ranged from 520.8 to 826 mg/l with average 628.3 mg/l and from 526.7 to 845 mg/l with average of 629.7 mg/l for sampling location 1 and 2, respectively. The highest concentrations of TDS and EC were recorded when the water level in the dam was low. Fig. 2(e) shows the temporal variations of water quality parameters of sampling location 1 compared to water level of the dam and amount of rainfall. The most desirable limit of TDS for drinking water is value less than 500 mg/l and all samples exceeded this limit, nevertheless no sample exceeds the maximum permissible level of 1500 mg/l prescribed by WHO (2008). Nutrient enrichment due to intensive agricultural practices and geological condition may enhance TDS and in turn increases the EC values since these two parameters are directly related to each other (Kannan and Joseph, 2010). The higher values of EC and TDS may also be due to semi-arid type climatic condition as well as high evaporation rate (Al-Mezori and Harami, 2013; Shekha et al., 2017).

Water clarity is expressed by turbidity. the greater the amount of suspended particles in water the murkier it appears and as a result the turbidity value will be higher. Turbidity values ranged from 0.25 to 5.9 with average of 2.6 NTU (Nephelocetric Turbidity Unit) in location 1 and ranged from 0.25 to 6 NTU in location 2. According to drinking water standard by WHO (2008), the maximum permissible level of turbidity is 5 NTU and sampled water from Dohuk dam were acceptable except for 7 and 8 samples from both locations, respectively. This could mainly be due to the level of particulate matter include sediments during intensive rainfall events.

Alkalinity of natural water is caused by bicarbonates, carbonates and hydroxides. The alkalinity content varied between 132 and 204 with average of 165.2 mg/l for location 1 and the same range for location 2 with average value of 164.9 mg/l. The alkalinity concentrations displayed no temporal variation during study period (Fig. 2(f)). All water samples exhibit alkalinity values above permissible limit of 120 mg/l prescribed by WHO (2008). The high value of alkalinity could be due to the dissolution of limestone and other carbonate minerals in the catchment area. It may also be noted that polluted water body, other anions like PO$_4$ and NO$_3$, may contribute to higher alkalinity (Kannan and Joseph, 2010).

Total hardness (TH) is an important parameter of water use for domestic purposes. According to the general guidelines for classification of water hardness as calcium carbonate; 0 to 60 mg/L is classified as soft; 61 to 120 mg/L as moderately hard; 121 to 180 mg/L as hard and more than 180 mg/L as very hard (Ramesh and Jagadeeswari, 2012). Hence, Table 1 shows that all water samples are considered as very hard since the values of total hardness ranged between 360.5 and 495.8 for location 1 and between 365.6 and 508 mg/l for location 2. The acceptable limit for domestic use is 75 mg/l. Excess hardness is undesirable mostly for aesthetic and economic reasons (Ramesh and Jagadeeswari, 2012). The main causes of water hardness is both calcium and magnesium ions.

In all water samples, calcium ion appears to be the dominant cation. The concentration of calcium ion in water ranged from 77.3 to 107.2 with average of 91.5 mg/l for location 1 and from 75.3 to 108.8 with average of 90.7 mg/l for location 2. This indicates that all water samples were above Iraqi standard value of 50 mg/l (MOE, 1998). The content of magnesium
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is comparatively less than calcium. Magnesium concentrations varied between 36.1 and 63.5 mg/l and between 35.1 and 68.8 mg/l for both locations, respectively. Of the total samples, 46% in location 1 and 44% in location 2 show concentrations outside the permissible limit of 50 mg/l. The concentrations of both Ca and Mg exhibited no temporal variation during study period (Fig. 2(a)). The high concentration of Ca and Mg is not desirable in washing, laundering and bathing. Although the sources of Ca and Mg in water body are mainly the geochemistry of the rock types, the prolonged agricultural activities prevailing in the basin may also directly or indirectly augment the concentration of both ions (Mohammed, 2010).

Sodium (Na) is one of the important naturally occurring cations and its concentration in fresh water is generally lower than calcium and magnesium. However, in the present study the average concentration of Na is comparatively higher that Mg. For aesthetic reason, the guideline value given by WHO (2008) is 200 mg/l, sodium concentrations values were found within permissible limit. Fig. 2(a) illustrates that the concentrations of Na were high during periods of low water level and concentrations reduced as water level up, possibly this could be due to the effect of dilution. Potassium concentrations were very low and vary from 4 to 8 mg/l in both locations. Parts of potassium go into clay structure and thereby its concentrations get reduced in water (Kannan and Joseph, 2010).

Bicarbonate concentrations (HCO$_3^-$) in both sampling locations were almost the same and varied from 161.04 to 248.88 mg/l, with slightly change in average values of 201.5 and 201.2 mg/l respectively. No sample exceeded the permissible limit (250 mg/l) set by WHO (2008) for drinking water. The primary source of bicarbonate in water body is the dissolved CO$_2$ in rainwater and the dissolution of carbonate minerals in the study area (Mizzouri, 2007).

Sulfate ion (SO$_4^{2-}$) was the most dominant anion with concentrations varied from 170 to 440 mg/l with average value of 280.2 mg/l in location 1 and from 163.2 to 448 mg/l with average 282.5 mg/l in location 2. Only 4.4% of samples from sampling location 1 and 6.6% from location 2 have desired concentrations for drinking water of 200 mg/l prescribed by WHO (2008). Remarkable variation of Sulfate concentrations can be observed in Fig. 2(b), the high concentrations can be seen during low water level and the concentration becoming lesser during high water level most possibly due to the effect of dilution. Sulfate ion is released to water naturally by leaching from gypsum, other common minerals and discharge of domestic sewage tends to escalate its concentration. Limestone minerals may produce level of sulfate up to 800 mg/l (Kiely, 1997). At higher concentrations, sulfate imparts a bitter taste to water and may cause laxative effects (WHO, 2004). The high content of sulfate in the study area is mainly due to geological formation. Quaternary and cretaceous aquifers within the study area produce several sulfate springs which containing large quantities of sulfate and released to the Duhok dam (Mizzouri, 2007).

Chloride (Cl$^-$) is a naturally occurring anion in all types of water. The chloride content of sampling water varied from the lowest value of 49.7 mg/l (in both locations) to the highest value of 99 mg/l (location 2). In natural water bodies, the likely sources of chloride is the leaching of chloride-containing minerals (such as apatite), inland salinity and the discharge of agricultural, industrial and domestic waste water (Abbasi, 1998). The result of this study ensures that the chloride concentrations were relatively constant and did not correspond to
different sources that could change with time (Fig.2(b)).

Nitrate (NO$_3^-$) concentrations in all the samples were found to be moderately low, with the lowest value of 0.5 mg/l and the peak value of 14.7 mg/l, but none of the samples exceeded the permissible limits of 50 mg/l for drinking water (WHO, 2008). The temporal variation of nitrate is displayed in Fig. 2(c) which indicated to the high level of nitrate during low water level in the dam and high concentration during high water level. Nitrate can reach surface water as a result of agricultural activities, from domestic waste water, and from oxidation of nitrogenous water products in human and animal excreta, including septic tank (Almasri, 2007).

### Table 1: Minimum, maximum, average and standard deviation values of water quality parameters at two locations of the Duhok dam reservoirs (91 water samples for each location).

| Parameters | Unit | Sampling location 1 | Sampling location 2 |
|------------|------|---------------------|---------------------|
|            | Min  | Max     | Av    | STD | Min  | Max     | Av    | STD |
| pH         | 7.68 | 8.41    | 8.1   | 0.2 | 7.7  | 8.46    | 8.2   | 0.2 |
| EC         | 814  | 1291    | 981.7 | 116.6 | 823  | 1321    | 983.7 | 114.1 |
| TDS        | 520.8 | 826    | 628.3 | 73.9 | 526.7 | 845    | 629.7 | 72.7 |
| TU         | 0.25 | 5.9     | 2.6   | 1.4 | 0.25  | 6      | 2.7   | 1.4 |
| TA         | 132 | 204    | 165.2 | 13.5 | 132  | 204    | 164.9 | 14.1 |
| TH         | 360.51 | 495.84 | 430.9 | 32.3 | 365.64 | 508.04 | 429.3 | 36.1 |
| Ca$^{2+}$  | 77.3 | 107.2   | 91.5  | 6.5 | 75.3  | 108.8   | 90.7  | 6.6 |
| Mg$^{2+}$  | 36.1 | 63.5    | 49.3  | 6.6 | 35.1  | 68.6    | 49.4  | 7.0 |
| Na$^+$     | 49  | 98     | 70.7  | 13.8 | 47   | 98     | 71.3  | 13.9 |
| K$^+$      | 4   | 8      | 5.8   | 0.8 | 4    | 8      | 5.9   | 0.8 |
| HCO$_3^-$  | 161.04 | 248.88 | 201.5 | 16.5 | 161.04 | 248.88 | 201.2 | 17.2 |
| SO$_4^{2-}$ | 170 | 440    | 280.2 | 64.2 | 163.2 | 448    | 282.5 | 67.9 |
| Cl$^-$     | 49.7 | 96     | 69.9  | 11.3 | 49.7  | 99     | 69.2  | 11.2 |
| NO$_3^-$   | 0.55 | 14.4   | 3.3   | 3.1 | 0.5   | 14.7   | 3.4   | 3.2 |

3.2 Water type classification (Hydrochemical facies)

Hydrochemical facies are water masses that have diverse geochemical attributes and are useful for determining the origins and distribution of both surface water and groundwater masses (Lloyd and Heathcote, 1985). In case of a clear domination of a particular cation or anion (> 50% of total cations and anions), the facies can be identified based on dominant constituents. However, if no clear-cut domination of any ion, 33% is taken as cut-off value (Saha et al., 2008).

Fig.3 clarifies the Piper trilinear diagram (Piper, 1944) for the data obtained from the chemical analysis of water samples from the study site. The diagram comprises of two lower triangles that illustrate the percentage distribution, on the milliequivalent basis, of the major cations (Ca$^{2+}$, Mg$^{2+}$, Na$^+$, K$^+$) and major anions (SO$_4^{2-}$, HCO$_3^-$, Cl$^-$, NO$_3^-$). Only one chemical water type in the study area was recognized as Ca–Mg–Na–SO$_4$–HCO$_3$ facies. This water type may, therefore, be due to the influence associated with the geology of the study area.

3.3. Suitability of water for irrigation purposes

Water in the study area is mainly used for irrigation. The irrigation water with adequate quality is very vital for attaining maximum crop productivity. In order to assess the overall irrigational water quality of the collected samples, Sodium Adsorption Ration (SAR) computed water quality parameter has been
used which is most widely applied to evaluate suitability of irrigation water. SAR is a measure of the sodicity of the soil determined via quantitative chemical analysis of water in contact with it. An excess HCO$_3^-$ ion in water reacts with Na$^+$ in soil resulting in a sodium hazard which deteriorates the soil properties by reducing permeability (Subramani et al., 2005).

SAR values were plotted against EC values (μS/cm) over the diagram to categorize analyzed water samples according to their irrigational suitability proportion. The SAR was calculated using the following equation:

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}} \quad (1)$$

Where, concentrations of all ions were expressed in meq/l. Based on the sodicity diagram the water samples were classified and shown in Fig. 4, and it is clear that all samples fall in group C3-S1 which indicated to high salinity water and low SAR. Hence, the water samples of the study site can be considered moderately suitable for irrigation.

![Temporal variation of water quality parameters for sampling location 1.](image)
Fig. 3. The Piper diagram for the water samples from the Dohuk dam

Fig. 4. Salinity diagram for water samples of two locations
4. CONCLUSIONS

The water quality of Duhok Dam has been assessed for its domestic suitability and irrigational purposes as well as temporal variation. Analysis of hydrochemical study has revealed that the water was in alkaline nature. The electrical conductivity and total dissolved concentrations of water samples were all found above permissible level of drinking purposes, however, were within the maximum desirable limits prescribed by WHO. All of the water samples were found to be very hard types in nature. Most of the water samples have been found unfit for drinking purposes due to high sulfate concentrations. The temporal variation of hydrochemical parameters was linked highly to fluctuations of water level and could also be to the climatic conditions such as rainfall. The results of chemical analysis reflect that the dominant cation in the study area was calcium and the dominant anion was sulfate that corresponds to the chemical facies of Ca–Mg–Na–SO₄–HCO₃. Based on the water quality parameters analyzed by SAR, the suitability of water for irrigation was moderate. Hence, the quality of the Duhok dam water was affected by changes in water level and anthropogenic activities, mainly agriculture surrounding the dam.

Complete and detailed quality assessment program including detection of the heavy metals (toxic elements) could be examined. Furthermore, microbiological examination of water samples should be carried out to monitor possible contamination from the waste water disposal of surrounding villages. Waste water disposal from nearby villages should be prohibited and replaced by properly designed septic tanks.

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