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Hydrochemical Assessment and Quality Classification of Water in Torogh and Kardeh Dam Reservoirs, North-East Iran

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Abstract**—**Khorasan Razavi is the second most important province in north-east of Iran, which faces a water shortage crisis due to recent droughts and huge water consummation. Kardeh and Torogh dam reservoirs in this province provide a notable part of Mashhad metropolitan (with more than 4.5 million inhabitants) potable water needs. Hydrochemical analyses on these dam reservoirs samples demonstrate that $MgHCO_3$ in Kardeh and $CaHCO_3$ and to lower extent $MgHCO_3$ water types in Torogh dam reservoir are dominant. On the other hand, Gibbs binary diagram demonstrates that rock weathering is the main factor controlling water quality in dam reservoirs. Plotting dam reservoir samples on Mg^{2+}/Na^{+} and HCO_3^{-}/Na^{+} vs. Ca^{2+}/Na^{+} diagrams demonstrate evaporative and carbonate mineral dissolution is the dominant rock weathering ion sources in these dam reservoirs. Cluster Analyses (CA) also demonstrate intense role of rock weathering mainly (carbonate and evaporative minerals dissolution) in water quality of these dam reservoirs. Studying water quality by the U.S. National Sanitation Foundation (NSF) WQI index NSF-WQI, Oregon Water Quality Index (OWQI) and Canadian Water Quality Index DWQI index show moderate and good quality.

Keywords**—**Hydrochemistry, water quality classification, water quality indexes, Torogh and Kardeh Dam Reservoirs.

I. Introduction

IN the recent decades, water shortage crisis increase dramatically as an important factor influencing our planet. As available water resources, quality and quantity have been influenced dramatically by the recent droughts, population growth and anthropogenic (irrigational, municipal and industrial) pollutants, very precise water management programs should be developed to control water crisis and prevent large catastrophe. Among various water resources, surface water is one of the main water supply originates from snow/ice melting, recent precipitation and groundwater. Surface water resources have great importance for providing water supply and river water systems returning about 35% of continental precipitation to oceans [1]. The same as other types of water resources, surface water is vulnerable to climate change and anthropogenic pollution.

Iran, with 1,648,195 km^2 area located in south-west Asia extends from 25^0 to 40^0 N and 44^0 to 64^0 E. Khorasan Razavi, the second most populated province located north-east Iran having borders with Afghanistan and Turkmenistan. Khorsan Razavi is arid and semi-arid region with average annual precipitation of 227 mm. This province consists of two large boundary basin Atrak (200 km^2) and Ghareh Ghom (254 km^2) and three inter province basins Namak desert, Central desert and East side basins (720 km^2). Surface water plays key role to provide irrigation and potable water in Khorasan Razavi province. Twenty-five main rivers exist in Khorasan Razavi and several dams have been constructed on these rivers. Kardeh and Torogh dams are the main dam reservoirs in Khorasan Razavi constructed over Kardeh and Kertyan rivers, respectively. These dams provide 20% of the potable water needs of Mashhad metropolitan with more than 4.5 million inhabitants and also irrigation water needs for nearby villages.

Kardeh dam has been constructed over Kardeh large basin with 13 rural settlements with 5,550 inhabitants. Huge amount of chemical fertilizers 2,370 tons and manure 7,110 tons used in upper hand basin adds large amount of nutrient to this dam reservoir [2]. Torogh dam, the other important dam reservoir in Khorasan Razavi province also faces water pollution as 2,200 tons of manure, 100 tons of chemical fertilizer and 2,000 liters of various poisons have been used in upper hand basin to increase cultivated land fertility [3], [4] (Fig. 1).

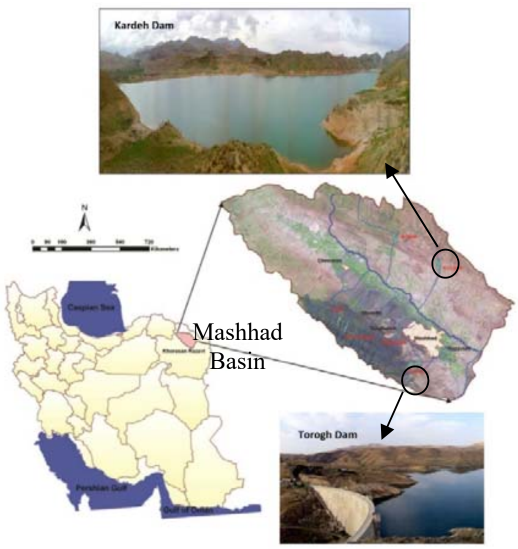

Fig. 1 Kardeh and Torogh dam reservoir position in Khorasan Razavi province and Mashhad basin

In Kardeh and Torogh dam reservoirs catchment area, three types of pollutants have been identified. Chemical fertilizers

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and manures used in upper hand basin add pollutants to the drainage system and finally dam reservoir. Waste water and sewages from rural settlements pollute surface water system and finally dam reservoirs. Garbage burying in sinkhole and caves as normal way to get rid of garbages' can also pollute surface water systems and influence dam reservoirs.

Water eutrophication normally occurs when nutrient materials containing (N and P compounds, Fe and Mn) from anthropogenic pollutions increase dramatically in the hypolimnion layer in natural lakes and dam reservoir. It causes a bad smell and taste in the water. Eutrophication increases intensively in Kardeh and Torogh dam reservoirs due to huge consummation of chemical fertilizers and detergent in upper hand basins.

The water quality indexes have great application to classify water resources based on various hydrochemical, physicochemical and biological properties [5]. Numerous scientists in various countries introduced different water quality indexes based on their requirements and their standards. The U.S. NSF revised WQI and introduced the NSF-WQI. The OWQI [6], Canadian Water Quality Index (CWQI) [7], British Columbia Water Act Quality Index (BCWAQI) [8], Malaysian Water Quality Index (MWQI) [9], Serbian Water Quality Index (SWQI) [10] and Drinking Water Quality Index (DWQI) index developed by the Canadian Council of Ministers of the Environment [11] are some of the main water quality indexes in the world.

The objective of the present study is to evaluate the quality of Kardeh and Torogh dam reservoirs by hydrochemical investigations. In addition, water quality indexes NSF-WQI, OWQI and DWQI have also been calculated in these two dam reservoirs.

II. Materials and Method

In the following study, 105 hydrochemical analyses (filed parameters, major cations and anions) of Kardeh and Torogh dam reservoirs from Khorasan Razavi Regional Water Authority archive have been studied. According to protocols of Khorasan Razavi Water Authority Hydrochemical Laboratory, filed parameters pH, Electrical Conductivity (EC) and Total Dissolved Solids (TDS) are measured in the field using pH meter 3310 WTW and Cond 3310 WTW portable tools. Two 100 ml Polyethylene bottles (one of them acidified for cation analysis) were transferred to Khorasan Razavi Regional Water Authority Hydrochemical Laboratory in Mashhad Iran for major cations and anions analyses immediately after field trips. Na^+ and K^+ were measured using Flame Photometer Sherwood 410, while SO_4^{2-}, Mg^{2+}, Ca^{2+} and Cl^- measured using Spectrophotometer model Dr 6000 and HCO_3^- and CO_3^{2-} measured using titration method.

III. Results and Discussion

Water samples in Kardeh and Torogh Dam reservoirs demonstrate mainly $MgHCO_3$ water type and to a lower extent $CaHCO_3$, while $CaHCO_3$ and to lower extent $MgHCO_3$ types are dominant in Torogh dam reservoir (Fig. 2).

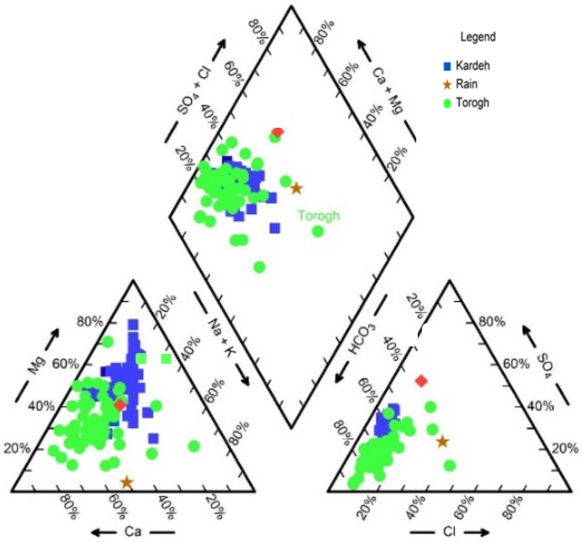
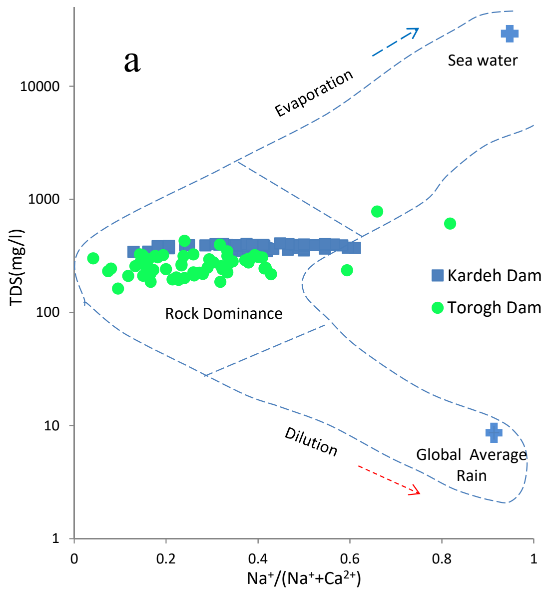


Fig. 2 Piper diagram of Kardeh and Torogh dam reservoirs

Gibbs [12] suggested diagram which provide valuable information on the importance of three main ends member of atmospheric precipitation, rock dominance and evaporation and crystallization origin. Plotting dam reservoir samples (Fig. 3) demonstrates that almost all of the Torogh and Kardeh dam reservoir samples plot in rock dominance fields, while a few of the samples plot in evaporation and crystallization dominant zone or outside of the diagram. It can be confirmed that rock dominance filed is the main source controlling water quality.



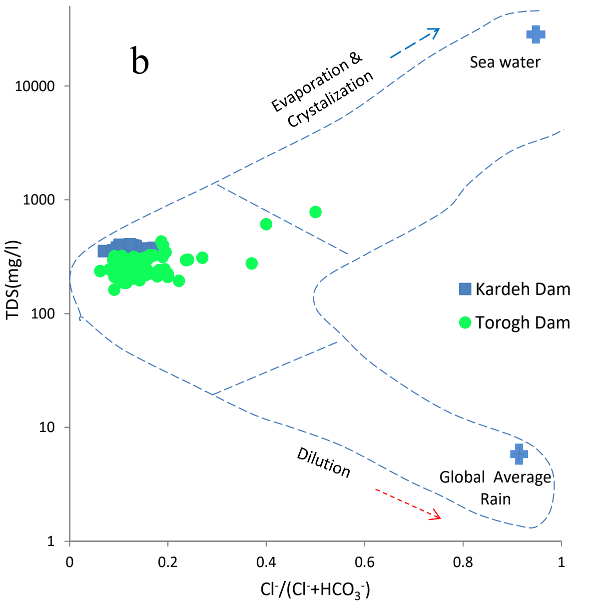


Fig. 3 Plotting Kardeh and Torogh dam reservoir samples on Gibbs model. TDS vs Na^+/ (Na^++Ca^{2+}) (a) and TDS vs Cl^-/ (Cl^-+HCO_3^-) (b)

Dam reservoir data on Mg^{2+}/Na^+ and HCO_3^-/Na^+ vs Ca^{2+}/ Na^+ diagram (Figs. 4 (a) and (b)) plots somewhere between silicate and carbonate mineral dissolution zone Show the importance of these types of mineral dissolution in dam reservoir [13].

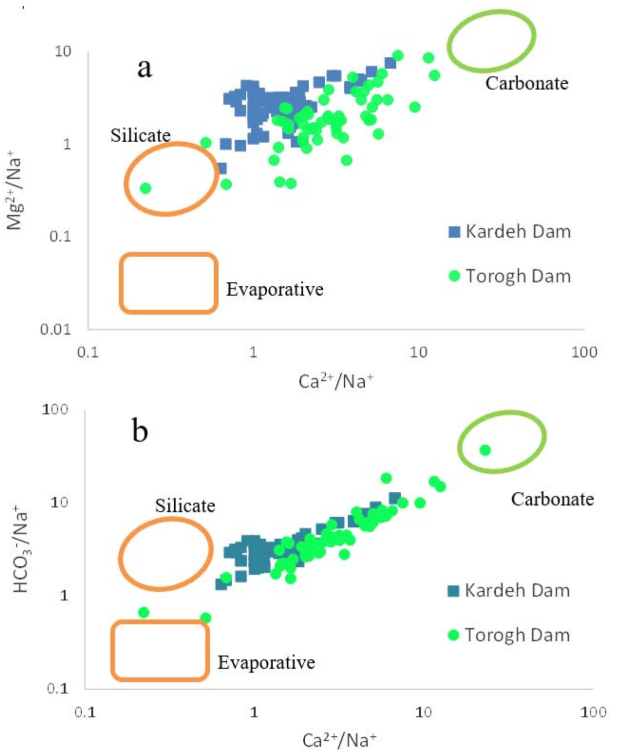
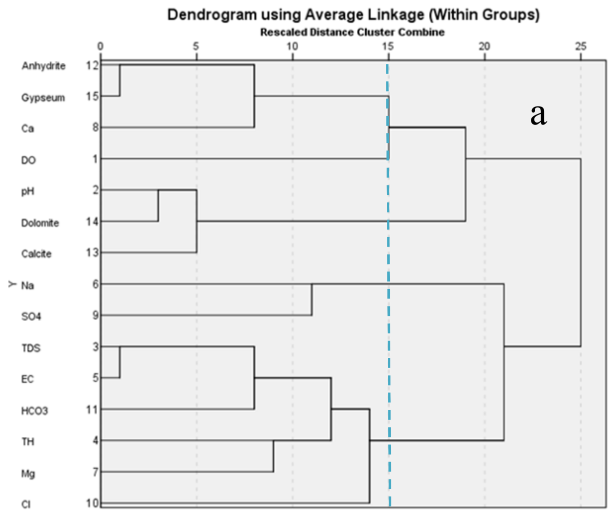


Fig. 4 Source diagrams using Na-normalized molar ratios Mg^{2+}/Na^+ (a) and HCO_3^-/Na^+ vs Ca^{2+}/ Na^+ (b)

In addition, the hydrochemical parameters in Kardeh and Torogh dam reservoirs have been analyzed by CA in SPSS software.

In Kardeh dam reservoir first cluster, saturation indices of evaporative mineral Gypsum and Anhydrite and Ca^{2+} ion demonstrate the importance of evaporative mineral (containing Ca^{2+}) dissolution in dam reservoir. In the second cluster, DO exists alone and has no clear correlation with other parameters. In the third cluster, pH and saturation indices of carbonate mineral Calcite and Dolomite demonstrate the precipitation of carbonate mineral by H^+ reduce and pH increase. In the fourth cluster, Na^+ and SO_4^{2-} may have two possible sources: the dissolution of evaporative mineral such as Mirabilite exists in this dam reservoir catchment area or antropogenic source, detergent from raw sewages. In the fourth cluster, the existence of physicochemical parameters TDS, EC and TH, in addition to Mg^{2+}, HCO_3^- and Cl^- ions, determine the significant role of these ions dissolution rate on the variation of TDS, EC and TH in dam reservoir (Fig. 5 (a)).

In Torogh dam reservoir, hydrochemical parameters have also been classified to four main clusters, but obvious changes occur. In the first cluster, saturation indices of evaporative mineral “Anhydrite and Gypsum” and Ca^{2+} and HCO_3^- exists, which depicts the evaporative mineral precipitation dependence to the concentration of Ca^{2+}. While, Ca^{2+} concentration also depends on HCO_3^- concentration. In the second cluster, the existence of Na^+, Cl^- and SO_4^{2-} may have two sources: natural sources from the dissolution of evaporative minerals exist in the catchment area of this dam reservoir or rural sewages. In the third cluster, saturation indices of carbonate mineral “Calcite and Dolomite” and pH show carbonate mineral saturation by pH increase. In the fourth cluster, the existence of Mg^{2+} exists in both evaporative and carbonate minerals with physicochemical parameters TH, EC, TDS and DO demonstrate Mg^{2+} dissolution (originated from both carbonate and evaporative mineral dissolution) control TH, EC and TDS variations in this dam reservoir (Fig. 5 (b)).



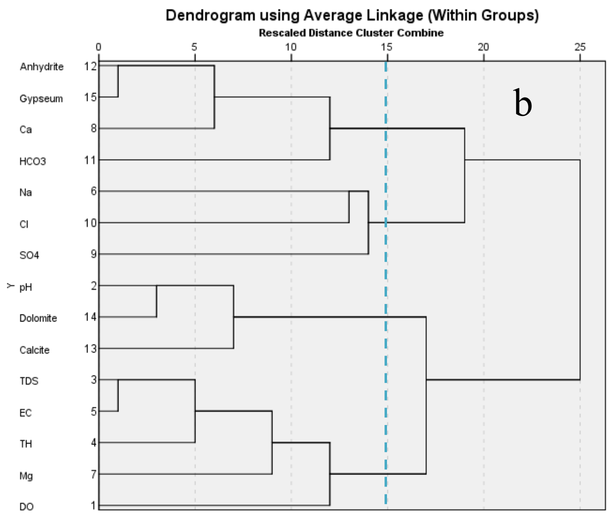


Fig. 5 CA of Kardeh (a) and Torogh (b) dam reservoirs based on hydrochemical datas

Studying N and P species in these dam reservoirs depicts that concentration of N species (NO_2^{2-}, NO_3^- and NH_4^+) are mostly lower than standard level limits presented by World Health Organization WHO [14]. NO_3^- is the more known species of N in environmental studies and shows higher average concentration 0.09 meq/l in Kardeh compared to Torogh dam reservoir 0.08 meq/l. NO_2^{2-} has also have higher average concentration 0.09 meq/l in Kardeh compared to Torogh dam reservoir 0.07 meq/l. NH_4^+ another N species which is not presented in the oxic layer (because nitrification by nitrosomus and nitrobacter at the oxic-anoxic boundary converts NH_4^+ to NO_3^-) demonstrate higher average concentration 0.84 meq/l in Torogh and 0.66 meq/l in Kardeh dam reservoir. The Prosperous species (PO_4 and P) average concentration also demonstrated higher concentration in Kardeh compared to Torogh dam reservoir. The average concentration of P and PO4 are 1.07 and 0.35 meq/l in Kardeh and 0.78 and 0.27 meq/l in Torogh dam reservoir, respectively. The higher concentration of N and P specious in Kardeh compared to Torogh dam reservoir is due to more nutrient compounds release (fertilizers and sewages) in the Kardeh dam reservoir catchment area.

Water quality indexes, NSF-WQI, OWQI and DWQI indexes in Kardeh and Torogh dam reservoir samples demonstrate good water quality in Torogh and moderate water quality in Kardeh dam reservoir (Table I).

TABLE I
WATER QUALITY INDEXES IN KARDEH AND TOROGH DAM RESERVOIR

Index	Kardeh	Torogh
NSF-WQI	65	75
OWQI	76	81
DWQI	75	88
Condition	Fair	Good

IV. CONCLUSION

Torogh and Kardeh dam provides notable part of Mashhad potable water needs. $CaHCO_3$ and $MgHCO_3$ are the main water types in Torogh, while in Kardeh dam reservoir $MgHCO_3$ is the main water type. Gibbs model demonstrate that rock weathering is the main ion providing source in these dam reservoirs. Mg^{2+}/Na^+ and HCO_3^-/Na^+ vs Ca^{2+}/ Na^+ diagrams demonstrate evaporative and silicate minerals and to lower extent evaporative minerals are the dominant rock weathering ion sources, while CA show the dominant role of carbonate and evaporative minerals in these dam reservoirs. Water quality indexes NSF-WQI, OWQI and DWQI show moderate water quality in Kardeh and good water quality in Torogh dam reservoir.

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Mojtaba Heydarizad is also a member of several associations including Iranian Association of Water Resources (IAWR) 2013-Present and Iran young geologists' campaign.