Assessment of Ramshir region groundwater quality for irrigation purposes using Piper and Wilcox diagrams

Payvand Papan[*1], Khashayar Peyghan*[2], Mojtaba Shirazi*[3]

1- PhD of Soil Sciences, Shahid Chamran University of Ahvaz and expert of Khuzestan Water and Electricity Organization(payvand_p2006@yahoo.com)
2- PhD Candidate in Department of Irrigation & Reclamation, University of Tehran, Karaj, Iran (khashayar.peyghan@ut.ac.ir)
3-Ph.D. Student, Soil Science Department, Faculty of Agriculture University of Shahid Chamran University of Ahvaz, Iran (mshirazi.soil@gmail.com)

Abstract

Groundwater, as a key source of fresh water worldwide, is undergoing uncontrolled extraction, which has led to a high decrease in the quantity and quality of these resources. The present study evaluated the groundwater quality of the Ramshir region (southwest of Iran) for irrigation purposes using Piper and Wilcox diagrams. For this aim, 18 groundwater samples collected and analysed in July 2017. The results showed that according to the Piper diagram, Ramshir groundwater is in the sulphate category and according to the Wilcox diagram is in the C4S1 class. Interpretation of analytical data hints mixed Ca-Mg-SO_4 and Ca-SO_4 are the dominant hydrochemical faces in the study area. Alkali earths and alkali (Ca^+, Na^+) and strong acids (SO_4^{2-}, Cl^-) are slightly dominating over alkalis earth (Mg^{2+}, K^+) and weak acids (HCO_3^-). Groundwater in the study area is generally hard, high to very high saline. High range of TH and TDS in a few places identify the unsuitability of groundwater for irrigation. Such areas require special care to provide adequate drainage and introduce alternative salt tolerance cropping.

Keywords: Groundwater, Irrigation Water Quality, Piper Diagram, Ramshir, Water Quality Indexes, Wilcox Diagram.

Introduction

Groundwater is a key freshwater resource globally by suppling 36% of drinking water and 42% of agricultural water (Asharf et al, 2021). In recent years, stress on the natural resources is increasing due to rapid industrialization and population growth and their conservation is one of the major challenges for humankind. Groundwater is a most vital resource for millions of people for both drinking and irrigation uses (Ghalib, 2017). In addition, an imprudent extraction of the groundwater resources and consecutive droughts in recent years have also led to expedited descend of the groundwater level and deterioration in groundwater quality (Hosseinifard and Aminiyan, 2015; Zahedi, 2017). Since the quality of groundwater resources is as important as its quantity; thus, it is also necessary that the quality of the groundwater resources should be essentially taken into the full consideration (Aghazadeh and Mogaddam, 2010; Neisi et al, 2018).

Besides the scarcity of water resources, intense agricultural and urban development has caused a high demand of groundwater resources in the arid and semiarid regions of Iran while great risk of contamination these resources is the main challenges facing the Iranian government. Accordingly, it is worth noting that monitoring of the quality of groundwater resources in Iran should be included as a vital step for water resources management, since it is considered as a primary source for drinking and irrigation water. Quality and quantity of rainfalls, geological structure, and aquifer mineralogy are the main factors that can affect the chemical quality of groundwater (Mirzabeygi et al, 2017; Yousefi et al, 2017). Therefore, several studies must be conducted to assess quality/quantity of groundwater in different regions of Iran. According to this, the hydrochemical characteristics of groundwater can indicate that whether groundwater resources are chemically unsuitable for drinking and agricultural irrigations or not (Aghazadeh and Mogaddam, 2010).

Arulbalaji and Gurugnanam (2017) carried out a study in order to assess the groundwater quality for domestic and irrigation purposes in Salem District, Tamil Nadu, India. They used several of water quality indexes including Piper and Wilcox diagrams. Alavi et al. (2016) conducted a study to assessment of Dez eastern water quality in the Khuzestan province for drinking and agricultural uses by Schuler and Wilcox diagrams. Results showed that according to the Wilcox diagram, water quality was a little salty but suitable for agricultural uses. Khoramabadi Shams et al. (2014) evaluated the water quality of Khorramrood River in Iran using indexes such as Wilcox diagram. For this aim, the quality parameters required for the calculation of quality indicators, were measured by using standard methods at six selected stations during six months in 2012. They stated that according to the Wilcox index, qualities of water in third station were medium and in the rest were good. Amiri et al. (2016) used Piper diagram to assessment of seasonal groundwater quality and potential saltwater intrusion in Urmia coastal aquifer, Iran.

The aim of this study was to assessment the groundwater quality of Ramshir region for irrigation purposes using Piper and Wilcox diagrams.

Materials and Methods

Study area

Ramshir county is located at 30° 53' 28" North, 49° 24' 21" East, in the south of Khuzestan Province in southwest of Iran (Taj et al, 2012). Ramshir area is 483 km^2. The mean annual rainfall is about 342.1 mm. The warmest season is from June to October, when the maximum temperature often exceeds 56 ˚C. The winter season is from January to March, when the minimum temperature often reaches 11.4 ˚C. Ramshir is 185 meters above sea level. The location of study area is shown in Fig. 1.

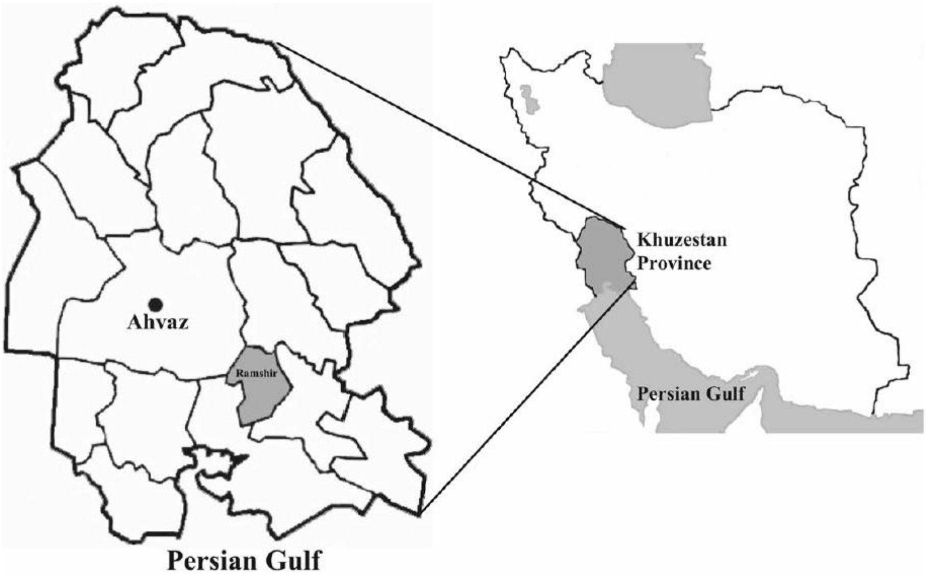

Fig. 1. Khuzestan province and geographical region of Ramshir County (Gholizadeh et al., 2016)

Water quality analysis

Water samples (18 samples) were taken from different wells in July 2017. Wells were pumped for 5 minutes prior to the collection of samples. Polythene bottles, which were cleaned with detergents, were used as containers. Each bottle was rinsed with distilled water before pouring the sample water. Proper labelling including the sample number and sampling location were done. EC and pH were analysed using field kit. Total dissolved solids (TDS) was calculated based on the EC by an empirical equation as below:

$$TDS = 0.64 \times EC \qquad (1)$$

Some parameters including Hardness, Ca^{2+}, Mg^{2+}, Cl^{-} and HCO_3^{-} determined by titration in the laboratory using the standard methods as suggested by the American Public Health Association (APHA, 1989, 1995). Flame photometer was used to measure the Na^{+} and K^{+}. SO_4^{2-} was determined by calculation. The accuracy of the chemical analysis was verified by calculating ion-balance errors where the errors were generally around 10%.

Piper diagram

Piper diagram is using to classify samples and to determine the chemical type of water. The total amount of cations and anions is considered 100 and the percentage of ions marked on the side triangles and the corresponding points on the side of the triangles will show on the middle lozenge. Eventually, determning the water quality in Piper diagram is performed based on the of focused points area (Choramin et al, 2015).

Wilcox diagram

Wilcox diagram proposed and completed by Wilcox in 1948 and Torn in 1951. It is a very common classifier for agriculture waters quality in which considered two factors; the horizontal axis in Wilcox diagram shows electrical conductivity (EC), and the vertical axis shows the sodium adsorption ratio (SAR) (Alavi et al, 2016. Salehi et al, 2021). SAR is an important parameter for determining the suitability of groundwater for irrigation because it is a measure of alkalinity/sodium hazard to crop. SAR is defined by (Karanth, 1987):

$$SAR=Na\sqrt{((Ca+Mg)/2)} \quad (2)$$

Where the concentrations are reported in meq/l.

Each of EC and SAR factors divided into four sections causing a total of sixteen water quality groups.Wilcox classification presented in Tables 1 and 2 (Wilcox, 1955).

Table 1. Water classification based on SAR and EC (Wilcox classification)

Classification based on SAR		Classification based on EC	
Class	Amount	Class	Amount (µmhos/cm)
S1	0-10	C1	100-250
S2	10-18	C2	250-750
S3	18-26	C3	750-2250
S4	>26	C4	>2250

Table 2. Water classification for agricultural uses according to Wilcox classification

Class	Water quality for agriculture
C1S1	Sweet—completely ineffective for agriculture
C1S2 – C2S1 – C2S2	Brackish—approximate perfect for agriculture
C1S3 – C2S3 – C3S1 – C3S2 – C3S3	Passion—usable for agriculture
C1S4 – C2S4 – C3S4 – C4S1 – C4S2 – C4S3 – C4S4	Very passion—harmful to agriculture

Results and Discussion

Water quality analysis

Physical and chemical parameters of the groundwater samples including statistical measures, such as mean, minimum, maximum, standard deviation and variance are reported in Table 1.
All the samples were slightly alkaline in nature, with a pH range of 7.1 to 8.2. The permissible limit of TDS in the irrigation water is 0 to 2000 mg/l. However in this study, the TDS values were varied between 1862 and 3998 mg/l. Among the 18 samples, 17 of them exceeded the permissible limit. Ca^{2+} and Mg^{2+} ranged 17.93 to 25.71 and 0.19 to 9.7 mg/l, respectively. Ca^{2+} was the dominant cation in this area. In normal groundwater system, the principal origin of these ions is sulphate minerals and their dissolution and depositional processes. Concentrations of Na^{+} and K^{+} were varied 7.3 to 28.05 and 0.07 to 0.2 mg/l,

respectively. In the study area, SO_4^{2-} was the dominant anion, with average concentration of 21.97 mg/l. SO_4^{2-} varied 14.53 to 30.1 mg/l. The concentration of Cl^- in the groundwater was 9.6 to 27.04 mg/l, with an average of 15.55 mg/l. The abundance of the major ions groundwater is in the following order: $Ca^{2+} > Na^+ + K^+ > Mg^{2+}$ and $SO_4^{2-} > Cl^- > HCO_3^-$.

Table 3. Physical-Chemical parameters of groundwater

Parameter	Unit	Mean	Minimum	Maximum	Standard Deviation	Variance
pH	-	7.3	7.1	8.2	0.25	0.063
EC	µmhos/cm	3957.4	2622	5632	568.8	323542.5
TDS	mg/l	2661.56	20	3998	770.75	594055.7
Na^+	mg/l	15.41	7.3	28.1	4.02	16.17
K^+	mg/l	0.13	0.07	0.2	0.32	0.001
Ca^{2+}	mg/l	20.7	17.93	25.71	2.33	5.44
Mg^{2+}	mg/l	5.4	0.19	9.7	2.46	6.03
Cl^-	mg/l	15.5	9.6	27.04	3.46	11.98
SO_4^{2-}	mg/l	586	2.33	219.36	57.33	3287.1
HCO_3^-	mg/l	21.98	14.53	30.1	3.3	10.93

Correlation between chemical parameters of groundwater

Correlation coefficient is a commonly used measured to establish the relationship between two variables. It is simply a measure to exhibit how well one variable predicts the other to exhibit how well one variable predicts the other. According to the results, EC and TDS show good positive correlation with Na^+ and Cl^-. In addition, TDS and Na^+ also exhibit high positive correlation with SO_4^{2-} and Cl^- ions, respectively. Correlation matrix between physical-chemical parameters of groundwater are presented in Table 4.

Table 4. Correlation matrix between physical-chemical parameters of groundwater

	pH	EC	TDS	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-
pH	1									
EC	0.368	1								
TDS	0.367	0.995	1							
Na^+	0.473	0.936	0.933	1						
K^+	-0.181	0.319	0.311	0.314	1					
Ca^{2+}	0.321	0.629	0.593	0.594	0.417	1				
Mg^{2+}	-0.122	0.337	0.393	0.160	-0.045	-0.334	1			
Cl^-	-0.511	0.954	0.936	0.952	0.205	0.646	0.158	1		
SO_4^{2-}	0.351	0.865	0.897	0.823	0.320	0.517	0.495	0.742	1	
HCO_3^-	-0.823	-0.132	-0.137	-0.295	0.191	-0.051	0.190	-0.263	-0.189	1

Piper diagram

A Piper diagram (Fig. 2.) was created for the Ramshir region using the analytical data obtained from the hydrochemical analysis. Generally, we can classify the sample points in the Piper diagram into six fields; (1) Ca-HCO_3, (2) Na-Cl, (3) Ca-Mg-Cl, (4) Ca-Na-HCO_3, (5) Ca-Cl, and (6) Na-HCO_3. However, in the present study, water types were confined to the SO_4^{2-} type.

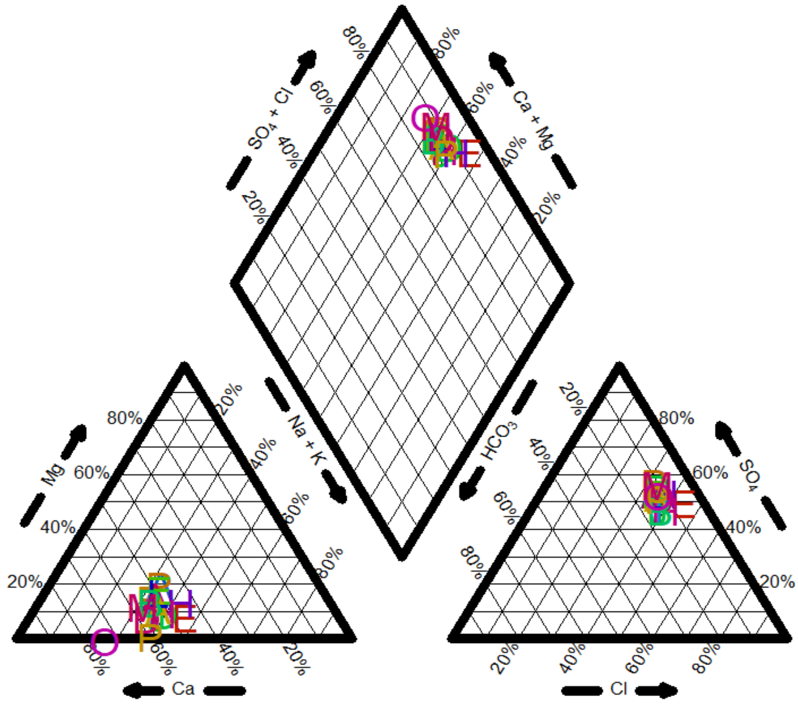

Fig. 2. Piper diagram for Ramshir region groundwater

Wilcox diagram

Based on the Wilcox diagram, 17 samples crossed the permissible limit EC for irrigation. Excess salinity reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soil (Saleh et al, 1999). The SAR values rang from 2.31 to 7.1 with an average value of 4.25. Groundwater samples of the study area fall in medium sodium class (S2) except one sample having the SAR value of 2.31. If the SAR value be greater than 6 to 9, the irrigation water will cause permeability problems on shrinking and swelling type of clayey soils (Saleh et al, 1999).

The Wilcox diagram relating sodium percentage and total concentration shows that most the groundwater samples fall in the field of unsuitable for irrigation. When the concentration of sodium is high in irrigation water, sodium ions tend to be absorbed by clay particles, displacing Mg^{2+} and Ca^{2+} ions. This exchange process of Na^{+} in water for $Ca^{2+}$and Mg^{2+} in soil reduces the permeability and eventually results in soil with poor internal drainage. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry.

The Wilcox diagram illustrates that most of the groundwater samples fall in the field of C4S1, indicating high salinity and medium sodium water, which can be used for irrigation on almost all types of soil with danger of exchangeable sodium. This can be unsuitable for plants having bad salt tolerance and also restricts their suitability for irrigation, especially in soils with restricted drainage. The Wilcox diagram shown as Fig. 3.

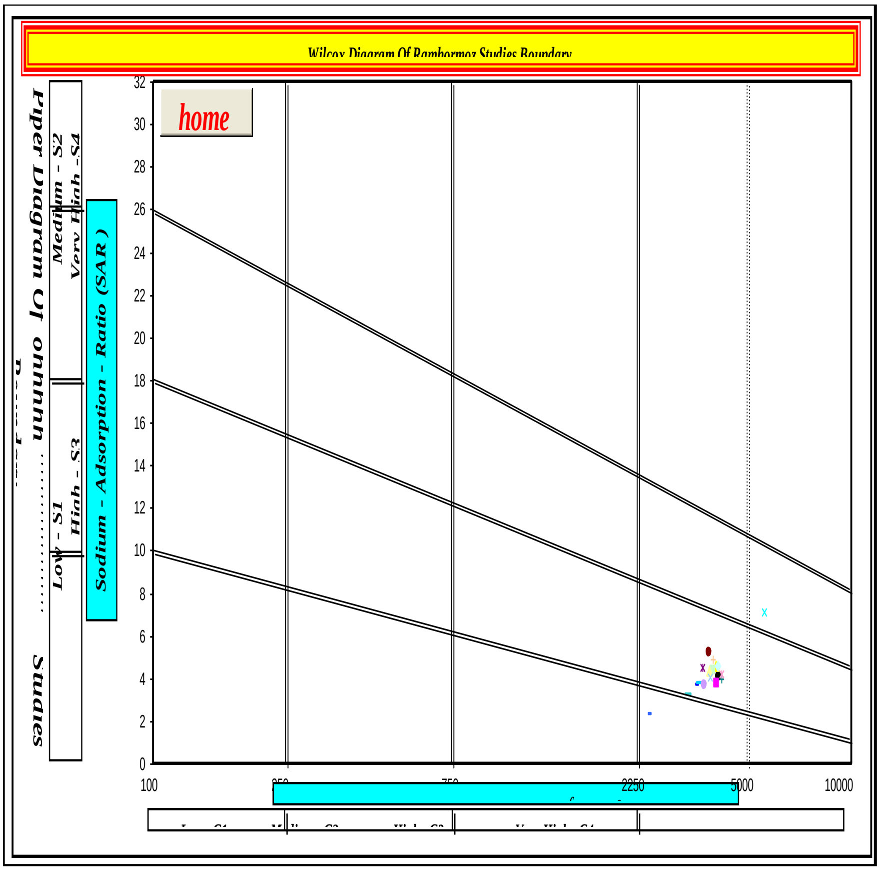

Fig. 3. Wilcox diagram for Ramshir region groundwater

Conclusion

Interpretation of hydrochemical analysis reveals that the groundwater in Ramshir are brackish in nature. The sequence of the abundance of the major ions is in the following order: Ca^{2+} > Na^{+} + K^{+} > Mg^{2+} and SO_4^{2-} > Cl^{-} > HCO_3^{-}. Groundwater in the study area exceeded the recommended limits of TDS as per the international irrigation standard. Due to high to very high salinity hazard, the groundwater of the study area is beyond the maximum allowable limit for irrigation even though it has low alkalinity hazard.

Acknowledgments

The authors thank the Applied Research Office of the Khuzestan Water and Electricity Organization and Shahid Chamran University of Ahvaz for their financial support.

References

Aghazadeh, N., & Mogaddam, A. A. (2010). Assessment of groundwater quality and its suitability for drinking and agricultural uses in the Oshnavieh Area, Northwest of Iran. Journal of Environmental protection, 1(01), 30.

Alavi, N., Zaree, E., Hassani, M., Babaei, A. A., Goudarzi, G., Yari, A. R., & Mohammadi, M. J. (2016). Water quality assessment and zoning analysis of Dez eastern aquifer by Schuler and Wilcox diagrams and GIS. Desalination and water treatment, 57(50), 23686-23697.

Amiri, V., Nakhaei, M., Lak, R., & Kholghi, M. (2016). Assessment of seasonal groundwater quality and potential saltwater intrusion: a study case in Urmia coastal aquifer (NW Iran) using the groundwater quality index (GQI) and hydrochemical facies evolution diagram (HFE-D). Stochastic Environmental Research and Risk Assessment, 30(5), 1473-1484.

APHA. (1995). Standard methods for examination of water and wastewater, 19th edn, American Public Health Association, Washington, DC.
APHA-AWWA, W. P. C. F. (1989). Standard Methods for the Examination of Waters and Waste Waters. 17th Edn. American Public Health Association. Inc. New York.
Arulbalaji, P., & Gurugnanam, B. (2017). Groundwater quality assessment using geospatial and statistical tools in Salem District, Tamil Nadu, India. Applied Water Science, 7(6), 2737-2751.
Choramin, M., Safaei, A., Khajavi, S., Hamid, H., & Abozari, S. (2015). Analyzing and studding chemical water quality parameters and its changes on the base of Schuler, Wilcox and Piper diagrams (project: Bahamanshir River). WALIA J, 31(S4), 22-7.
Ghalib, H. B. (2017). Groundwater chemistry evaluation for drinking and irrigation utilities in east Wasit province, Central Iraq. Appl Water Sci 7 (7): 3447–3467.
Gholizadeh, S., Lalehzari, E., Bavani, M. M., Hosseini, A., Khalkhali, H. R., & Rafinejad, J. (2016). Bioecology and scorpion envenomation in Ramshir district, Khuzestan Province, southwestern Iran. Applied entomology and zoology, 51(1), 37-42.
Hosseinifard, S. J., & Aminiyan, M. M. (2015). Hydrochemical characterization of groundwater quality for drinking and agricultural purposes: a case study in Rafsanjan plain, Iran. Water Quality, Exposure and Health, 7(4), 531-544.
Karanth, KR. (1987). Ground water assessment, development and management. Tata McGraw Hill, New Delhi, pp 720.
Khoramabadi Shams, G., Yusefzadeh, A., Godini, H., Hoseinzadeh, E., & Khoshgoftar, M. (2014). Water quality zoning based on water quality index and Wilcox index using geographic information system. Jundishapur Journal of Health Sciences, 6(3).
Mirzabeygi, M., Yousefi, N., Abbasnia, A., Youzi, H., Alikhani, M., & Mahvi, A. H. (2017). Evaluation of groundwater quality and assessment of scaling potential and corrosiveness of water supply networks, Iran. Journal of Water Supply: Research and Technology—AQUA, 66(6), 416-425.
Neisi, A., Mirzabeygi, M., Zeyduni, G., Hamzezadeh, A., Jalili, D., Abbasnia, A., ... & Khodadadi, R. (2018). Data on fluoride concentration levels in cold and warm season in City area of Sistan and Baluchistan Province, Iran. Data in brief, 18, 713.
Nematollahi, M. J., Ebrahimi, P., Razmara, M., & Ghasemi, A. (2016). Hydrogeochemical investigations and groundwater quality assessment of Torbat-Zaveh plain, Khorasan Razavi, Iran. Environmental Monitoring and Assessment, 188(1), 1-21.
Piper, A. M. (1944). A graphic procedure in the geochemical interpretation of water- analyses. Eos, Transactions American Geophysical Union, 25(6), 914-928.
Saleh, A., Al-Ruwaih, F., & Shehata, M. (1999). Hydrogeochemical processes operating within the main aquifers of Kuwait. Journal of Arid Environments, 42(3), 195-209.
Salehi, S., Esmaeily, A., & Farhadi, H. (2021). Determination of Groundwater Quality Using a GIS-AHP Based System and Compared with Wilcox Diagram (Case Study: Rafsanjan Plain). Amirkabir Journal of Civil Engineering.
Taj, S. H., Vazirian, M., Vazirianzadeh, B., Bigdeli, S. H., & Salehzadeh, Z. (2012). Effects of climatological variables on scorpion sting incidence in Ramshir area south west of Iran. J Exp Zoology India, 15, 575-577.
Wilcox, L. (1955). Classification and use of irrigation waters (No. 969). US Department of Agriculture.
Yousefi, M., Mohammadi, A. A., Yaseri, M., & Mahvi, A. H. (2017). Epidemiology of drinking water fluoride and its contribution to fertility, infertility, and abortion: an ecological study in West Azerbaijan Province, Poldasht County, Iran. Fluoride, 50(3), 343-353.

Zahedi, S. (2017). Modification of expected conflicts between drinking water quality index and irrigation water quality index in water quality ranking of shared extraction wells using multi criteria decision making techniques. Ecological Indicators, 83, 368-379.