American Research Journal of Civil And Structural Engineering
Volume 1, Issue 1, pp: 47-57
Research Article Open Access

Classification of Zayandehrud River Basin Water Quality Regarding Agriculture, Drinking, and Industrial Usage

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Abstract: Iran is located in arid and semi-arid of the world and it has shortage of freshwater resources. So, to review the status of water use and protection of water resources against pollution, especially in the global water crisis is necessary and vital. Zayandehrud River as the largest river of the central plateau of Iran and the most important surface water flow in Isfahan province, which preserving its quality is important because of agriculture - environmental, industry and drinking. In this regard, the assessment of the quality of the 15 stations in the Zayandehrud river basin has been done by using the analysis of physical and chemical parameters to during 5 decades from 1967-2009. Surveying the results shows thatdrinking water quality based on the diagram Schuler is good and acceptable. Regarding agriculture and irrigation, according to Wilcox diagram, except for two stations Hossein Abad and Henjin which were salty)C3S1), the other stations suitable were a bit salty but suitable for agriculture (C2S1). Water quality of ten stations has been hard water; four stations fairly hard and the only Henjin station has been estimated quite hard. The type and faces of this basin water have beenchock bicarbonate at 13 stations and in two stations Hossein Abad and Henjin have been sodic sulfate and Magnesium Sulfated. Qualitative classification of stations based on both industrial and according to Langelier index is estimated to be corrosive except Hossein Abad station that has been deposited.

Keywords: Crisis - Water Quality - Zayandehrud - Wilcox - Schuler – Langelier

Introduction

The surface water or rivers are the most important water resources which have a major role in supplying water required for various activities such as agriculture, industry, drinking water and electricity production. Many of the country's water resources planning are based on the potential of surface water sources. One of the problems facing for transferring river water is the amount of pollutants that exist in river water in the form of solution or suspended solids (Najafi, Tabatabai, & Savage, 2006). Knowing the quality of water resources is one of the important requirements for the planning, development, protection and control of them (Jabari & Najmi, 2010). Given that millions of people are affected by water pollution annually and it is considered a threat to modern societies, studying addressing surface water sources such as rivers, is one of the necessities (Mossadegh, 2003). Since information about rivers regarding capacity of pollutants entrance will help a lot in controlling pollution and future planning, many studies have been done in this field in various formats. As an example, Statistical tests of Principal Components Analysis (PCA) and Cluster Analysis)CA(are used to determine the source of contamination in the water supply and by the evaluation of multiple parameters measured in a specific time period (Chapman, Organization, & Press, 1996), showed that pollution elements (e.g., K) must be attributed to the natural origin of geology or human origin (Pesce & Wunderlin, 2000).ForexampleVega, Pardo, Barrado, and Debán (1998), physical and chemical variables of water have been studied by using statistical analysis during 2.5 year at the three stations regarding the assessment of seasonal changes and pollutant effects on water quality of pisuerga River, a Spain. In this study, the application of PAC has been showed that the amount of mineral material, human pollution and the temperature have been decreased. Toinvestigate the spatial and temporal variations of river Sequoia River, Argentina, Alberto and colleagues (2000) by using statistical methods CA and PCA, showed that the CA method showed good results but with little detail of spatial and temporal variations in water quality. It must be also mentioned that PCA method requires 13 parameters to show 71% spatial and temporal variations.

Another area of research that is used to infer the quality of river water can be cited direct study of plants and animals that live in it because aquatic organisms and communities can present the current situation, also changes over time and the effect of contaminant cumulative and biological indicators can also show hidden environmental impacts (Esmaili sari, 2003). For example, Azrina, Yap, Rahim Ismail, Ismail, and Tan (2006) studied the effects of human activities on the distribution and diversity of macro-benthic communities and water quality in Langat River, Malaysia that the relationship between physical, chemical conditions and benthic invertebrates in large communities were investigated through multiple stage regression analysis and the results showed the food and diversity of benthic invertebrates in large communities were mainly influenced by TSS and EC of river water. It is also necessary physical and chemical parameters are accurately simulated in the planning and estimated the possibility of neural network applications in the areas. For instance, Misaghi and Mohammadi (2004)by using the neural network showed that the neural network has good ability to simulate changes in the quality parameters in Zayandehrud basin and for qualitative data of BOD and DO.

In addition to the above methods, it is possible to investigate chemical quality parameters of river water by using the existing software as Hydrochemistry (AquaChem, Chemistry) and output match with Piper diagrams, Shulander and so on. Since as we know the rate of water chemical parameters depends on factors such as geological formations in the basin area, ion exchange between surface water and groundwater and the river discharge regime which in this context, for example, we can mention a few samples. Sundaray, Nayak, and Bhatta (2009)in a case study conducted in India on Mahanad river investigated the river water quality to suit for agriculture for six different time periods at 31 stations and calculated water suitability for use in agriculture by using mathematical relationships and the parameters the ratio of sodium absorbance, residual sodium carbonate, water permeability in soil and the amount of magnesium which obtained results were consistent with Wilcox diagram. Based on Wilcox index, all samples from different areas of the study classified as excellent to good (low to medium salinity with low sodium) which were appropriate for all soils and also for salt-sensitive products.Mostakmeli and Tarshiziyan (2000) recognized chemical type and kind of water in Magnesium Sulfated by Piper and Stiff diagrams through studying river water quality in Shirin-Dareh Basin in North Khorasan province. Ghasemi, Zare, Shahsavar, and Yaghobi Kikileh (2010) investigate aquifer status to examine the qualitative and quantitative changes of Hamadan - Bahar plain groundwater. They determined a few changes through water level reading in each well in different months and Polygon them in a 15 year period (1992 to 2006) and concluded that groundwater level is dropped 11 m. They also categorized wells in two groups of quality in order to evaluate the qualitative changes by using Wilcox diagram. Results showed that due to aquifer proximity to residential and industrial areas, water quality das decreased from South-East to North-East of the basin.

Considering the importance of water quality monitoring, checking water quality parameters from 15 stations of Zayandehrud catchment in order to drinking, agriculture and industry will be one of the goals of the present study.

Materials and Methods

Zayandehrud catchment with 41500 km^2area, is located in the center of Iran and there is no outlet to the sea. Zayandehrud River is the largest river in this basin, which stretches from West to East and originated from Zagros Mountains and eventually goes Gavkhuni Marsh (Figure 1). The basin has semi-arid or dry climates.

Annual rainfall is 130 mm on average in Isfahan city, which most of the precipitation falls in the winter; so rainfall is not significant during the summer heat season. On the other hand, temperature is high in summer and in July is about 30 degrees centigrade. Most of the precipitation falls in the cold season and temperatures is around 3 ° C. Annual potential evaporation is 1500 mm. All these figures and numbers confirm the fact that an economic farming is impossible without controlled irrigation and good management. The First and the main Supplier source of water requirement for Dashte-Isfahan is Zayandehrud River and other sources such as streams, canals and wells don't have important role in providing needed water. Geographic characteristics and statistical periods (during 5 decades 1967-2009) for some stations under study in Zayandehrud basin are presented in Table 1.

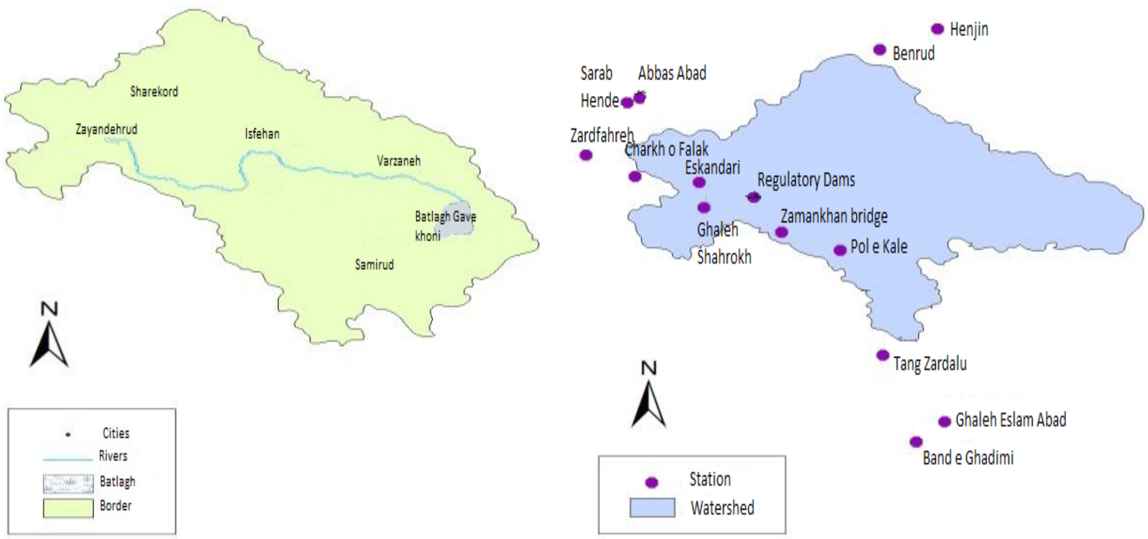

Fig1. *Zayandehrud River Catchment and Stations under Study*

Table1. *Geographic Characteristics and Statistical Period for some Stations under Study in Zayandehrud basin*

Station	River	Sign	UTM (x)	UTM (y)	Statistical period	
Ghaleh Eslam Abad	Bahmanzaad	A	576938	3451837	1997	2009
Zardfahreh	Vahargan	B	388441	3653311	1982	2009
Tang Zardalu	Kasgan	C	543576	3502139	1977	2009
Charkh o Falak	Sibak	D	413016	3639270	1982	2009
Band e Ghadimi	Tang Sahari	E	561690	3435721	1995	2009
Benrud	Benrud	F	541441	3734051	1967	2009
Hossein Abad	Ghohrud	G	546242	3738137	1967	2010
Sarab Hende	Darband	H	410029	3694174	1967	2011
Abbas Abad exit	Golpayegan Dam	I	416311	3697475	1970	2009
Ghaleh Shahrokh	Zayandehrud	J	448713	3614036	1969	2009
Eskandari	Plasjan	K	446977	3632180	1969	2010
Regulatory Dams	Zayandehrud	L	475870	3621848	1967	2009
Zamankhan bridge	Zayandehrud	M	490156	3595698	1967	2010
Pol e Kale	Zayandehrud	N	521689	3581811	1968	2011
Henjin	Zayandehrud	O	570769	3748776	1967	2012

Before the analysis of water quality data, the degree of accuracy and the accuracy of chemical data is determined by calculating ionic charge balance error (error response: RE) by using the following equation:

$$RE = \frac{\sum Cations - \sum Anions}{\sum (Anions + Cations)} \times 100 \quad (1)$$

If this value is greater than 5%, Data reliability will be questionable. Schuler, Wilcox Graphical indicators and also Langelier index have been used for quality classification of basin water. The following is a brief description of them.

Schuler Chart

Schuler semi-log chart is used to show the primary ions m Eq per liter and total dry residue and total hardness of water resources in a chart. Schuler chart is commonly used for the classification of "drinking" in water hydrology reports. Drinking water are classified into six groups of good, acceptable, fair, inappropriate, totally inappropriate and potable based on five chemical parameters of sodium, chloride, sulfate, dried residues (TDS) and hardness of drinking water of (Table 2).

Table2. *Classification criteria for the drinking water according to Schuler classification (Mgr/L)*

Quality	TH	TDS	SO4	Cl	Na
Good	<250	<500	<145	<175	<115
Acceptable	250-500	500-100	145-280	175-350	115-230
Average	500-1000	1000-2000	280-580	350-700	230-460
Inappropriate	1000-2000	2000-4000	580-1150	700-1400	460-920
Quite undesirable	2000-4000	4000-8000	1150-2240	1400-2800	920-1840
Non-potable	>4000	>8000	>2240	>2800	>1840

Wilcox Diagram

One of the most important indicators for the interpretation the quality of raw water in "agriculture" is Wilcox index. Wilcox classification has been proposed by Wilcox in 1948 and has been completed three years later by Torn. The index is a very common method nowadays for classification of waters in agriculture. In this classification, two factors are considered: electrical conductivity (EC) and sodium adsorption ratio (SAR) which any of them are converted into four sections (Table 3) sections (Table 3) that the overall result is the emergence of the 16 groups (Table 4). Eventually, the quality of water is stated for various uses including irrigation.

Table3. *Classification criteria for farming water according to Wilcox classification*

Water Quality	EC	Class	SAR	Category
Excellent	<250	C1	<10	S1
Good	250-750	C2	10-18	S2
Average	750-2250	C3	18-26	S3
Inappropriate	<2250	C4	>26	S4

Table4. *Different water classification and types of quality based on Wilcox classification*

Water category	Water quality	Agriculture
C1S1	Freshwater	Completely harmless
C1S2,C2S2,C2S1	A little salty	Almost Appropriate
C1S3 ,C2S3 ,C3S1 ,C3S2 ,C3S3	Passion	Applying the necessary measures
C1 S4 ,C2S4 ,C3S4, C4S4, C4S3 ,C4S2 ,C4S1	Very salty	Harmful to agriculture

Langelier Index

One of the methods used for the prediction of corrosion characteristics or deposition of water is provided by Langelier (Takubangloo, 2003). He helped from developed theories governing water solutions in order to analyze water profile. Langelier suggested that difference between pH and pHs which are the acidity of the water (measured) and calculated acidity based on the results of the chemical analysis of water with assuming saturation of calcite or calcium carbonate can also be used as a numerical indicator of water specifications, respectively (Table 5).

Table5. *Interpretation of Langelierindex amount*

Interpretation	Index amount
Tend to dissolve CaCo3 (corrosive)	LI<0
No corrosion and deposition	LI=0
Tend to sequestration CaCo3 (sedimentation)	LI>0

Results and Discussion

In order to control the quality of the data, the values of ionic charge balance error (percent error response) have been calculated according to equation 1 and is presented in Table 6. As we have seen the data has significant quality (since the percentage error is less than 5%).

Table6. *Values of response error (RE) for the qualitative data from stations in the Zayandehrud river basin*

Station	Total anions	Total Cations	The percentage error
Ghaleh Eslam Abad	4.33	4.26	0.82
Zardfahreh	3.3	3.27	0.42
Tang Zardalu	4.63	4.62	0.03
Charkh o Falak	3.9	3.89	0.19
Band e Ghadimi	3.84	3.81	0.34
Benrud	4.33	4.33	0.03
Hossein Abad	10.5	10.3	1.09
Sarab Hende	5.28	5.22	0.63
Abbas Abad exit	5.17	5.08	0.88
Ghaleh Shahrokh	3.63	3.62	0.11
Eskandari	5.16	5.14	0.17
Regulatory Dams	3.4	3.41	0.02
Zamankhan bridge	3.49	3.47	0.26
Pol e Kale	4.04	4.03	0.06
Henjin	12.2	12.2	0.11

The results obtained from studying hydro chemical quality of surface waters of 15 stations in the Zayandehrud river catchment by using Schuler classification are given inTable 7. According to this table, drinking water quality is good and acceptable in this basin. Figure 2 is a representative of Schuler diagram.

Table7. *Percentage of each class in Schuler classification for drinking in the whole area under study*

The water classification	TDS	TH	PH	Na	Cl	So4
Good	87.5	93.75	50	93.75	100	87.5
Acceptable	12.5	6.25	43.75	6.25	0.00	6.25
Average	0.00	0.00	6.25	0.00	0.00	6.25

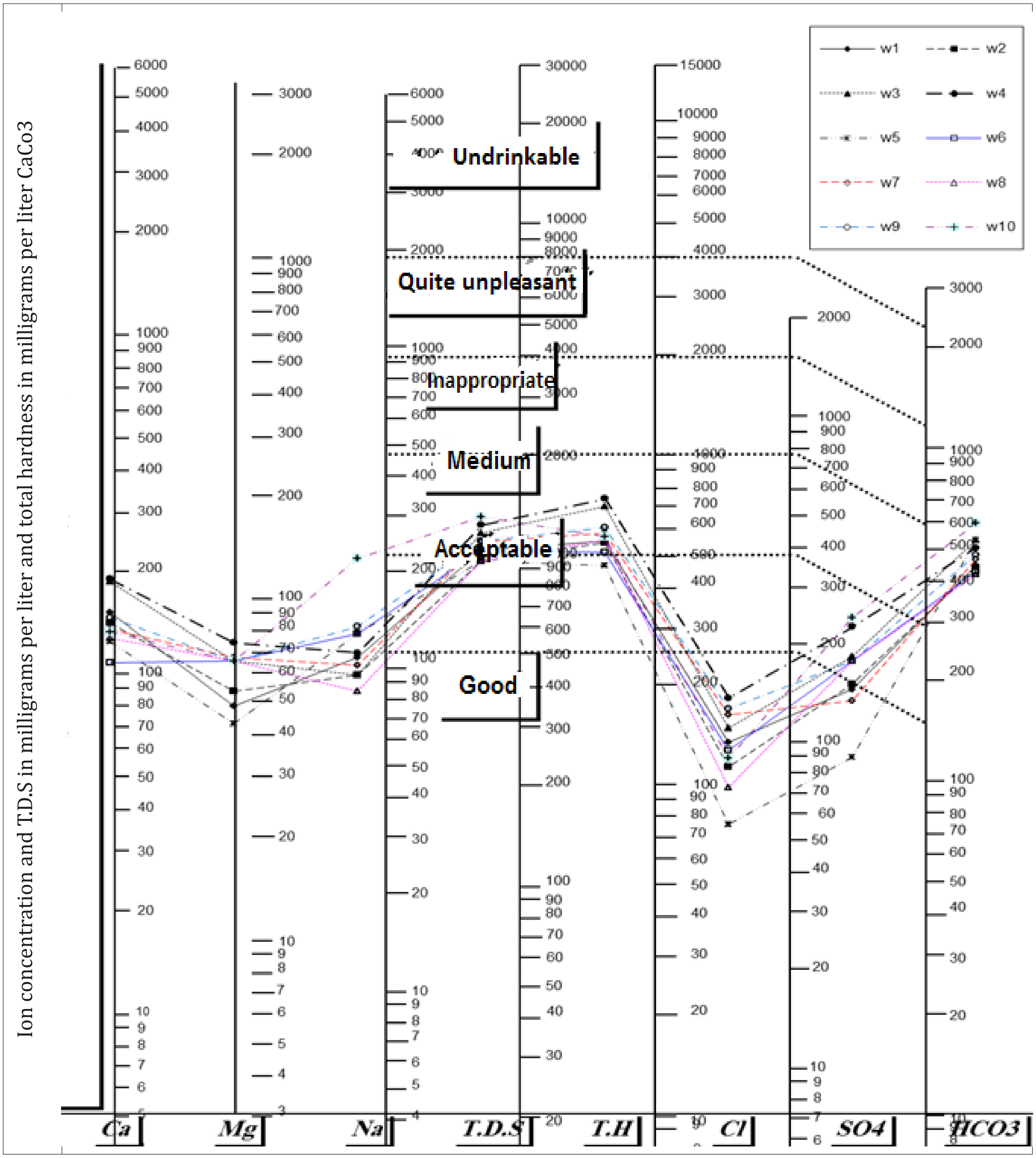

Fig2. *Schuler diagram for classification of drinking water quality*

As it can be inferred from Table 8, it is observed the qualitative classification of 13 stations in the basin understudying is C2S1 (medium salinity - low sodium) based on the values of SAR and EC form from agricultural view point (irrigation), that is, slightly salty water is suitable for irrigation agricultural lands at their downstream and 2 stations Hossein Abad and Henjin have been salty C3S1 which is definitely suitable for agriculture. Figure 3 shows the Wilcox graph to classify Zayandehrud basin water quality.

Table8. *Qualitative classification Zayandehrud basin stations, according to agriculture based on Wilcox graph*

Station	Sign	SAR	EC	Water Class	Water quality for agriculture
Ghaleh Eslam Abad	A	0.32	385.94	C2-S1	Slightly salty - perfect for agriculture
Zardfahreh	B	0.21	310.28	C2-S1	Slightly salty - perfect for agriculture
Tang Zardalu	C	0.4	431.5	C2-S1	Slightly salty - perfect for agriculture
Charkh o Falak	D	0.26	372.28	C2-S1	Slightly salty - perfect for agriculture
Band e Ghadimi	E	0.19	346.84	C2-S1	Slightly salty - perfect for agriculture
Benrud	F	1.06	413.97	C2-S1	Slightly salty - perfect for agriculture
Hossein Abad	G	3.67	1011.1	C3-S1	Passion - usable for agriculture
Sarab Hende	H	1.27	517.48	C2-S1	Slightly salty - perfect for agriculture
Abbas Abad exit	I	1.14	503.68	C2-S1	Slightly salty - perfect for agriculture
Ghaleh Shahrokh	J	0.33	341.32	C2-S1	Slightly salty - perfect for agriculture
Eskandari	K	0.38	479.51	C2-S1	Slightly salty - perfect for agriculture
Regulatory Dams	L	0.32	314.12	C2-S1	Slightly salty - perfect for agriculture
Zamankhan bridge	M	0.37	321.59	C2-S1	Slightly salty - perfect for agriculture
Pol e Kale	N	0.59	373.86	C2-S1	Slightly salty - perfect for agriculture
Henjin	O	1.69	1148.47	C3-S1	Passion - usable for agriculture

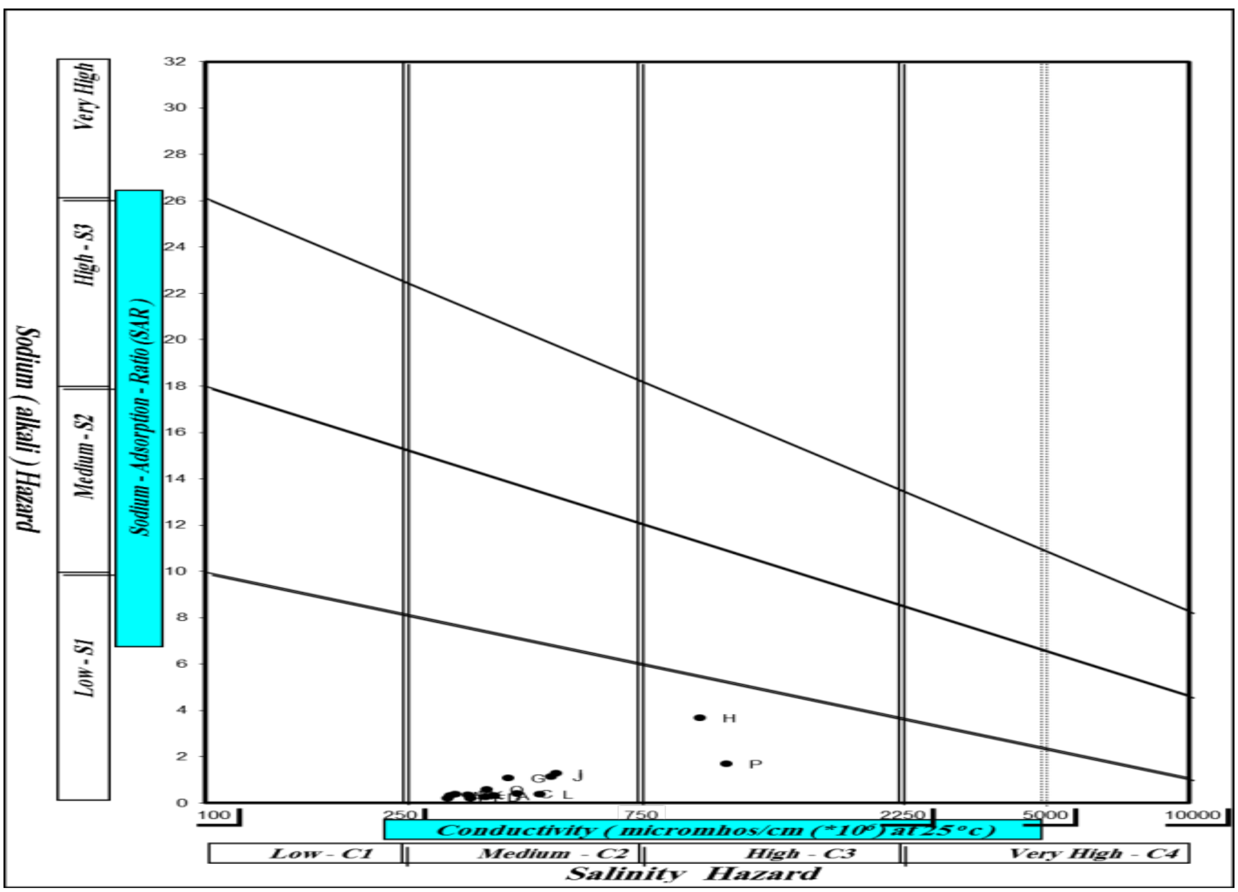

Fig3. *Wilcox diagram for classification of water quality for agriculture - irrigation*

The most important determinant of water quality is its hardness. Water hardness is defined as the number of mEq g of calcium and magnesium ions in a cubic dB. Hardness is divided into three types: 1) temporary hardness which is related to calcium bicarbonate and magnesium soluble in water. In this case, bicarbonate of calcium and magnesium are converted to insoluble carbonates by heating and boiling water and in the form of solids and exit from the environment. 2) Permanent hardness is produced because of other calcium and magnesium salts such as nitrate, sulfate and chloride which are not deposited by boiling water and remain in the form of solution , and 3) total hardness is defined as the sum of permanent and temporary hardships . According to Table 9, water quality of ten stations has been hard water, four stations are fairly hard and the only Henjin station is quite hard.

Table9. *Qualitative classification for stations of Zayandehrud river basin based on temporary and permanent hardness*

Station	Total hardness	Permanent hardness	Temporary hardness	Water quality
Ghaleh Eslam Abad	188.67	0	188.67	Hard
Zardfahreh	149.69	0	149.69	Relatively hard
Tang Zardalu	200.31	0	200.31	Hard
Charkh o Falak	173.12	0	173.12	Hard
Band e Ghadimi	176.73	0	176.73	Hard
Benrud	147.79	0	147.79	Relatively hard
Hossein Abad	228.03	0	228.03	Hard
Sarab Hende	174.18	0	174.18	Hard
Abbas Abad exit	175.32	0	175.32	Hard
Ghaleh Shahrokh	158.15	0	158.15	Hard
Eskandari	226.04	0	226.04	Hard
Regulatory Dams	149.08	0	149.08	Relatively hard
Zamankhan bridge	149.2	0	149.2	Relatively hard
Pol e Kale	161.94	0	161.94	Hard
Henjin	426.86	65.05	361.81	Very hard

Table 10 shows types and kinds of water quality for 15 stations under study. According to this table, type and kind of water quality in 13 stations have been calcic bicarbonate and just two stations; Hossein Abad and Henjin have had sodic sulphate type and kind.

Table10. *Ionic frequency, type and kind of water and how to develop it*

Station	Type of water	Water facies	Type and facies	Cations concentration	Concentration of anions
Ghaleh Eslam Abad	Bicarbonate	Calcic	Bicarbonate calcic	Ca > Mg > Na+K	HCO3 > SO4 > Cl
Zardfahreh	Bicarbonate	Calcic	Bicarbonate calcic	Ca > Mg > Na+K	HCO3 > SO4 > Cl
Tang Zardalu	Bicarbonate	Calcic	Bicarbonate calcic	Ca > Mg > Na+K	HCO3 > Cl > SO4
Charkh o Falak	Bicarbonate	Calcic	Bicarbonate calcic	Ca > Mg > Na+K	HCO3 > SO4 > Cl
Band e Ghadimi	Bicarbonate	Calcic	Bicarbonate calcic	Ca > Mg > Na+K	HCO3 > SO4 > Cl
Pole Bardekan	Bicarbonate	Calcic	Bicarbonate calcic	Ca > Mg > Na+K	HCO3 > SO4 > Cl
Benrud	Bicarbonate	Calcic	Bicarbonate calcic	Ca > Na+K > Mg	HCO3 > SO4 > Cl
Hossein Abad	Sulfated	Sodic	Sodic sulphate	Na+K > Ca > Mg	SO4 > HCO3 > Cl
Sarab Hende	Bicarbonate	Calcic	Bicarbonate calcic	Ca > Na+K > Mg	HCO3 > Cl > SO4

Abbas Abad exit	Bicarbonate	Calcic	Bicarbonate calcic	Ca > Na+K > Mg	HCO3 > Cl > SO4
Ghaleh Shahrokh	Bicarbonate	Calcic	Bicarbonate calcic	Ca > Mg > Na+K	HCO3 > Cl > SO4
Eskandari	Bicarbonate	Calcic	Bicarbonate calcic	Ca > Mg > Na+K	HCO3 > SO4 > Cl
Regulatory Dams	Bicarbonate	Calcic	Bicarbonate calcic	Ca > Mg > Na+K	HCO3 > SO4 > Cl
Zamankhan bridge	Bicarbonate	Calcic	Bicarbonate calcic	Ca > Mg > Na+K	HCO3 > SO4 > Cl
Pol e Kale	Bicarbonate	Calcic	Bicarbonate calcic	Ca > Mg > Na+K	HCO3 > SO4 > Cl
Henjin	Sulfated	Magnesium	Magnesium Sulfated	Mg > Na+K > Ca	SO4 > HCO3 > Cl

Another factor that affects the water quality is corrosive. Lack of control of chemical water quality in the distribution network caused corrosion phenomena and deposition and resulted in health and economic harm. Corrosive is one of the most important problems in the water industry and can cause general health, changing quality and high cost of the water distribution system and it makes economic, aesthetic and health problems. Corrosive water will also create problems for beneficiaries. Table 11 represents a qualitative classification of stations in the Zayandehrud basin based on a Langelier index that its interpretation will be shown in Table 5. According to the table, qualitative classification of stations under study has been corrosive from industrial viewpoint and based on aLangelier index except Hossein Abad station which has been deposited.

Table11. *Qualitative classification of stations in the Zayandehrud basin based on a Langelierindex (Industrial)*

Station	PH	PHs	PHs-PH	Water quality
Ghaleh Eslam Abad	7.43	8.5	-1.066	Corrosive
Zardfahreh	7.44	8.8	-1.364	Corrosive
Tang Zardalu	7.54	8.4	-0.865	Corrosive
Charkh o Falak	7.36	8.5	-1.142	Corrosive
Band e Ghadimi	7.47	8.8	-1.329	Corrosive
Pole Bardekan	7.08	8.8	-1.722	Corrosive
Benrud	7.74	8.2	-0.46	Corrosive
Hossein Abad	7.83	7.5	0.33	Sedimentation
Sarab Hende	7.54	8	-0.462	Corrosive
Abbas Abad exit	7.45	8	-0.552	Corrosive
Ghaleh Shahrokh	7.59	8.6	-1.012	Corrosive
Eskandari	7.58	8.4	-0.822	Corrosive
Regulatory Dams	7.63	8.6	-0.975	Corrosive
Zamankhan bridge	7.63	8.6	-0.974	Corrosive
Pol e Kale	7.46	8.3	-0.836	Corrosive
Henjin	7.37	7.5	-0.129	Corrosive

Corrosive waters make significant costs through different ways which the most important ones are as follows: damage to plumbing and residential water supply network, creating a bitter taste to water due to the relatively large amounts metallic compounds, increasing of loss and risk of poisoning because of the use of water which have toxic metals such as lead and copper.

Conclusion

Iran is located in arid and semi-arid of the world and it has shortage of freshwater resources. The current surface water or rivers are the most important water resources which have a major role in supplying water required for various activities such as agriculture, industry, drinking water. Zayandehrud is the largest river in the central plateau of Iran, which originated from central Zagros Mountains, especially ZardKuh Bakhtiari and extends in Iran's central desert some 200 km to the East and eventually goes Gavkhuni Marsh. So, to review the status of water use and protection of water resources against pollution, especially in the global water crisis is necessary and vital. Given the importance of Water quality monitoring, assessment water quality parameter of the 15 stations in the river basin Zayandehrud has been done during 5 decades from 1967-2009 for drinking, agriculture and industry which are goal of the present research. Surveying the results shows that of Drinking Water Quality based on the diagram Schuler is good and acceptable. Regarding agriculture and irrigation, according to Wilcox diagram, except for two stations Hossein Abad and Henjin which were (salty C3S1), the other stations suitable were a bit salty but suitable for agriculture (C2S1). Water quality of ten stations has been hard water; four stations fairly hard and the only Henjin station has been estimated quite hard. The type and kind of this basin water has been calcic bicarbonate at 13 stations and in two stations Hossein Abad and Henjin have been sodic sulfate and Magnesium Sulfated. Qualitative classification of stations based on both industrial and according to Langelier index is estimated to be corrosive except Hossein Abad station that has been deposited. It is suggested other estimates shall be carried out in accordance with current standards for the basin such as heavy metal pollution, toxic metals, pesticides, turbidity, organic substances, domestic sewage, pollution, etc.,

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Citation: Mohammad Salarian, Masumeh Najafi, S Vahid Hosseini, Mohammad Heydari, *"Classification of Zayandehrud River Basin Water Quality Regarding Agriculture, Drinking, and Industrial Usage", American Research Journal of Civil and Structural Engineering, vol 1, no. 1, pp. 47-57.*