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Original Research Paper

An Investigation of the Chemical Quality of Groundwater Sources

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The quality problems of groundwater sources had become more important than the quality of groundwater sources. The aim of this study is to investigate the chemical quality of groundwater sources for domestic purpose in Semnan city of Iran by using Aq.Qa software and compared with national standard. We examined the physicochemical quality fluctuations of 15 wells in Semnan during three seasons in the year of 2014. 13 physicochemical parameters of drinking water were calcium, chloride, conductivity (EC), magnesium, permanent hardness, pH, residual chlorine, sulfate, temperature, total alkalinity, total dissolved solid (TDS), total hardness (TH), and turbidity. We compared the results with national standard values of drinking water and drew the chemical diagrams of water with the Aq.QA software. We applied the stiff diagram, ion balance, piper diagram, and schoeller diagram, for determining the water type, anionic-cationic balance, chemical characteristics of water and mean concentration of water parameters, respectively. Water type was calcium sulfate, in 11% of samples. The TDS range of 45 samples was 185-1100 mg/l (fresh and slightly saline level). The pH range of well water samples was the basic in summer. The Temperature range of 45 samples was 12-23 °C. The EC range of well water samples in spring was higher than the well water samples in summer and fall. The TH range of 45 samples was 720-1600 mg/l ($CaCO_3$) (hard and very hard level). The TH range of well water samples in spring was higher than the well water samples in summer and fall.

Keywords: Aq.QA, Semnan, Total dissolved Hardness, Water quality, Well water.

INTRODUCTION

Water considered as the most vital natural resource without which life would be nonexistent (Arabi et al., 2010). Available, safe, and adequate water source is a necessary condition for sustainable development in a society (Asonye et al., 2007). Groundwater source was widely extracted for potable (drinking water supply) and agricultural purposes (Zekster and Everett, 2004). The depletion in quality and the increase in pollution levels of groundwater sources mainly attributed to natural resources such as geology formation, and human-made resources such as industrial, agricultural, and commercial activities.

Nowadays, groundwater sources constitutes 100% of the Semnans water purposes, such as agricultural, domestic, and industrial purposes. It was important that we investigated the groundwater quality as regards area arid climate. Therefore, a detailed map of groundwater source quality contributed to the groundwater quality surveillance program. The geographical information system (GIS), and Aq.QA software helped us to prepare this map. Adedeji et al. (2010) reported the investigation of the groundwater quality in Uyo, Akwa-Ibom state of Nigeria by sampling and analyzing 40 borehole water samples. The results indicated that water samples were highly acidic (Adedeji et al., 2010). Balakrishnan et al. (2011) investigated the groundwater quality in Gulbarga City, Karnataka State, India. For this study, they tested 76 bore wells and open wells representing the entire corporation area. The results of chloride indicated that 46 (60.53%) of the samples complied with a value of 250 mg/L. (Balakrishnan et al., 2010).

Batayneh (2006) investigated the eastern Dead Sea coastal aquifers. The finding indicated that Saline intrusion into coastal aquifers considered as a main problem because saline intrusion constituted the commonest of all the pollutants to freshwater (Batayneh, 2006). Due to direct effects of population increase, and excessive application of chemical fertilizers on the static water level or groundwater table decline and quality diminishing of groundwater sources, we performed this study in Semnan city. We investigated the variation in

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physicochemical quality of groundwater sources in the study area during spring, summer, and fall seasons. 13 physicochemical parameters of drinking water were calcium (Ca^{+2}), chloride (Cl^-), conductivity (EC), magnesium (Mg^{+2}), permanent hardness (NCH), pH, residual chlorine, sulfate (SO_4^{-2}), temperature (Tem), total alkalinity (T. Alk), total dissolved solid (TDS), total hardness (TH), and turbidity (T).

MATERIALS AND METHODS

Description of the study area (Semnan City)

Fig. 1 showed the location of Semnan city, Semnan province, Iran. The area of the city was 22191 km^2. The estimated Semnan population in 2014 was 148975 people. Summit altitudes of ridges in Semnan were 1117 m above sea level. It is located within an area of arid climate. The area had relatively cold winters and hot summers. Temperature ranged from -4.6 to 35.4 degrees °C. Average annual precipitation in the area was 140 mm. The major lithology formations included Dolomite, limestone, and gypsum.

Sample collection

We employed the GIS software package ArcGIS 9.2 for mapping and analyzing the data for the investigation of groundwater quality (Kalaiselvan et al., 2010). We detected active drinking wells for analyzing the physicochemical characteristics of groundwater in the study area. We took the water samples from fifteen selected drinking water wells in different areas in Semnan City and Semnan suburbs, Semnan province, Iran from March 2014 to December 2014. We collected the samples in white plastic containers.

Analytical methods

We performed all tests in triplicate (1755 test), and reported the mean data values. We tested the water samples for 13 physicochemical parameters of drinking water such as Ca^{+2}, Cl^-, EC, Mg^{+2}, NCH, pH, residual chlorine, SO_4^{-2}, Tem, T. Alk, TDS, TH, and T. We determined all tests according to procedure detailed in standard methods. We measured the parameter such as: pH, Tem, T, and EC by using pH meter (HACH, USA), turbidity meter, and conductivity meter (HACH, USA), respectively. We analyzed the TDS according to the gravimetric method (2540).

We measured the NCH, TH, total alkalinity, and Cl^- according to standard methods 2340, 2340, 2320, and 4500, respectively. We measured the Ca^{+2}, and Mg^{+2} with an atomic absorption spectrophotometer (Perkin - Elemer AAS3110), while the SO_4^{-2} by using a colorimetric method with visible/UV, spectrophotometer (Unico UV2100, Germany) (HAPA, 2012). We performed all tests at laboratory temperature (20 ˚C). Also measured at the field included each coordinates of the sampled locations using GPS.

Water chemical diagrams

We interpreted the results of all tests with Rock Ware (2006) Aq.QA spreadsheet for water analysis. We applied the stiff diagram, ion balance, piper diagram, and schoeller diagram, for determining the water type, balance of anionic-cationic, chemical specification of water (basic), chemical characteristics of water (minimum and maximum concentration of parameters), and mean concentration of parameters of water parameters, respectively (Rock Ware, 2006).

RESULTS

We showed the results obtained from this study below. We illustrated the groundwater physicochemical quality and graphical presentation of groundwater physicochemical quality.

Results of groundwater physicochemical quality

We summarized the laboratory and field analyses of water samples from 15 wells. We interpreted the concentrations of physicochemical parameters in groundwater according to the mean, minimum and maximum concentrations. We also compared the results with Iranian National standards, world health organization (WHO) standards, and environmental protection agency (EPA US) standards (Tables 1-3). Table 4 showed classification of groundwater according to aggressive index (AI) value (Kalaiselvan et al., 2010). Table 4 showed TH classification as well as the percentage hardness of groundwater samples. Table 5 showed classification of groundwater according to TDS values. Table 6 showed classification of groundwater according to EC values. Table 7 showed TH classification as well as the percentage hardness of groundwater samples (Balachandar, 2010).

As found in table 1-3, the turbidity, pH, TDS, Cl^-, and SO_4^{-2} of all samples taken did not exceed the maximum acceptable concentrations, (were 5 NTU, 6.5-9, 1500 mg/L, 400 mg/L, and 400 mg/L, respectively). The pH range of well water samples was basic in summer. The residual chlorine of many samples taken exceeded the maximum acceptable concentration, (was 0.2-0.8 mg/L). The results of residual chlorine during spring, summer, and fall seasons of 2014 showed that 27%, 50%, and 25% of samples exceed the maximum acceptable concentration, respectively. The TH of many samples taken exceed the maximum acceptable concentration, (was 500 mg/L as $CaCO_3$).

The results of TH during spring, and summer seasons of 2014 showed that 5%, and 14% of samples exceed the maximum acceptable concentration, respectively. As found in table 4, the results of AI during spring season of 2014 showed that 7% of samples was aggressive level, (AI> 12). As found in table 5, the TDS of all samples taken did not fall under moderately saline, very saline, and brine category. As found in table 6, the EC of samples taken did not fall under excellent and doubtful category. The fall samples had the highest conductivity. As found in table 7, the TH of samples taken did not fall under soft, and moderately hard water category. The spring samples had the highest TH.

Graphical presentation of groundwater physicochemical quality

Piper diagram was a composition of anions and cations triangle, and grouped waters into main types (Fig. 2). The Schoeller diagram showed the composition of major and minor parameters of groundwater in the Semnan city in a diagram (Fig. 3). Stiff diagram was a method for plotting graphical summaries of the major anions and cations chemistry, as meq. Stiff diagrams allowed the composition of water samples to be compared (Fig. 4).

Ion balance diagram was a composition of anions and cations, and indicated balance or unbalance of anionic-cationic of groundwater sample in the Semnan city (Fig. 5). The plot corresponding to piper diagram was showed in Figure 2 where three classes of composition were obtained. Water type was calcium sulfate, in 11% of samples.

Figure 1: Location map of Semnan city

Table 1. The physicochemical characteristics of drinking wells samples from Semnan city, Semnan Province in spring season-2014

No.	Parameter	Unit	Highest desirable level	Maximum acceptable concentration	Mean concentration	Concentration range	
						Minimum	Maximum
1	Calcium (Ca^{+2})	mg/L	300	-	83	48	128
2	Chloride (Cl^{-})	mg/L	250	400	127	28	324
3	EC	µs/cm	-	-	918	370	2210
4	Magnesium (Mg^{+2})	mg/L	50	-	22	10	49
5	NCH	mg/L as $CaCO_3$	-	-	155	70	500
6	pH		6.5-8.5	6.5-9	7.5	6.8	7.8
7	Residual chlorine	mg/L	-	0.2-0.8	0.3	0	1
8	Sulfate (SO_4^{-2})	mg/L	250	400	102	20	254
9	TDS	mg/L	1000	1500	496	190	1100
10	Temperature	˚C	-	-	17	12	23
11	TH	mg/L as $CaCO_3$	200	500	298	160	720
12	Total Alkalinity	mg/L as $CaCO_3$	-	-	26	20	28
13	Turbidity	NTU	≥ 1	5	0.4	0.25	0.8

(Source: Iranian National standards, 2014)

Table 2. The physicochemical characteristics of drinking wells samples from Semnan city, Semnan Province in summer season-2014

No.	Parameter	Unit	Highest desirable level	Maximum acceptable concentration	Mean concentration	Concentration range	
						Minimum	Maximum
1	Calcium (Ca^{+2})	mg/L	300	-	85	40	184
2	Chloride (Cl^{-})	mg/L	250	400	102	28	296
3	EC	µs/cm	-	-	713	371	1457
4	Magnesium (Mg^{+2})	mg/L	50	-	19	10	44
5	NCH	mg/L as $CaCO_3$	-	-	131	70	300
6	pH		6.5-8.5	6.5-9	7.5	6.8	8.2
7	Residual chlorine	mg/L	-	0.2-0.8	0.3	0	o.7
8	Sulfate (SO_4^{-2})	mg/L	250	400	96	16	353
9	TDS	mg/L	1000	1500	451	185	886
10	Temperature	˚C	-	-	19	15	20
11	TH	mg/L as $CaCO_3$	200	500	293	180	640
12	Total Alkalinity	mg/L as $CaCO_3$	-	-	27	24	28
13	Turbidity	NTU	≥ 1	5	0.4	0.3	0.5

(Source: Iranian National standards, 2014)

Table 3. The physicochemical characteristics of drinking wells samples from Semnan city, Semnan Province in fall season-2014

No.	Parameter	Unit	Highest desirable level	Maximum acceptable concentration	Mean concentration	Concentration range	
						Minimum	Maximum
1	Calcium (Ca^{+2})	mg/L	300	-	87	64	112
2	Chloride (Cl^{-})	mg/L	250	400	102	28	296
3	EC	µs/cm	-	-	1169	1006	1680
4	Magnesium (Mg^{+2})	mg/L	50	-	22	15	24
5	NCH	mg/L as $CaCO_3$	-	-	151	100	200
6	pH		6.5-8.5	6.5-9	7.6	7.1	7.8
7	Residual chlorine	mg/L	-	0.2-0.8	0.5	0	o.7
8	Sulfate (SO_4^{-2})	mg/L	250	400	141	95	250
9	TDS	mg/L	1000	1500	539	515	840
10	Temperature	˚C	-	-	16	15	20
11	TH	mg/L as $CaCO_3$	200	500	310	300	340
12	Total Alkalinity	mg/L as $CaCO_3$	-	-	28	28	28
13	Turbidity	NTU	≥ 1	5	0.4	0.2	0.5

(Source: Iranian National standards, 2014)

Table 4. Groundwater classification based on AI value from Semnan city, Semnan Province -2014

AI	Water class	No. of groundwater samples		
		spring season	summer season	fall season
< 10	Non aggressive	0	0	0
10-12	Moderate	14 (93%)	15 (100%)	15 (100%)
> 12	Aggressive	1 (7%)	0	0

(Source: Massey and Steele, 2012)

Table 5. Groundwater classification based on TDS value from Semnan city, Semnan Province -2014

TDS (mg/L)	Water class	No. of groundwater samples		
		spring season	summer season	fall season
< 1000	Fresh water	14 (93%)	15 (100%)	15 (100%)
1000-3000	Slightly saline	1 (7%)	0	0
3000-10000	Moderately saline	0	0	0
10000-35000	Very saline	0	0	0
> 35000	Brine	0	0	0

(Source: Davis and De Wiest, 1996)

Table 6. Groundwater classification based on EC value from Semnan city, Semnan Province -2014

EC (µs/cm)	Water class	No. of groundwater samples		
		spring season	summer season	fall season
< 250	Excellent	0	0	0
250-750	Good	5 (33%)	10 (67%)	0
750-2250	Permissible	10 (67%)	5 (33%)	15 (100%)
> 2250	Doubtful	0	0	0

(Source: Balachandar, 2010)

Table 7. Groundwater classification based on TH value from Semnan city, Semnan Province -2014

TH (mg/L as $CaCO_3$)	Water class	No. of groundwater samples		
		spring season	summer season	fall season
0-75	Soft water	0	0	0
75-150	Moderately hard water	0	0	0
150-300	Hard water	8 (53%)	11 (73%)	9 (60%)
> 300	Very hard water	7 (47%)	4 (27%)	6 (40%)

(Source: Sawyer and Mc Carty, 1997)

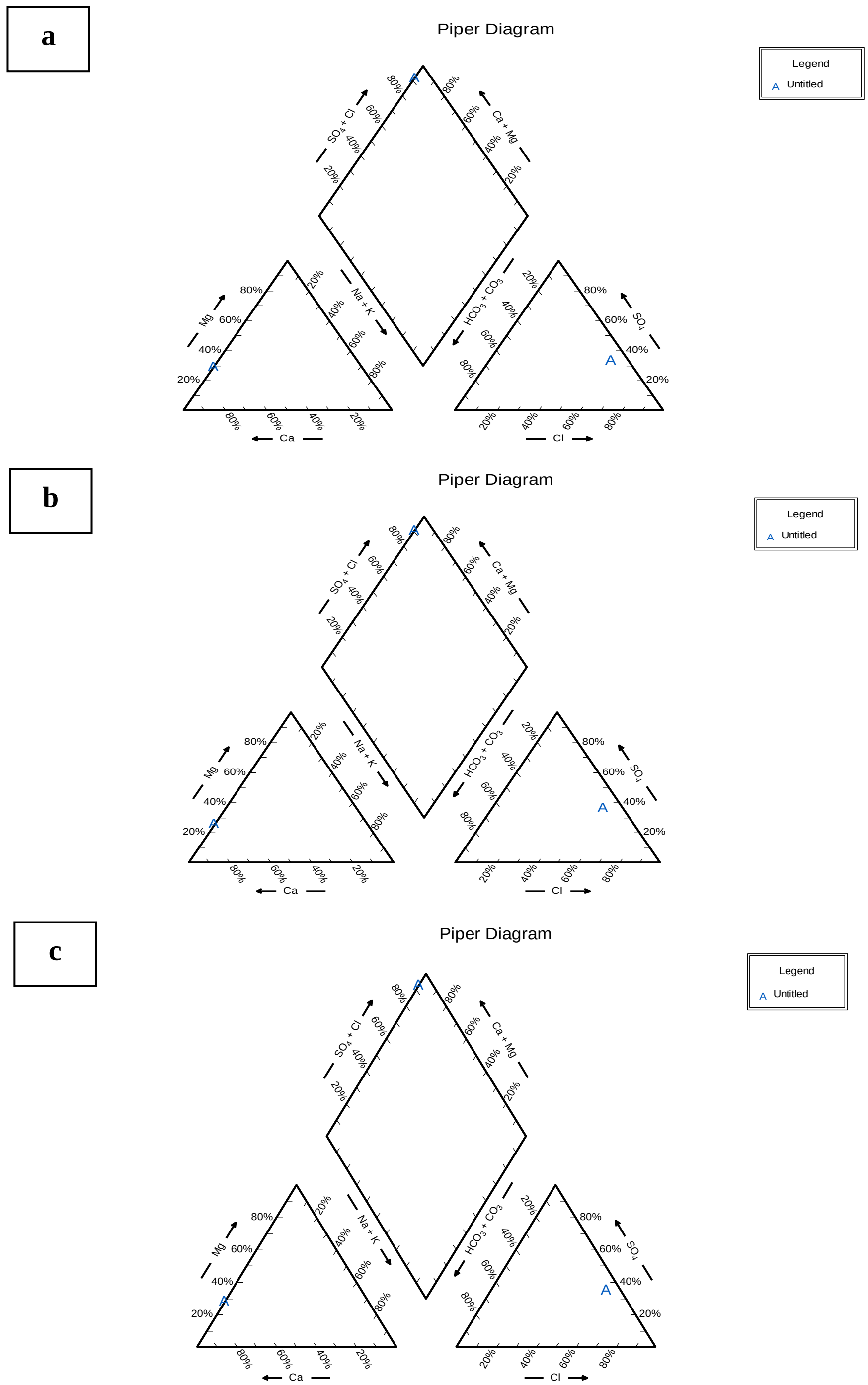

Figure 2: Piper diagram for groundwater samples from Semnan city and suburbs in 2014 (a: spring season; b: summer season; c: fall season)

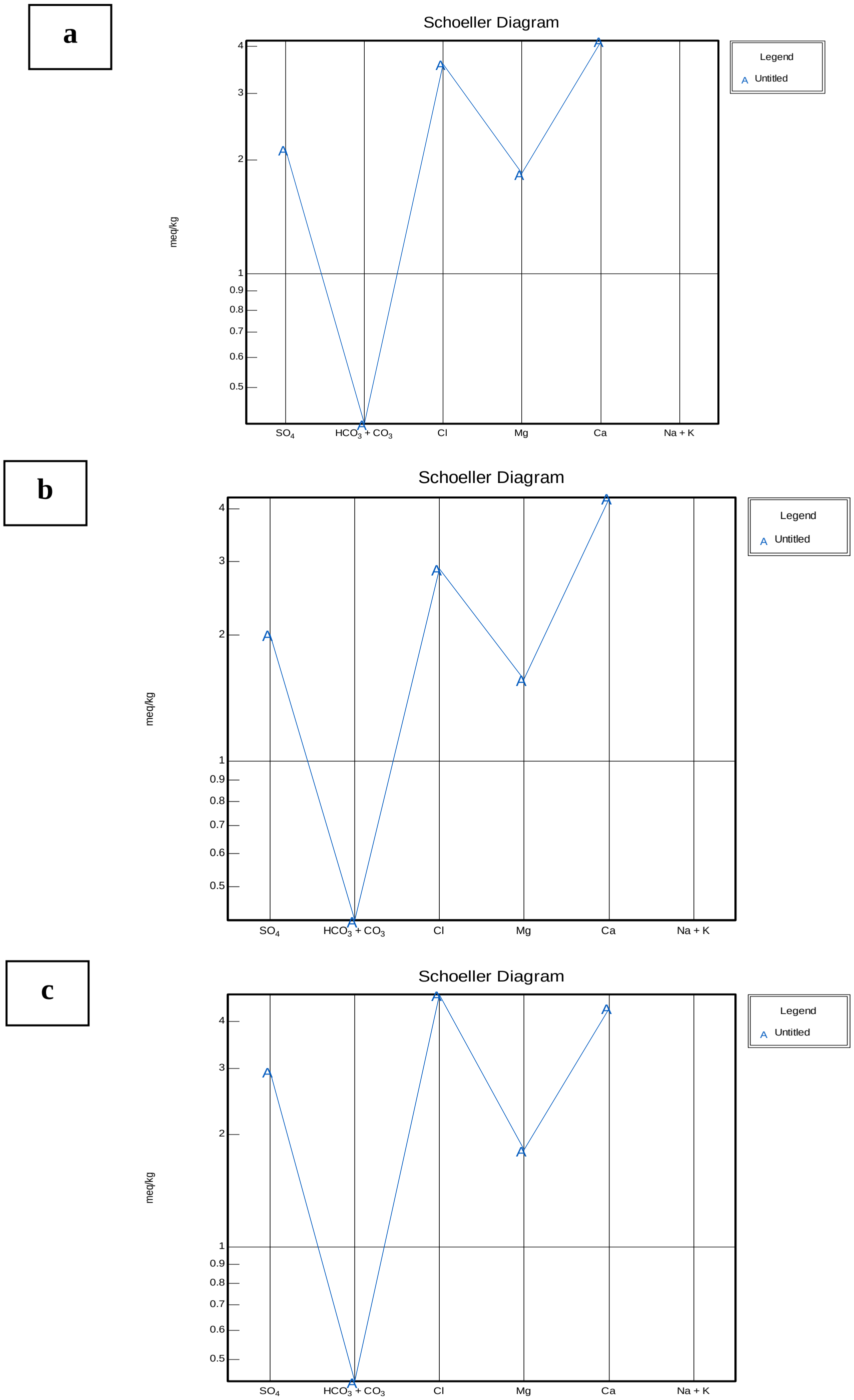

Figure 3: Schoeller diagram for groundwater samples from Semnan city and suburbs in 2014 (a: spring season; b: summer season; c: fall season)

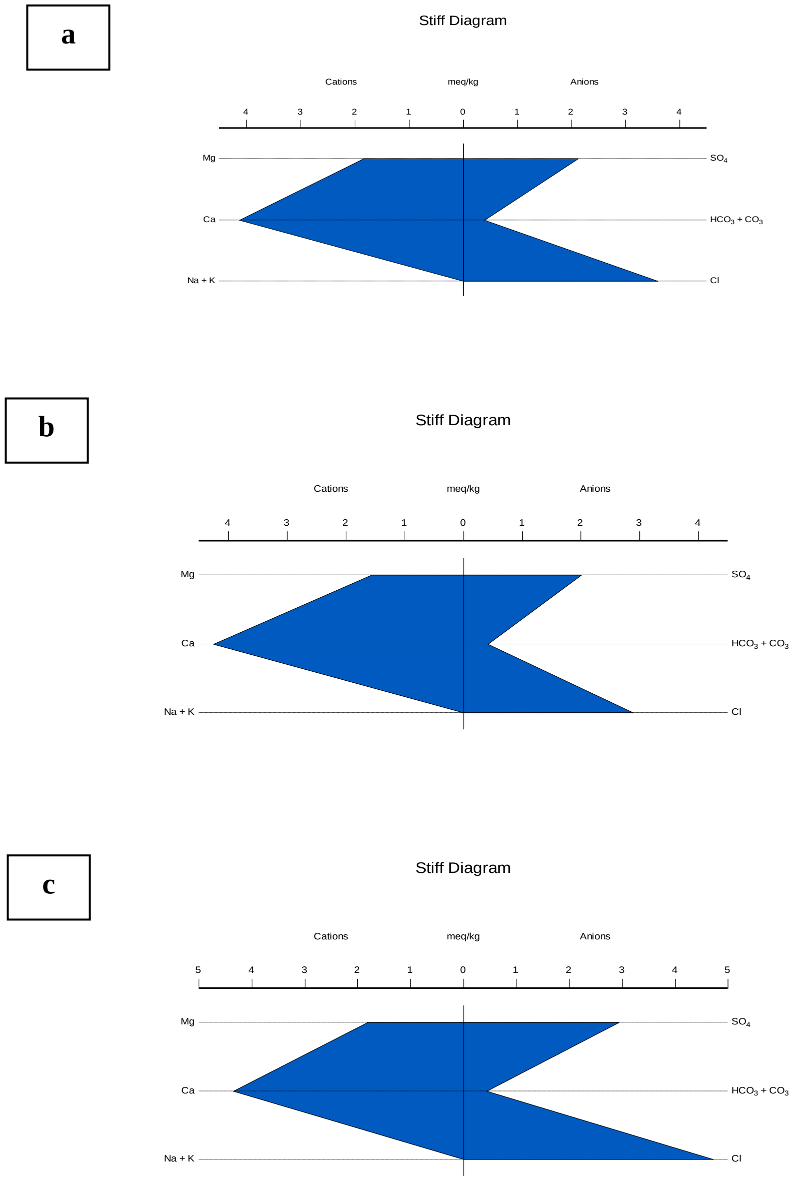

Figure 4: Stiff diagram for groundwater samples from Semnan city and suburbs in 2014 (a: spring season; b: summer season; c: fall season)

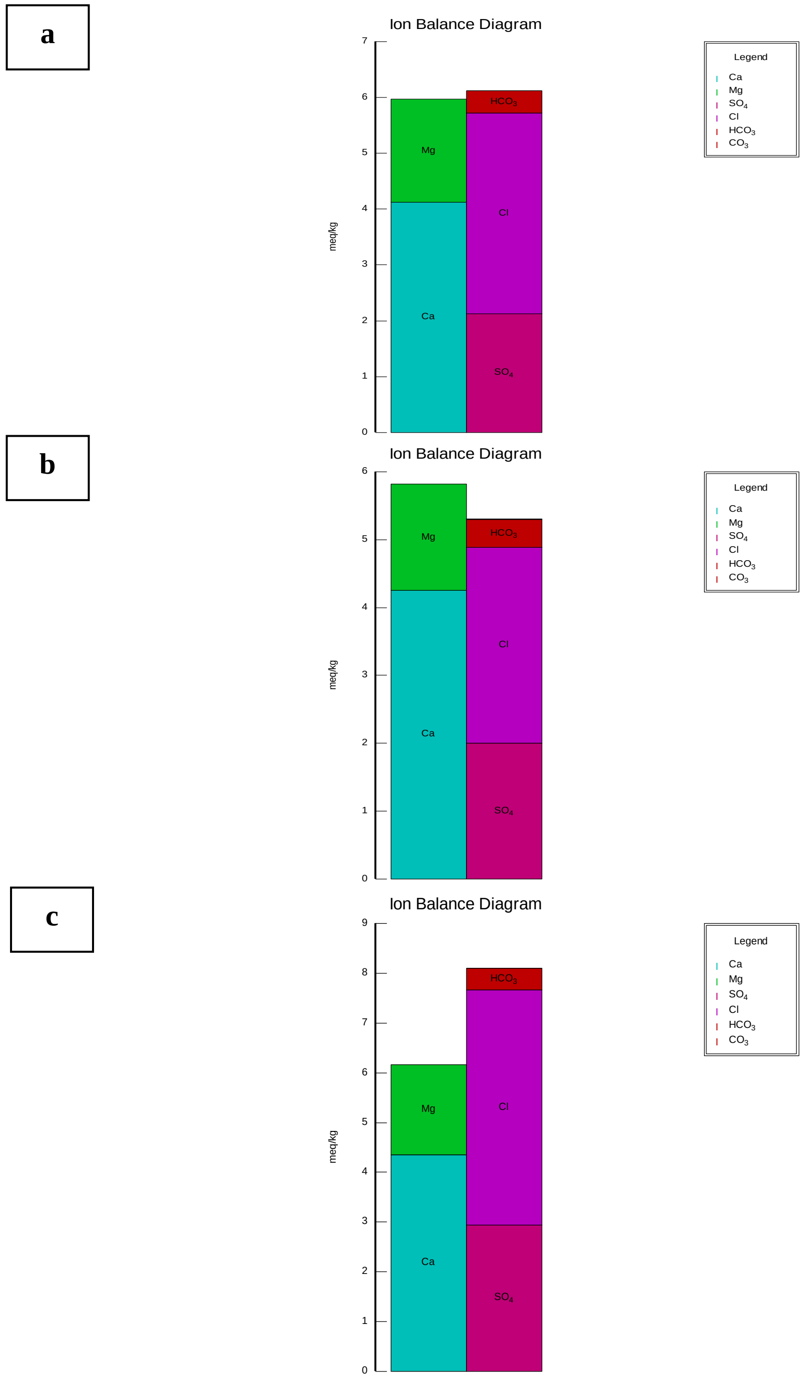

Figure 5: Ion balance (anionic-cationic) for groundwater samples from Semnan city and suburbs in 2014 (a: spring season; b: summer season; c: fall season)

The Schoeller diagram showed that Cl^-, and HCO_3^-,+ CO_2 were the most, and the least, respectively (Fig. 3). As found in Fig. 4, wells in study area all had a similar shape polygon with dominant calcium cations and chloride anions. As found in Fig. 5, wells in study area showed balance of anionic-cationic of groundwater sample in spring season.

DISCUSSION

Drinking water quality standards were established the for protection of public health. Drinking groundwater standards established according to the highest desirable level and maximum acceptable concentration (MCL_S) in water. The MCL_S TDS and TH in healthy drinking water were 1500 mg/L, and 500 mg/L as $CaCO_3$, respectively. The analysis of ground water samples led to classifying of water from the study area into two water types with formulae Ca-Cl and Ca-SO4 showing chloride and sulfate water types. Most of the groundwater samples analyzed had calcium chloride (89%) water type except sample Sufiabad, Emamzadeh Abdullah, Family, Loard, And Dozihear which had calcium sulfate water type. Therefore, a majority of the cations and anions were calcium and chloride, respectively.

The calcium water type was expected and could be attributed to lithology formations such as dolomite, limestone, and calcite. Murad et al. (2012) reported a water quality change that was characterized by a transition from soudium-sulfate type groundwater in the northwest to a calcium-chloride type groundwater in the southeast of Eastern Part of Abu Dhabi Emirate, United Arab Emirates (Murad et al., 2012). From the viewpoint of health, the concentration of calcium in groundwater was unimportant. The aggressive index was shown as;

AI = pH + log ([total alkalinity] × [calcium hardness]).

All the samples analyzed were moderate with AI values ranging from 10.1 to 11.99 except sample Surkhea, southern part of the study area, with AI value 12.76. The mean concentrations of TDS in spring, summer, and fall seasons obtained were 496, 451, and 539 mg/L, respectively. According to TDS classification, the groundwater in the area studied was considered as fresh water. Sample Surkhea, southern part of the study area, also reported the highest TDS value of 1100 mg/L in spring season. The TDS concentration could be attributed to rocks types. According to TDS classification, the groundwater in the Surkhea was considered as slightly saline. Oyedele (2009) reported the range sample had a TDS concentration of less than 465 mg/L in both layers 1 and 2 (more than 95% of the investigated stations) (Oyedele, 2009). The mean values of EC in spring, summer, and fall seasons obtained were 918, 713, and 1169 µs/cm, respectively.

According to EC classification, the groundwater in the area studied was considered as permissible, good, and permissible water, respectively. Sample Surkhea, southern part of the study area also reported the highest EC value of 2210 µs/cm in spring season. Therefore, the EC value as a function of TDS was directly proportional to the TDS concentration in groundwater. The EC value could be attributed to basic rocks type, and mean annual rainfall. According to EC classification, the groundwater in the Surkhea considered as permissible. The EC value indicated that seasonal patterns, with the highest EC usually reported in September (fall season). The soil parameter was considered to be significant only next to geology and geomorphology since it affected on groundwater combination during rainfall period. Rainfall and irrigation recharge patterns were probably liable for the observed seasonal variations. The highest values in spring were likely related to leaching of soluble ions from the soils after unusually high winter recharge. The EC recorded in groundwater from north Chennai, Tamilnadu, India was within the range of 600 to 34000 mS/cm as reported by Ponniah Raju (2013) for soil (Ponniah Raju et al., 2013). The mean concentrations of TH in spring, summer, and fall seasons obtained were 298, 293, and 310 mg/L as $CaCO_3$, respectively.

According to TH classification, the groundwater in the area studied was considered as hard, and very hard water, respectively. Sample Surkhea, southern part of the study area, also reported the highest TH value of 720 mg/L as $CaCO_3$ in spring season. The TH concentration could be attributed to rocks types. According to TH classification, the groundwater in the Surkhea considered as very hard water. The hardness < 500 ppm was recommended for drinking purpose. Scott et al. (2011) reported that recharge from the Rangitata River affected groundwater samples with high Ca/Mg ratios (. Scott et al. 2011).

CONCLUSION

The groundwater physicochemical quality of Semnan City and suburbs for domestic purpose was investigated. The following conclusions were obtained from the experiments:

(1) The variations seasons perceptibly affected groundwater physicochemical quality.

(2) The turbidity, pH, EC, residual chlorine, TH, Cl^-, and SO_4^{-2} achieved the highest concentration in fall season.

(3) The temperature and TDS achieved the highest concentration in summer season.

(4) Sample Surkhea, southern part of the study area, had the highest TDS, EC, and TH concentrations in spring season. The quality of groundwater was the best in the northern part of the study area and deteriorated in the southern part of the study area.

(5) The mean concentration of TDS considered as fresh water in all seasons. The mean value of EC considered as good, and permissible water in all seasons. The mean concentration of TH considered as hard, and very hard water in all seasons.

(6) The general progressive decline of groundwater quality did not occur in the study area.

(7) Site definite groundwater quality problems in the sulfate aquifer seemed to be attributed to leaching of poor quality water.

(8) The groundwater in the area studied was suitable for use in homes.

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