Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2023.29554

294 (2023) 51–59
May

Physical and chemical evaluation of groundwater quality in Jouf region in Saudi Arabia for energy, agriculture and drinking purposes

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Received 10 February 2023; Accepted 15 April 2023

ABSTRACT

In the current study, groundwater quality assessment for energy, potable, and irrigation purposes was done in the Jouf region in Saudi Arabia. The samples of groundwater were gathered from twenty wells distributed from the fourth direction. The physical features like total dissolved solids (TDS), pH, conductivity, and turbidity values in the study area have been examined and it found that 90% of the gathered water specimens exhibited TDS magnitude in the range of 393–1,000 mg/L and pH values were in the range 6.39–7.54, indicating safe water for drinking and the rest can be used in energy purpose. The abundance of main cations is calcium (Ca^{2+}) and magnesium (Mg^{2+}) hardness, sodium (Na^{+}), and potassium (K^{+}), and anions are chloride (Cl^{-}) followed by SO_4^{2-}. The cation ions contents in all samples were within the permissible limit except sample S-HD. The results revealed that the increase in SO_4^{2-} is convoyed by increases in the proportion of sodium and magnesium because the existing sulfates are in the form of sodium, magnesium, and calcium salts. All results confirmed that the samples from the south region presented the best water quality except S-HD. Moreover, boron (B) hasn't been detected in all water samples indicating that no other hazardous substances are possibly present in groundwater in the Jouf region. A pre-treated prior to use is necessary for consumption or agricultural irrigation of groundwater based on the purpose.

Keywords: Water quality; Salinity; Physicochemical properties; Spectrophotometric; Energy purposes; Jouf region

1. Introduction

The Kingdom of Saudi Arabia needs more water supplies. It also stems from the role played by water in the development plans of the Kingdom, as well as the global relevance of water issues and policies [1]. The effective delivery of a sustainable, safe, and clean water source is receiving a priority of research in Saudi Arabia where water is an essential source of life [2,3]. And, as the population of the Kingdom of Saudi Arabia (KSA) grows, the risk of depriving more people of adequate food supplies in poor areas, especially those subject to water scarcity, increases. Increasing agricultural food production is needed to ensure global food security and therefore, irrigation will increasingly to help meet this request [4–6]. In the race to enhance agricultural productivity and water consumption, irrigation will become controlled. Agriculture is the foremost consumer of KSA water around 84% of KSA water is used in irrigation. In addition, KSA has limited resources of water and low recharge rates due to arid conditions [7]. In Saudi Arabia, groundwater combined with desalinated sea water is the main supply of potable water system [4,8,9]. The primary groundwater resources that provide drinking water have features that have a significant impact on the quality

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Presented at the International Conference on New Trends in Renewable Energy and Environment for 2030 Vision (ICNTREE 2022), 24–26 January 2023, Jouf, Saudi Arabia

1944-3994/1944-3986

of the water [10]. In developing nations, it is important to give more thought to groundwater quality issues and possible management strategies. The interaction of water with soils and sediments, the flow channel, the types of rocks, and the prevalent geochemical conditions, such as dissolution, redox state, precipitation, leaching, ion exchange, etc., all affect the quality of groundwater [11]. From the perspective of public health, as well as for its comprehensive management and effective exploitation under the growing influence of climate change, water quality evaluation is crucial. In desertic aquifers, a variety of factors, including topography, soil chemistry, water interaction with aquifer minerals, and internal mixing of chemically diverse groundwater along flow pathways in the subsurface, regulate the climate and the hydrochemistry of groundwater [12,13]. Hydrogeochemical processes such as the weathering of aquifer minerals and the duration of water retention in the subsurface [12,14] determine the genetic makeup of groundwater. Since groundwater is the only source of drinkable water in these arid locations because there are no surface water resources, potable water quality assurance is more important than ever [15]. Groundwater salinization is a prevalent issue in arid and semi-arid regions because of the harsh climatic conditions there. In certain areas, the soil also becomes salinized as a result of a high rate of evaporation brought on by the extremely high temperatures.

Jouf region is considered one of the new agricultural regions in KSA with very high potential in agricultural development recently. Groundwater is currently limiting factor for intensifying the agricultural activities and providing drinking water sources. Consequently, there is lack of information on groundwater quality in Jouf region to make necessary management decisions toward energy, potable and irrigation uses. Hence, the assessment of physical and chemical properties of groundwater quality in Jouf area at Saudi Arabia are very important issue in order to increasing the concern of water [11]. High levels of the physico-chemical features make water unsafe and unadopted to the international standards. For the purpose of defining a water quality that is secure and appropriate for public health, the World Health Organization (WHO) and the Saudi Standards and Metrology Organization (SASO) produced drinking water standards for both packaged and un-packed water. The maximum permissible level of chemical components is defined by these criteria. [12,13]. Many investigations examined the evaluation of groundwater quality in various parts of Saudi Arabia, particularly in the Jouf and Al-Jawf districts. The results of this research show how critical it is to improve water management strategies and implement efficient water treatment techniques in the area to guarantee availability to safe and clean water for home and agricultural usage.

The main objective of this investigation is to assess the physico-chemical properties of groundwater in the Jouf region in Saudi Arabia to their oriented toward energy, agriculture and drinking purposes. In this study, water quality is the critical factor in achieving high management of groundwater. The different physical parameters have been examined for the groundwater samples, such as pH, conductivity, total dissolved solids (TDS), and turbidity. Also, the chemical content of the samples has been analyzed such as total, Mg^{2+}, Ca^{2+}, Na^+, K^+, Cu, Fe, Zn, B, S^{2-}, Cl^-, SO_4^{2-}, and SiO_2. This project supports the KSA Strategic Plans and the National Vision of 2030 by suggesting the appropriate groundwater application depending on the physicochemical evaluation.

2. Experimental set-up

2.1. Materials and methods

All materials in this work were in analytical grade and utilized without further treatment. Ethylenediaminetetraacetic acid (EDTA) disodium salt was purchased from Loba Chemie, India. Eriochrome black T (EBT), ammonium chloride (NH_4Cl), magnesium chloride ($MgCl_2$), potassium chloride (KCl), sodium chloride (NaCl), silver nitrate ($AgNO_3$) and murexide indicators were provided by Sigma-Aldrich, St. Louis, US. Potassium chromate (K_2CrO_4) was purchased from Chemical Works, Beijing. Cyclohexanone was procured from Alpha Chemika, India. Ammonia solution (NH_4OH, 25%) and sodium hydroxide (NaOH) were acquired from BDH Chemicals Ltd. (Poole, England). For all dilutions and test preparations, ultrapure water (Milli-Q, Millipore Corporation, Bedford, USA) was created and utilized. FerrVer iron, CuVer copper, molybdate powder, citric acid, SulfaVer 4 powder, ZincoVer 5 zinc, potassium 1, potassium 2, potassium 3, sulfide 1, sulfide 2, and BoroVer 3 reagents were provided from Hach to determine of targeted ions by spectrophotometers DR-1900.

2.2. Instruments

For the analysis of the experiment, a Hach UV-Vis spectrophotometer DR-1900 (Loveland, 5600 Lindbergh Dr, Colorado, United States) with a glass cell and a 50 mm optical path was employed. Conductivity and TDS were determined utilizing a conductivity meter (Hanna, Model H1763100, Romania). The pH of the solution was adjusted and measured employing a pH meter (BOECO, Model BT-700, Germany). A flame photometer was used to determine the content of Na (Jenway, Model PFP7, UK).

2.3. Preparation of reagents and buffer solutions

EBT indicator for total hardness titration was prepared through weighing 0.2 g of EBT and mixed with 50 g of KCl. Murexide indicator for calcium hardness titration was prepared by adding of 0.2 g of murexide into 100 g of NaCl. Buffer solutions were used for the determination of total and calcium hardness. For the determination of total hardness, the buffer prepared by adding 0.644 g of $MgCl_2$ in 50 mL water, and mixed with solution of 16.9 g of NH_4Cl in 143 mL of NH_3. For the determination of calcium (Ca^{2+}) hardness, the buffer solution was 1 M of NaOH. Determination of chloride (Cl^-) has been valued using Mohr method. In this method, the indicator of 5% K_2CrO_4 was synthesised using 0.5 g in 10 mL distilled water.

2.4. Groundwater samples collection

The samples have been collected from different places distributed in all four directions of Sakaka City at Jouf region, KSA. On March 22, 2022, water samples that were used in our investigation were taken. The total collected samples were 20 samples as follows: 5, 4, 6, and 5 samples from north, east, west, and south direction, respectively (Fig. 1). North samples were coded as N-SN, N-ND, N-AH, N-FA, and N-AM while the east samples were E-NA1, E-NA2, E-KA, and E-AT. West samples were coded as W-NS, W-AE, W-ED, W-MA, W-FB1, and W-FB2 and the last samples at south direction were coded as S-HD, S-NS1, S-NS2, S-NS3, and S-SS. Each sample was collected in two bottles using glass and Nalgene bottles (500 mL). Within 48 h, the specimens were tested after being stored at 4°C. Blanks and quality controls were evaluated in each batch to guarantee that the specimen's pollution did not occur, and that the sensitivity of the assessment remained constant throughout the experiments. The Chemistry Department Laboratory and the Central Laboratory at Jouf University hosted all of the analyses for our study.

2.5. Determination procedure

2.5.1. Physical parameters, total hardness and chloride content in groundwater

The physical properties of the collected groundwater samples, including pH, conductivity, and TDS, have been determined using pH and conductivity meters. Total hardness and the content of Ca^{2+} and Mg^{2+} were estimated using a complexation titration approach with EDTA (0.02 M) as a titrant. To determine Cl^- content, the precipitation titration method was applied with $AgNO_3$ (0.028 N) as titrant.

2.5.2. Elements and ions determination in groundwater

Elements and ions including, K^+, Na^+, Fe, Cu, B, Zn, Cl^-, S^{2-}, SO_4^{2-}, and SiO_2 have been determined in this evaluation. Using Hach spectrophotometer, each element and ion has a procedure with specific reagents applied to calculate their content in the samples. Briefly, to determine of Fe, 10 mL of the specimens introduced in a 50 mL cell and FerrVer iron reagent (sodium metabisulfite (20%–30%), sodium dithionite (10%–20%), 1,10-phenanthroline, and mono(4-methylbenzenesulfonate) (1%–5%) then added to the sample and kept for 3 min until reaction completed. To determine of Cu, 10 mL of the specimens were transferred in a 50 mL cell, and CuVer copper reagent (2,2'-bicinchoninate dipotassium salt and potassium phosphate monobasic) was then added to the sample and kept for 2 min until reaction completed. For SiO_2 determination, 10 mL of the specimens were introduced in a 50 mL cell and molybdate reagent powder (ammonium molybdate), acid reagent powder (sodium chloride (20%–30%), sulfamic acid (80%–90%)), and citric acid reagent, were

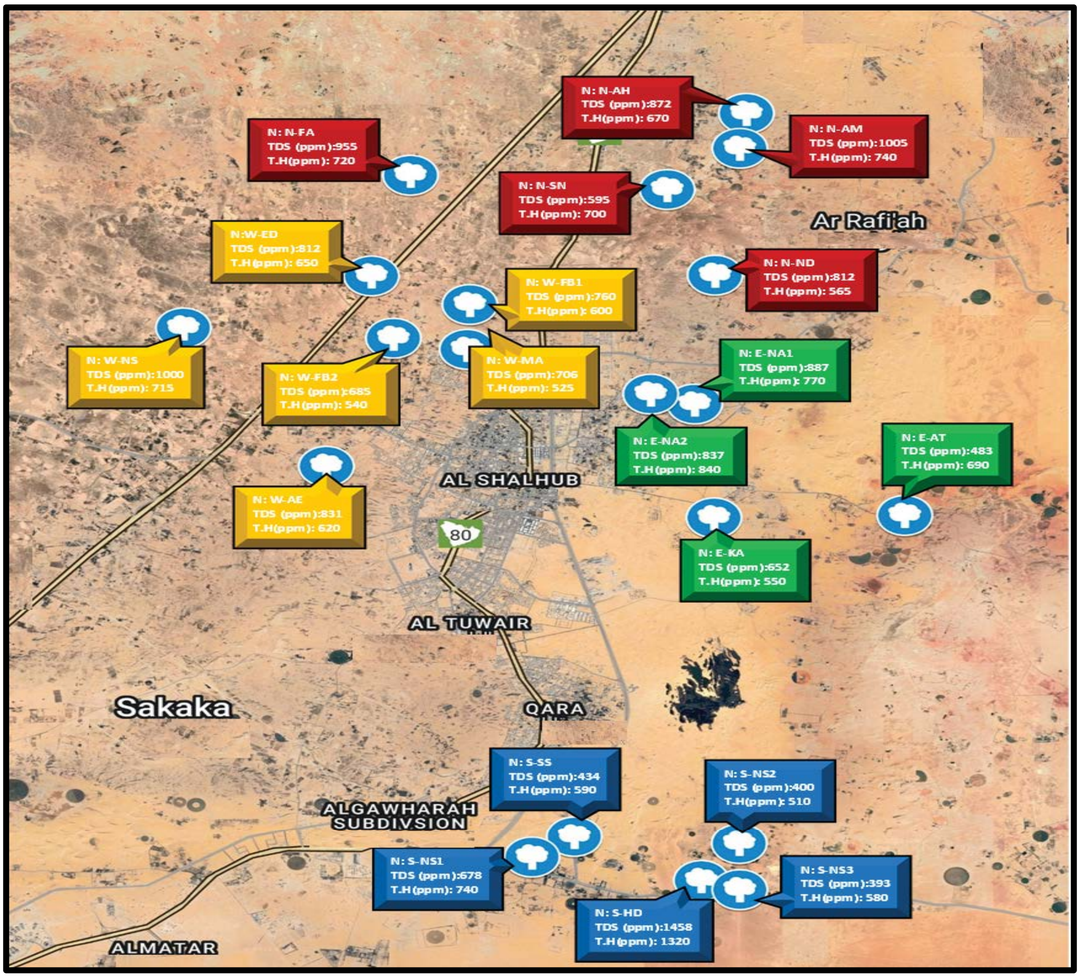

Fig. 1. Location map of the study area with comparison of total dissolved solids and total hardness contents.

added to the sample and kept for 2 min until the reaction was completed. For SO_4^{2-} determination, 10 mL of the specimens introduced in a 50 mL cell and SulfaVer 4 powder (barium chloride ($BaCl_2$) and dihydrate citric acid) then added to the sample and kept for 5 min until reaction completed. For Zn determination, 20 mL of the specimens introduced in a 50 mL cell and ZincoVer 5 zinc reagent (potassium cyanide (1%–5%), boron potassium oxide (50%–60%), boron oxide (10%–20%)) were then added to the sample followed by 0.5 mL of cyclohexanone and swirled for 30 s then kept for 3 min until reaction completed. For K^+ determination, 25 mL of the specimens introduced in a 50 mL cell and potassium 1 reagent (tetra sodium EDTA, dehydrate (100%)), potassium 2 reagent (formaldehyde (30%–40%) and methyl alcohol (10%–20%)), and potassium 3 reagent (sodium tetraphenylborate) were then added to the sample and swirled for 30 s then kept for 3 min until reaction completed. For S^{2-} determination, 10 mL of the specimens were introduced in a 50 mL cell, and 0.5 mL of sulfide 1 reagent (sulfuric acid) was added and then swirled to mix well followed by sulfide 2 reagent (potassium dichromate) was then added to the sample and mixed vigorously for 30 s then kept for 5 min until reaction completed. For B determination, 2 mL of the specimens introduced in a 50 mL cell and 35 mL of solution A (75 mL of concentrated sulfuric acid with BoroVer 3 reagent (potassium chloride and carmine)) were then added to the sample and kept for 25 min until reaction completed. The flame photometer was used to determination of Na^+ in samples. For each solution that was produced, the results of all these determination processes were compared to a corresponding reagent blank.

3. Results and discussion

3.1. Physico-chemical features of the collected samples

Table 1 presents the characteristics of drinking bottled water quality and metropolitan water with the permissible limits according to the Saudi Standards and Metrology Organization (SASO) [16,17] and the World Health Organization (WHO) [18]. In comparison to these limits, the physical properties of groundwater at Jouf region presented a normal range except one sample was abnormal, as can be observed in Table 2. The findings of pH magnitude were in the range between 6.39 and 7.54. The results show that the south water samples have lowest TDS (393–678 ppm) which are better than others. Moreover, 90% of the gathered specimens exhibited TDS values within the 393–1,000 ppm range. The results showed that only 10% of the groundwater samples examined had TDS levels that were higher than the permitted limit of 1,000 ppm. The clearance of the water samples is one of major characteristics and almost 85% of the samples were cleared. It can be seen from the physical characteristics; all the groundwater were suggested to pre-treated prior to use either for consumption or agricultural irrigation [19–23].

Table 3 shows the total hardness, calcium, magnesium, and chloride contents in groundwater in the Jouf region. As presented, the eastern region groundwater samples have higher hardness content (550–840 mg/L), while the lowest contents were observed in south samples. In general, all levels of total hardness, calcium, magnesium, and chloride contents in groundwater at Jouf region were within the permissible limit except sample S-HD which exceeded the allowable limits. It can be observed that in all samples, the percentage of Mg^{2+} was higher than Ca^{2+}, which means that the Jouf region has a dolomitic rock with the chemical composition of ($Ca Mg(CO_3)_2$) in its nature of sedimentary rocks (Fig. 2).

3.2. Water quality evaluation

The quality of water used for potable is the foremost significant factor in human health [24]. Water quality evaluation is based on the water content of elements, anions and cations. The 20 samples were examined to assess the quality of water concerning water quality standard (Table 1).

Table 1
Characteristics of drinking bottled water quality and the metropolitan water with the permissible limits according to the Saudi Standards and Metrology Organization (SASO) and the World Health Organization (WHO)

Chemical standard	Maximum limits allowed for bottled drinking water	Maximum limits for drinking unbottled water
pH	6.5–8.5	6.5–8.5
Conductivity (μS/cm)	200–1,000	200–2,000
Total dissolved solids (ppm)	100–500	100–1,000
Total hardness (ppm)	200	–
Magnesium (ppm)	150	–
Iron (ppm)	0.3	–
Zinc (ppm)	0.1	–
Fluoride (ppm)	0.7–1.5	1.5
Copper (ppm)	2	1
Sulfate (ppm)	250	–
Boron (ppm)	0.5	2.4
Sulfide (ppm)	0.05	–
Sodium (ppm)	20–200	20–200
Chloride (ppm)	250	250
Calcium (ppm)	100–300	100–300

Table 2
Physical properties of groundwater at Jouf region

Sample code	Color	Odor	pH	Conductivity (µS/cm)	TDS (ppm)
N-SN	Transparent	None	7.46	1,188	595
N-ND	Transparent	None	7.48	1,622	812
N-AH	Very light yellow	None	6.99	1,743	872
N-FA	Transparent	None	6.51	1,910	955
N-AM	Light yellow	None	6.94	2,010	1,005
E-NA1	Transparent	None	7.33	1,773	887
E-NA2	Transparent	None	7.21	1,672	837
E-KA	Transparent	None	6.62	1,304	652
E-AT	Transparent	None	7.40	965	483
W-NS	Very light yellow	None	7.35	1,996	1,000
W-AE	Transparent	None	7.28	1,661	831
W-ED	Transparent	None	7.35	1,624	812
W-MA	Transparent	None	7.54	1,411	706
W-FB1	Transparent	None	7.22	1,520	760
W-FB2	Transparent	None	7.27	1,370	685
S-HD	Transparent	None	6.39	2,919	1,458
S-NS1	Transparent	None	7.27	1,355	678
S-NS2	Transparent	None	7.42	802	400
S-NS3	Transparent	None	6.54	785	393
S-SS	Transparent	None	7.00	868	434

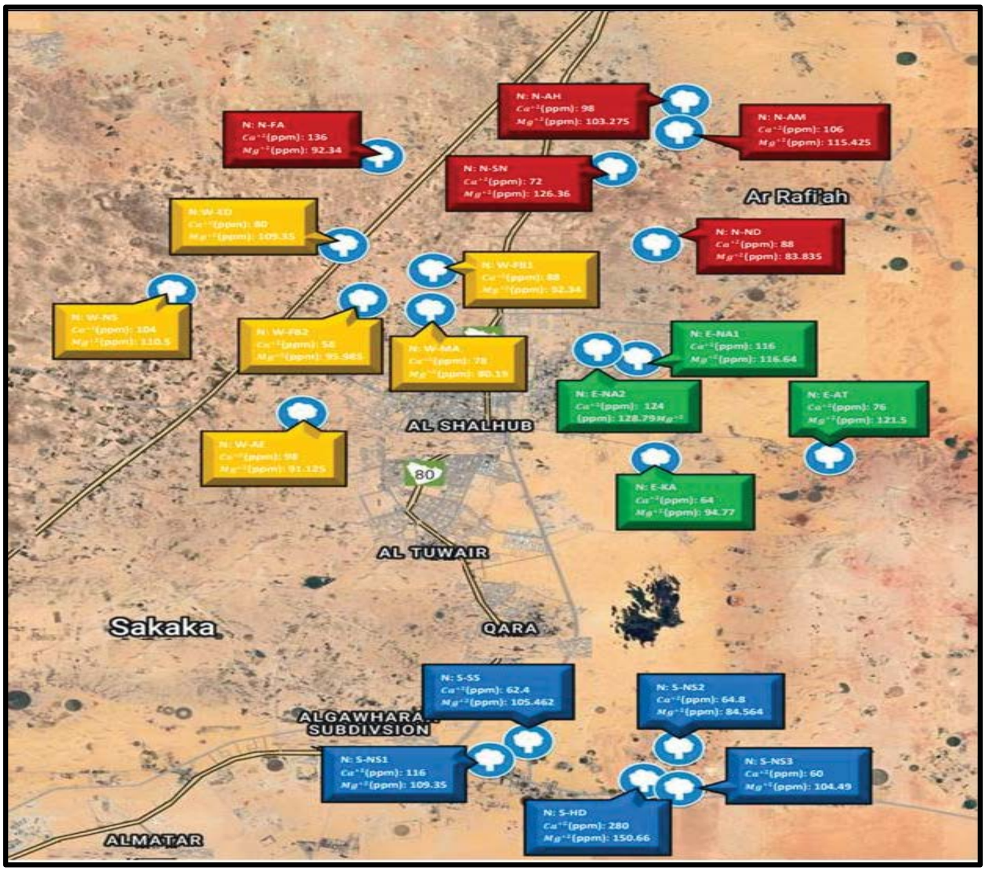

Fig. 2. Concentration of magnesium and calcium ions in all groundwater samples.

Table 3
Levels of total hardness, calcium, magnesium and chloride contents in groundwater at Jouf region

Sample code	Total hardness (mg/L)	Ca^{+2} (mg/L)	Mg^{+2} (mg/L)	Chloride (mg/L)
N-SN	700	72	126.36	196
N-ND	565	88	83.83	340
N-AH	670	98	103.27	282
N-FA	720	136	92.34	327
N-AM	740	106	115.42	530
E-NA1	770	116	116.64	265
E-NA2	840	124	128.79	212
E-KA	550	64	94.77	201
E-AT	690	76	121.50	155
W-NS	715	104	110.56	331
W-AE	620	98	91.125	305
W-ED	650	80	109.35	224
W-MA	525	78	80.19	231
W-FB1	600	88	92.34	166
W-FB2	540	58	95.98	234
S-HD	1320	280	150.66	403
S-NS1	740	116	109.35	190
S-NS2	510	64.8	84.56	115
S-NS3	580	60	104.49	123
S-SS	590	62.4	105.46	136

3.2.1. Elements contents of groundwater

It can be seen from Fig. 3 that the contents level of Zn, Cu, and Fe were in the permissible limits, except three samples from the north and west region exceeded the limits, of Zn. Also, the results detected that one sample has higher contents of both Cu and Fe. The samples collected from the south region presented the best water quality, except S-HD wasn't congruent with the rest of the south groundwater results. Silica (SiO_2) is a derivative compound of the chemical element silicon (Si) and has been determined in order to monitor the efficiency of pre-treatment of the groundwater with suitable ion exchangers. Fig. 4a shows the contents of SiO_2 in the range from 3.8 to 14.1 mg/L which, is referred to the source of SiO_2 as the lands and rocks. The values of SiO_2 in all samples were convergent [25].

3.2.2. Cations and anions content of groundwater

Figs. 4b & c, 5 and Table 3 present the contents of the main cations and anions in groundwater at Jouf. As can be seen from Fig. 4b, the concentration of sulfate varied in all the samples under study in the range between 50 to 640 mg/L. The higher contents of SO_4^{2-} were found in all the western region samples and the lowest contents were observed in both north and south samples except the sample S-HD. The increase in SO_4^{2-} contents leads to gaining water tasting embittered and causes dehydration for the children when they drink water at these levels [26]. These results confirmed the low quality of water in the east and

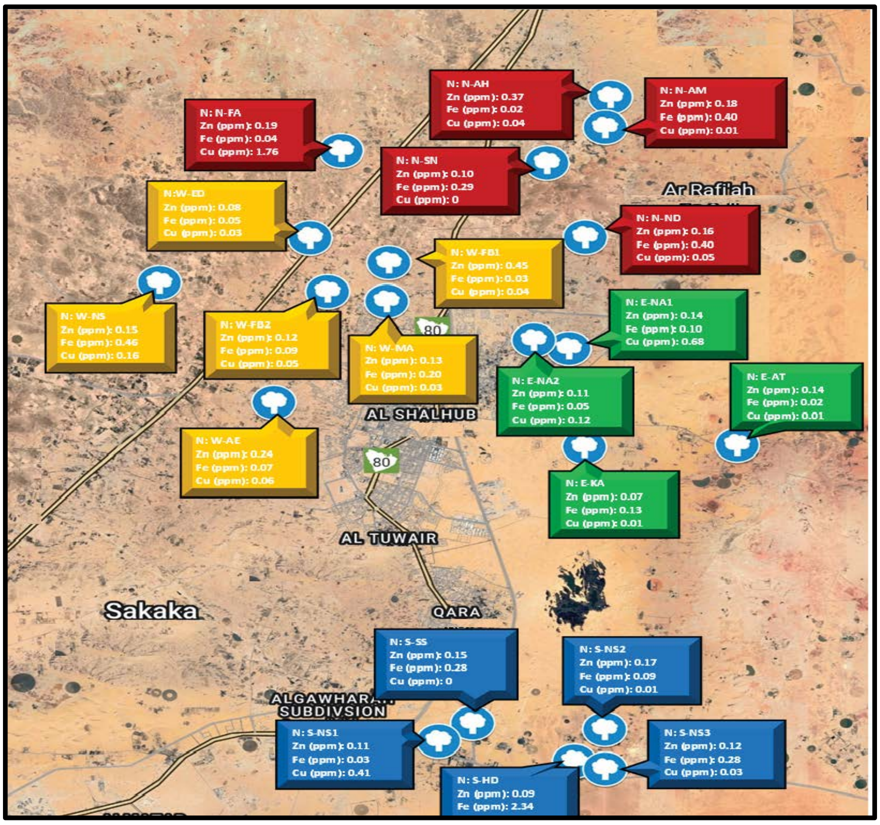

Fig. 3. Concentration of elements in groundwater samples (zinc, copper and iron).

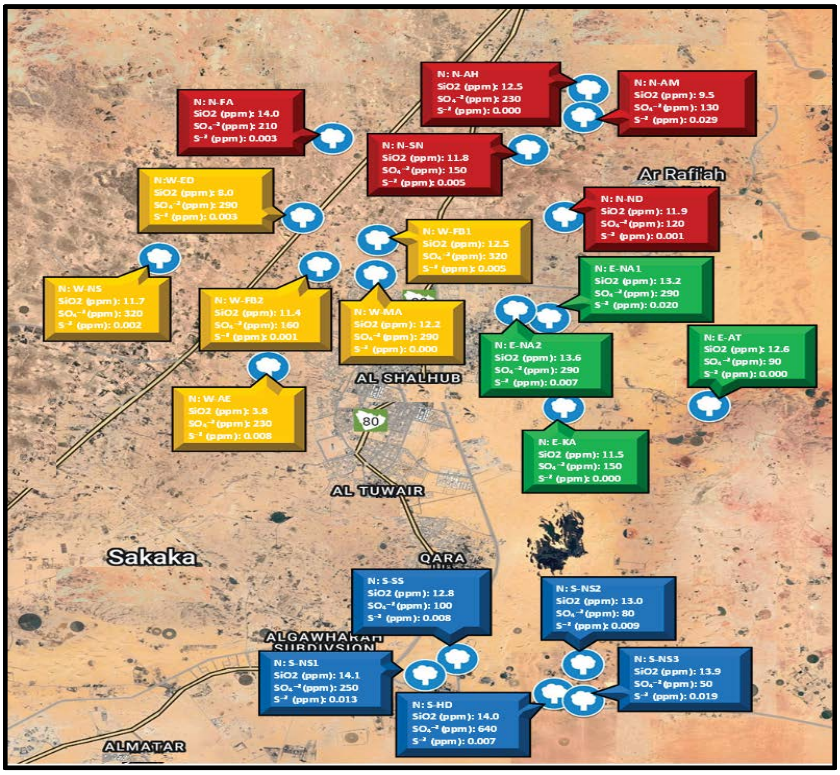

Fig. 4. Concentration of silica (A), sulfate (B) and sulfide (C) in all groundwater samples.

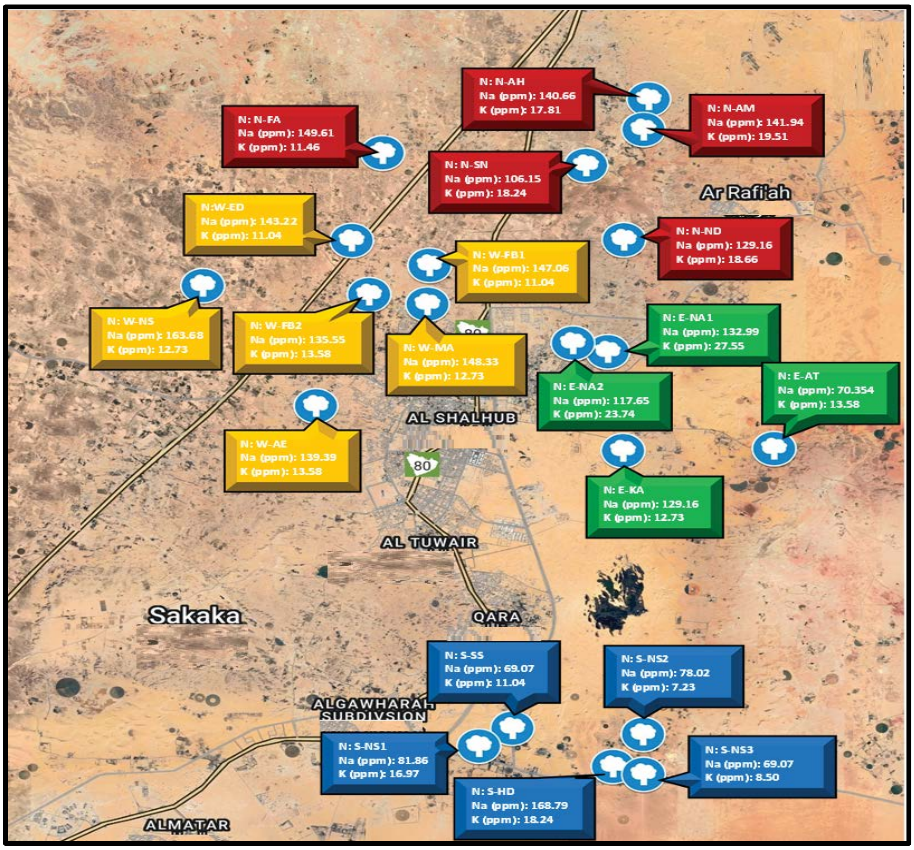

Fig. 5. Concentration of potassium and sodium contents in all groundwater samples.

Table 4
Measurement of the concentrations of elements in well water at Jouf region

Sample code	Iron (mg/L)	Copper (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Boron (mg/L)	Zinc (mg/L)
N-SN	0.29	0	18.24	106.15	0	0.10
N-ND	0.40	0.05	18.66	129.16	0	0.16
N-AH	0.02	0.04	17.81	140.66	0	0.37
N-FA	0.04	1.76	11.46	149.61	0	0.19
N-AM	0.40	0.01	19.51	141.94	0	0.18
E-NA1	0.10	0.68	27.55	132.99	0	0.14
E-NA2	0.05	0.12	23.74	117.65	0	0.11
E-KA	0.13	0.01	12.73	129.16	0	0.07
E-AT	0.02	0.01	13.58	70.354	0	0.14
W-NS	0.46	0.16	12.73	163.68	0	0.15
W-AE	0.07	0.06	13.58	139.39	0	0.24
W-ED	0.05	0.03	11.04	143.22	0	0.08
W-MA	0.20	0.03	12.73	148.33	0	0.13
W-FB1	0.03	0.04	11.04	147.06	0	0.45
W-FB2	0.09	0.05	13.58	135.55	0	0.12
S-HD	2.34	2.84	18.24	168.79	0	0.09
S-NS1	0.03	0.41	16.97	81.86	0	0.11
S-NS2	0.09	0.01	7.23	78.02	0	0.17
S-NS3	0.28	0.03	8.50	69.07	0	0.12
S-SS	0.28	0	11.04	69.07	0	0.15

west samples. Fig. 4c shows the presence of quantities of sulfide ions in some well water samples with low concentrations and less than the permissible limit, which does not pose any danger to public health. Still, it may show an undesirable odor in the water as well as cause corrosion of the pipes transferring this water. These quantities can simply be disposed of by chlorine sterilization. The contents of Cl^- ion in water samples are illustrated in Table 3. The findings show that these specimens of healthy water contain varying concentrations of chloride ions, which has significance and correlation with the salinity of the water. It is evident from the results presented in Table 3 that the water of the southern wells is characterized by containing the lowest concentrations of chloride ions. The contents of both sodium and potassium ions are presented in Fig. 5, which shows that the results of the concentrations of sodium and potassium were found to be the lowest possible in the water of the southern wells. As for the rest of the well water specimens, they exhibited very high content of sodium and potassium, which may cause danger, and it is not recommended to use for drinking, whether for people with kidney failure, heart disease, significant blood pressure, or and even healthy persons due to the possibility of exposure to these diseases over time. Compared to the results of SO_4^{2-}, the increase in SO_4^{2-} is convoyed by increases in the proportion of sodium and magnesium because the existing sulfates are in the form of sodium, magnesium, and calcium salts.

3.3. Boron contents of groundwater

Hydroponically grown plants can develop a hazardous response from irrigation water polluted with boron [27]. As presented in Table 4, boron hasn't been detected in all water samples indicating that no other hazardous substances are possible presence in groundwater at the Jouf region. Less than 1 ppm of boron is advised for commercial plant nutrition.

4. Conclusion

Jouf region is rich in groundwater and has characteristics as one of the essential agriculture regions in Saudi Arabia. In this paper, 20 samples were examined to assess the physico-chemical characteristics of groundwater in the Jouf region in Saudi Arabia and evaluate the water quality of a given water quality standard. The evaluation can provide they're oriented into energy, agriculture, and drinking purposes. The TDS results of the south water samples have the lowest magnitude (393–678 ppm) and only 10% of the tested groundwater specimens have TDS values more significant than the allowed limit of 1,000 ppm. The percentage of Mg^{2+} was higher than Ca^{2+}, which means that the Jouf region has a dolomitic rock with the chemical composition of (Ca $Mg(CO_3)_2$) in its nature of sedimentary rocks. There was an observation that the increase in SO_4^{2-} is convoyed by increases in the proportion of sodium and magnesium because the existing sulfates are in the form of sodium, magnesium, and calcium salts. Also, boron hasn't been detected in all water samples. In general, after pre-treating it as advised, the groundwater of the research region can be used safely for drinking or agricultural irrigation.

Acknowledgment

The authors appreciatively acknowledge to Chemistry Department, Jouf University for access to the analytical equipment.

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