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Hydrochemical and quality of water resources in Saudi Arabia groundwater: A comparative study of Riyadh and Al-Ahsa regions

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Abstract
Due to the arid climate of the Saudi Arabia, groundwater is a most precious natural resource, providing reliable water supplies for population of these areas. The main aim of this study is to evaluate the quality of groundwater resources in the selected study areas of Riyadh and Al-Ahsa regions. This study focuses on the chemical analysis of the available groundwater resources in these two areas of Saudi Arabia. The distribution of the chemical constituents (major, minor and trace elements) is determined and compared with each other. The groundwater salinity as one primary indicator of water quality for irrigation was found to be moderately high in most studied water samples for both areas. Besides salinity, chloride makes these waters unsuitable for irrigation, affecting agricultural activities. However, boron and trace elements were within acceptable levels. Comparative study revealed that the Al-Ahsa groundwater is generally considered higher in its salinity, chloride, and sodium content than Riyadh groundwater. Generated piper diagrams revealed that the majority of investigated waters types in Al-Ahasa were sodium chloride – sulphate, however, in Riyadh the majorities were to calcium magnesium sulphate – chloride. The most important results of speciation calculations, computed by Phreeq model, are saturation indices for minerals, which indicate whether minerals should dissolve or precipitate. The results indicated that most studied water samples in Al-Ahsa were undersaturated for anhydrite, gypsum, and halite. However, in Riyadh most water samples were undersaturated for anhydrite and halite, and saturated for Gypsum.

Keywords Riyadh; Al-Ahsa; groundwater quality; waters types; phreeq model.

1 Introduction

Chemical and physical parameters of groundwater play an important role in assessing water quality (Kumaresan and Riyazuddin, 2006). Groundwater quality as one of the most important aspects in water resource studies is largely controlled by discharge and recharge pattern, nature of host and associated rocks, and contaminated activities (Ackah et al., 2011; Sayyed and Wagh, 2011). The Kingdom of Saudi Arabia, known as one of the most water scarce countries in the world, is depending mostly in groundwater as main water source (Al-Omran, 2002). Al-Salamah et al. (2011) concluded that, more than 80 - 90% of the water use is derived from groundwater. The total groundwater reserve is estimated to be about 2,259 billion cubic meters (Abderrahman and Al-Harazin, 2008). The total available volumes of renewable water resources from surface water and groundwater recharge are ranged between 5,000 to 8,000 million cubic meters (MCM), and more than 780 MCM are produced in the Arabian shelf and the rest are in western coastal parts of the Kingdom (JCC, 2012). The groundwater is stored in more than 20-layered principal and secondary aquifers of different geological ages over Saudi Arabia (MAW, 1984; Abderrahman and Rasheeduddin, 2001). The principal aquifers are: Saq, Wajid, Tabuk, Dammam, Minjur, Biyadh, Dhruma, Wasia, Umm Er Radhuma and Neogene. The secondary aquifers are: Al-Jauf, Al-Khuff, Al-Jilh, Upper Jurassic, Sakaka, Lower Cretaceous, Aruma, Basalts, and Wadi Sediments. The Saq aquifer is very large and has almost similar aquifer parameters throughout the country (MAW, 1984). The groundwater of the Saq aquifer is generally contained good quality water with an average of TDS of 300-1000 mg L^{-1}. The Poor quality water is restricted to basalt covered areas, near the edge of the basement complex and wadi outlets (Sharaf and Hussein, 1997). The Saq groundwater is classified into six water types, the most dominant were $Ca(HCO_3)_2$ or $NaHCO_3$ and NaCI types. The Na_2SO_4 type is restricted to the basalt and paleovalleys areas (Alawi and Abdulrazzak, 1993; Mohammed et al., 2011). Al-Omran et al. (2005) concluded that the Chloride and sulphate are the dominant anions; calcium and sodium are the dominant cations in Riyadh region. The Arabian shelf includes deep sedimentary aquifers which are formed mostly of limestone and sandstone that overlay the basement rock formation known as Arabian Shield, and covers about two third of Saudi Arabia (MAW, 1984). The relatively slow groundwater movement causes long residence times within the aquifers. Therefore, the main portion of the groundwater is fossil water and has been dated by isotope analyses to be more than 20,000 years old in the Al-Ahsa area (Bakiewicz, 1982). Due to results of several extensive groundwater studies over the last years, It is recognized a fact that the current overexploitation and groundwater mining in Saudi Arabia leads to depletion of water resources and requires immediate action. Consequently, several measures are already in place especially regarding agricultural sector (Mohammed et al., 2011). Sharaf and Hussein (1997) and Abdel-Aal et al. (1997) reported that the Saudi Arabia groundwater deteriorating in alarming way due to increase of water salinity. The electrical conductivity had been increased from 1.93 dS m^{-1} in 1983 to 2.76 dS m^{-1} in 1997 in Saq Aquifer; furthermore Al-Salamah et al. (2011) concluded that the groundwater depletion was observable in Saudi Arabia, and if this depletion continues unabated, the agricultural land may not be able to survive.

In the present study, the objectives are: (a) to record and compare the present quality status of the groundwater for irrigation purposes in the Al-Ahsa and Riyadh region, (b) to classify the hydro-chemical characterization of studied waters, and (c) to aid the management and future development of groundwater resources in the two region.

2 Materials and Methods

2.1 Sampling sites and dates

In this study, water samples were collected from 62 different locations that cover two regions of Saudi Arabia, Riyadh and Al-Ahsa, in attempt to capture the spatial variations in the water resources quality of the studied areas (Fig. 1). The Riyadh sampling locations were georeferenced and located between 25^o 07' 59.8" N - 046^o 07' 59.9" E and 25^o 04' 18 .7" E - 046^o 06' 31.7" N, however the Al-Ahsa georeferenced were between 24^o 52' 37.2" E - 49^o 23' 31.2" N and 25^o 24'06.4" E - 49^o 42' 06.6" N. Once collected, water samples were transported immediately to the laboratory in ice boxes and chemical analyses were carried out to assess the water quality.

Fig. 1 Location of studied areas

2.2 Water quality measurements

The water pH, EC, soluble ions, Boron, and Heavy metals were determined as follow:

i: The Water reaction (pH) was determined using a pH meter (pH meter - CG 817).

ii: The Total soluble salts was measured by using electrical conductivity meter (EC) in dS/m at 25°C (Test kit Model 1500_20 Cole and Parmer).

iii: The Soluble Potassium and Sodium were determined by using flame photometer apparatus.

iv: The Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, and NO_3^{-} were determined according to Matiti (2004)

v: The Heavy metals (Zn, Cu, Fe, Mn, Co, Cd, Ni, B, Cr, and Pb) and Boron were determined using ICP-Perkin Elemer Model 4300DV.

2.3 Water quality evaluation for irrigation

The suitability of water resources in Riyadh and Al-Ahsa for irrigation was evaluated by FAO (Ayers and Westcoat, 1985), U.S. salinity laboratory (Richard, 1954), and KSA (Kingdom of Saudi Arabia, 2003) methods.

2.4 Hydrochemical facies

The hydro-chemical characteristics of the mineral water were evaluated by Piper diagram (Piper, 1944).

2.5 Geochemical modeling

Interaction between water and surrounding rocks and soil are considered to be the main processes controlling the observed chemical characteristics. The deviation of water from equilibrium with respect to dissolved minerals is quantitatively described by saturation index (SI). The SI of a mineral is obtained from the following formula:

$$SI = \log IAP/k_t \qquad (1)$$

where IAP is ion activity product of dissociated chemical species in solution and k_t is the equilibrium solubility product of the chemical involved (Alexakis, 2011).

The hydro-geochemical equilibrium model, Phreeqc model (Parkhurst and Appelo, 1999), was used to calculate the SI of water with respect to the main mineral phases.

3 Results and Discussions

3.1 Groundwater quality

3.1.1 Water salinity

Water salinity was measured and presented as EC values (dS m^{-1}). The monitoring of water electrical conductivity has been increasingly attracting attention, not only because water electrical conductivity can be used as a surrogate measure of such water properties as salinity, but also because investigation of water conductivity provide important information about the impact that farm practices, such as irrigation, have at both the field and regional scale (Aly and Benaabidate, 2010).

In the study areas, about 82% of studied water samples in Al-Ahsa were moderately saline and have slight to moderate degree of restriction on use for irrigation (Ayers and Westcot, 1985). The remaining 18% of studied samples were exceeded the permissible limit for irrigation and have severe degree in restriction on use. However in Riyadh region about 82.5% of studied water samples were classified as moderately saline water and have slight to moderate degree of restriction on use, the remaining 17.5% were classified as saline water and have severe degree in restriction on use according to the classification of Ayers and Westcot (1985) and KSA (2003), this results was in agreement with the results found by Al-Omran et al. (2005).

The water salinity average in Al-Ahsa was 3.2 dS m^{-1} with a range between 1.5 and 9.7 dS m^{-1}. The lowest value was observed in Northern part however the highest value was in southern part of Al-Ahsa (Table 1). In general water samples collected from southern part of Al-Ahsa exhibited higher values of water salinity than northern and middle parts. The increases in the water salinity in southern part were 204% of the northern part which represents very rapid and severe water quality deterioration in southern part. This is due to the continuous agricultural expansion and development in this part than other in the oasis and the increased demands on water supplies, which is manifested in more groundwater abstraction and so deterioration.

The water salinity average in Riyadh region was 2.9 dS m^{-1} with a range between 1.8 and 6.1 dS m^{-1} (Table 2). Generally the results show that the Al-Ahsa oasis waters salinity was higher than that of Riyadh regions, and the increase was about 110%.

3.1.2 Chloride

As expected, chloride distribution and trend follow the same trend of water salinity. The observed average value of chloride concentration obtained in Al-Ahsa was 23.4 meq L^{-1}, and ranged between 8.9 and 75.6 meq L^{-1} (Table 1). Also the southern part recorded the highest value and increase by about 224% of northern part. In Riyadh region the average chloride concentration was 13.8 meq L^{-1}, and ranged between 5.1 and 33.4 meq L^{-1} (Table 2). It is clear that the Riyadh chloride concentration is less than that of Al-Ahsa oasis, and about 73% in Riyadh 96% in Al-Ahasa groundwater samples have potential risk of chloride hazard (chloride > 10 meq L^{-1}) (Ayers and Westcot, 1985).

3.1.3 Alkalinity

The sodium/alkali hazard is typically expressed as the sodium adsorption ratio (SAR). This index quantifies the proportion of Na to Ca and to Mg ions in a sample. Sodium hazard of irrigation water can be well estimated by determining the SAR. SAR values were calculated using the equation $SAR = Na/(Ca+Mg)^{0.5}$ (Richard, 1954).

Table 1 and 2 showed that there is no sodicity problem in Riyadh and all water samples have SAR less than 9, however in Al-Ahasa, only 14% of waters have severe sodicity problem in most cases (SAR > 9). Moreover the pH and bicarbonate values were in the safe and normal range.

The studied water quality evaluation according to U.S. salinity laboratory method (Richard 1954), showed that the majority of water samples of Al-Ahsa were shared between classes C4-S3 and C4-S2, indicating very high salinity and medium to high sodium hazard. On the other hand, in Riyadh region the classes were between C4-S1 and C4-S2, indicating very high water salinity and low to medium sodium hazard. Furthermore, the evaluation by KSA (2003) revealed that most studied water samples were moderately saline, and also the risks of alkalinity were more obvious in Al-Ahsa than in Riyadh regions. Therefore, the Riyadh water is then can be used for irrigation on almost all types of soils with little hazard of exchangeable sodium.

3.1.4 Boron, nitrate, and trace elements

Boron is an essential element for plant growth and is needed in relatively minute amount, however, it may turn toxic if found in appreciably greater amount than need. Groundwater, unlike surface water, may contain toxic amount of boron (Aly, 2001). Water samples were analyzed for its boron concentrations as well as some trace elements, heavy metals and nitrate. The descriptive statistical data are shown in Table 3. The result concluded that most studied waters in both areas were within the acceptable levels for boron and trace elements concentrations. However, only two samples in Al-Ahsa have Boron concentration more than 0.7, consequently these two samples have slight to moderate degree of restriction on use (Ayers and Westcot, 1985). In general the nitrate concentrations in both studied areas were higher than the normal range of groundwater, this indicate that these groundwaters are subject for contaminations by nitrate. About 95% of waters nitrate concentrations in Al-Ahsa were located between 5 and 30 mg L^{-1} with an average of 12 mg L^{-1} (Table 1), and only 5% of studied water samples contain nitrate less than 5 mg L^{-1}. Consequently 95% of water samples have slight to moderate degree of restriction on use regarding nitrate, and 5% of the samples have no restriction on use. In Riyadh region the average nitrate concentration was 16.7 mg L^{-1} (table 2), and 85% of water samples have slight to moderate degree of restriction on use. A 15% of the samples have no restriction on use (Ayers and Westcot, 1985).

Table 1 Descriptive statistics of Al-Ahsa oasis water chemical composition (n=22)

	Max.	Mini.	Mean	Stdev	Vari.	St. error	Med.	Skew
pH	7.8	7.1	7.4	0.3	0.5	0.2	7.4	0.2
EC (dS m^{-1})	9.7	1.5	3.2	2.1	1.4	0.3	2.6	2.6
Ca^{++} (meq L^{-1})	38.1	5.4	9.8	7.9	2.8	0.4	6.8	2.9
Mg^{++} (meq L^{-1})	10.8	1.2	2.5	2.2	1.5	0.2	1.7	3.1
Na^{+} (meq L^{-1})	59.9	7.5	19.7	12.7	3.6	0.4	16.3	2.6
K^{+} (meq L^{-1})	1.4	0.3	0.7	0.3	0.5	0.3	0.6	1.7
HCO_3^{-} (meq L^{-1})	8.9	2.7	4.1	1.8	1.3	0.3	3.3	1.5
Cl^{-} (meq L^{-1})	75.6	8.9	23.4	17.4	4.2	0.5	17.3	2.4
SO_4^{--} (meq L^{-1})	3.9	1.6	2.2	0.6	0.8	0.2	2.0	1.9
SAR	14.7	4.1	7.9	2.1	1.5	0.3	8.1	1.2
adjRNa	24.3	5.0	10.5	3.9	2.0	0.3	10.0	2.2
NO_3 (mg L^{-1})	18.7	0.8	12.0	3.8	2.0	0.3	11.2	-0.6

Table 2 Descriptive statistics of Riyadh water chemical composition (n=40)

	Max.	Mini.	Mean	Stdev	Vari.	St. error	Med.	Skew
pH	8.0	7.1	7.6	0.2	0.01	0.1	7.6	-0.7
EC (dS m^{-1})	6.1	1.8	2.9	1.2	0.03	0.2	2.5	1.7
Ca^{++} (meq L^{-1})	25.9	5.7	11.5	4.5	0.05	0.2	9.9	1.4
Mg^{++} (meq L^{-1})	27.9	0.5	7.2	5.5	0.06	0.2	5.9	1.7
Na^{+} (meq L^{-1})	21.4	4.6	11.3	3.9	0.05	0.2	10.2	1.3
K^{+} (meq L^{-1})	0.8	0.1	0.2	0.1	0.01	0.1	0.2	2.9
HCO_3^{-} (meq L^{-1})	9.2	2.7	4.9	1.6	0.03	0.2	4.8	0.9
Cl^{-} (meq L^{-1})	33.4	5.1	13.8	7.2	0.07	0.3	11.6	1.6
SO_4^{--} (meq L^{-1})	24.7	5.2	10.3	5.1	0.06	0.2	8.1	1.3
SAR	4.8	1.7	3.7	0.7	0.02	0.1	3.7	-0.5
adjRNa	5.0	2.1	3.0	0.2	0.01	0.1	3.1	-0.7
NO_3 (mg L^{-1})	28.0	1.6	16.7	6.6	2.6	0.3	18.4	-0.7

Table 3 Descriptive statistics of Riyadh and Al-Ahsa water trace elements (n=62)

	Cd	**Co**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**	**B**
Max.	0.01	0.01	0.02	0.00	0.32	0.21	0.01	0.00	0.03	2.0
Mini.	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.02	0.0
Mean	0.01	0.01	0.01	0.00	0.00	0.08	0.00	0.01	0.02	0.4
Stdev	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.09	0.4
Vari.	0.03	0.06	0.09	0.00	0.00	0.04	0.04	0.00	0.30	0.7
St. error	0.03	0.04	0.04	0.00	0.00	0.03	0.03	0.00	0.08	0.1
Median	0.01	0.01	0.01	0.00	0.00	0.04	0.00	0.00	0.02	0.2
Skew	-0.81	0.30	-0.39	0.00	0.00	-0.52	2.24	1.00	1.23	2.2

3.2 Hydrochemical facies

The chemical data of the groundwater samples for both areas were plotted on a Piper trilinear diagram (Piper, 1944) (Fig. 2). This diagram provides a convenient method to classify and compare groundwater types, based on the ionic composition of different water samples (Aly and Benaabidate, 2010; Aly et al., 2011; Semerjian, 2011; Baba et al., 2008). This diagram reveals that there are two different groundwater types have been identified in Saudi Arabia. The first is in Al-Ahsa and rich in sodium chloride – sulphate water type. The second is in Riyadh and rich in calcium magnesium sulphate – chloride water type (Fig. 2). In the first area, the type of water that predominates is NaCl, which is mainly due to the geology of the area which comprises halite. However, in the second area, the type of water that predominates is CaSO4, which is mostly due to the geology of the area which comprises Gypsum and/or Anhydride.

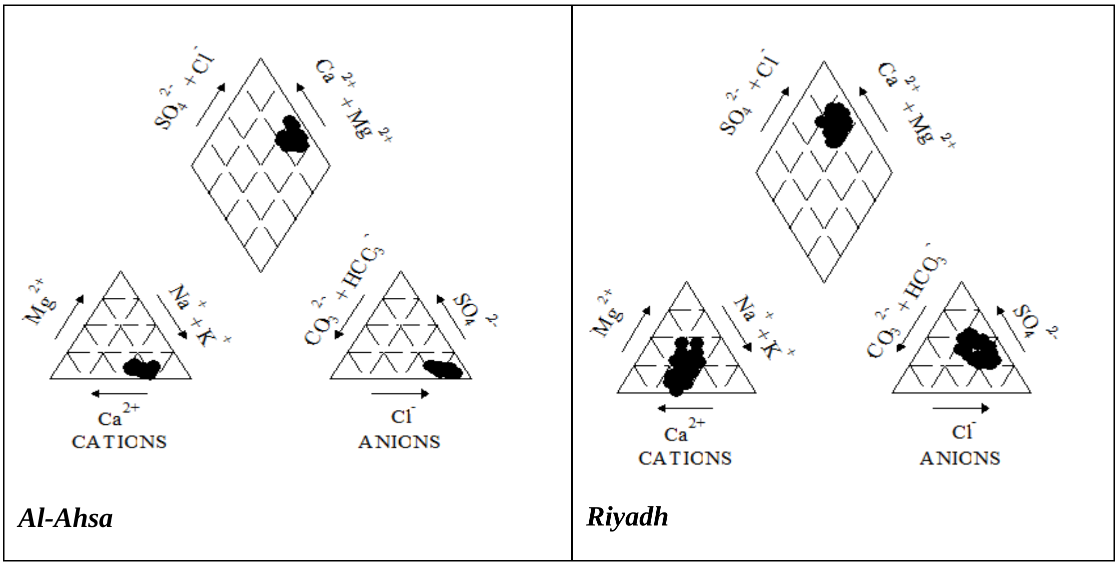

Fig. 2 Piper– tri-linear diagram showing the major ionic composition of the studied water sample.

3.3 Geochemical modelling

The saturation index (SI) is the form most commonly used for groundwater. Water is in equilibrium with a mineral when the SI of this mineral is equal to zero. It is undersaturated if this index is below zero and it is oversaturated when the SI is above zero. However, the inaccuracy on the pH measurements due to measuring devices, the variation of this parameter when the water flow toward surface and the error that could occur during chemical analysis, result in an inaccuracy in the calculation of the saturation index. Therefore, it is recommended to consider that the saturation is obtained in a wider area such that $-1 < SI < +1$ (Daoud, 1995).

The test of the saturation states of studied waters with respect to Anhydrite, Gypsum, and halite were obtained graphically by calculation of the saturation index using Phreeqc model (Fig. 3 and 4).

The use of the SI showed that, in Al-Ahsa region, almost all studied waters were undersaturated with respect to the Anhydrite, Gypsum, and halite with exception of one samples, located in southern part of the Al-Ahsa, which was saturated for Anhydrite and Gypsum (Fig. 3). Therefore, there is a possibility for further Ca^{2+}, Na^+, SO_4^{2-}, and Cl^- concentration increase in the studied water samples due to the dissolution of these minerals. However, in Riyadh region, the waters were undersaturation for; all samples with respect to halite, 62.5% of samples with respect to anhydrite, and 27.5% of samples with respect to Gypsum, the remaining water samples with respect to anhydrite and gypsum were saturated (Fig. 4).

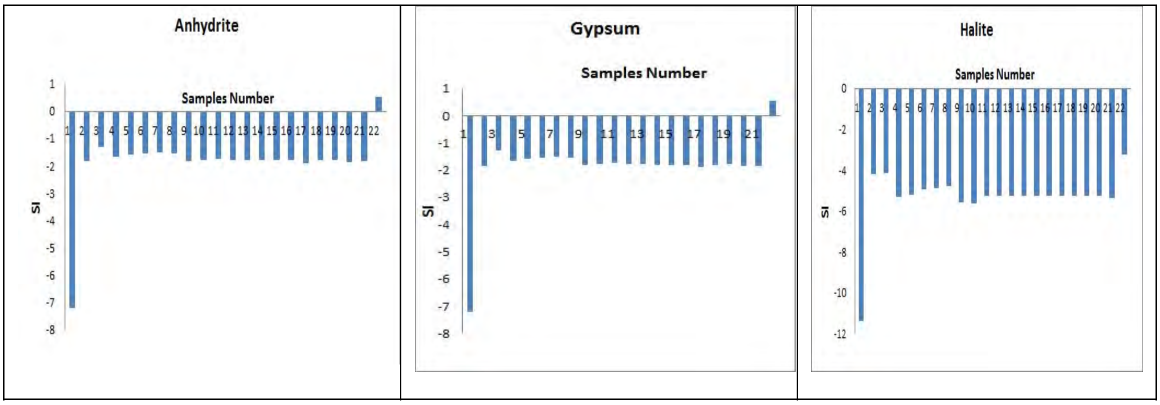

Fig. 3 The Al-Ahsa groundwater saturation with respect to some minerals.

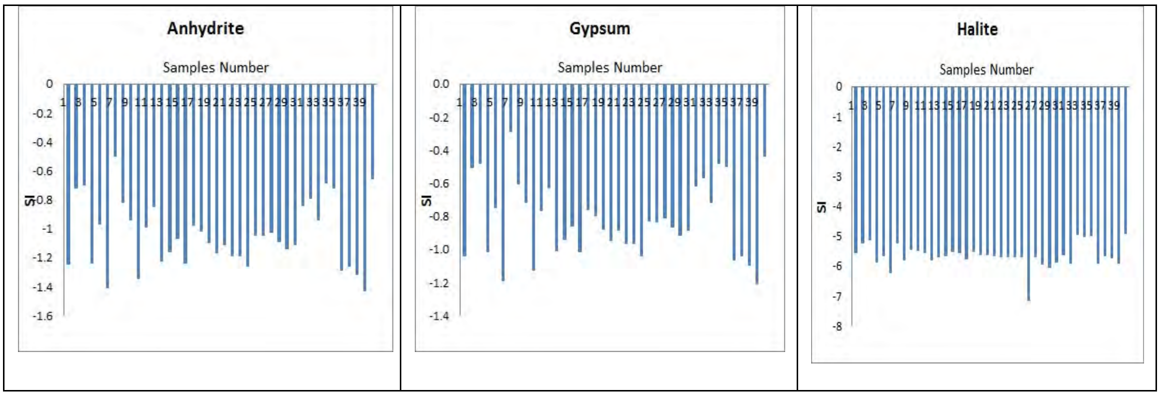

Fig. 4 The Riyadh groundwater saturation with respect to some minerals.

4 Conclusions

Groundwater, a major source of water supply in Saudi Arabia, is facing severe quantity and quality problems. The large concentrated agriculture constitutes is the main source of its contamination. Once contaminated, the options available for its use are both limited and costly. Water scarcity combined with the typically arid climate and the excessive use of soils for agriculture causes severe water salinity problems. Most groundwaters of Riyadh and Al-Ahsa regions were moderately saline, and contain high quantity of chloride. No sodicity problem was anticipated in Riyadh; however, in Al-Ahsa about 14% of studied waters have severed sodicity problem. The pH and bicarbonate values were in safe and normal range in both studied areas. Most studied waters were within the acceptable levels for boron and trace elements; however, nitrate concentrations in both areas were higher than the normal range of groundwater. This indicates that these groundwaters are subject for contaminations by nitrate, due to the continuous expansion of agricultural development. The hydrochemical analysis shows that the studied water samples corresponded mainly to sodium chloride – sulphate water types in Al-Ahsa; however in Riyadh the waters were rich in calcium magnesium sulphate – chloride. The geochemical modeling shows that, in Al-Ahsa region, almost all studied waters were undersaturated with respect to the Anhydrite, Gypsum, and halite; however, in Riyadh area, most waters were undersaturated for halite and anhydrite, and saturated for gypsum.

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References

Abdel-Aal SI, Sabrah RE, Rabie RK, Abdel-Magid HM. 1997. Evaluation of groundwater quality of irrigation in central Saudi Arabia, Arab Gulf. Journal of Scientific Research, 15: 361-377

Abderrahman A, Rasheeduddin M. 2001. Management of Groundwater Resources in Eastern Saudi Arabia. International Journal of Water Resources Development, 17: 185-210

Abderrahman WA, Al-Harazin IM. 2008. Assessment of climate changes on water resources in the Kingdom of Saudi Arabia. GCC Environment and Sustainable Development Symposium, 28–30 January 2008, Dhahran, Saudi Arabia, D-1-1 – D-1-13

Ackah M, Agyemang O, Anim AK, et al. 2011. Assessment of groundwater quality for drinking and irrigation: the case study of Teiman-Oyarifa Community, Ga East Municipality, Ghana. Proceedings of the International Academy of Ecology and Environmental Sciences, 1(3-4): 186-194

Alawi J, Abdulrazzak M. 1993. Water in the Arabian Peninsula: Problems and Prospective. In Water in the Arab World Perspectives and Prognoses (Rogers P, Lydon P, eds). Harvard University, USA, 171-202

Alexakis D. 2011. Assessment of water quality in the Messolonghi-Etoliko and Neochorio region (West Greece) using hydrochemical and statistical analysis methods. Environmental Monitoring and Assessment, 182: 397-413

Al-Omran AM. 2002. Irrigation water conservation in Saudi Arabia. Journal of the Saudi Society of Agricultural Sciences, 1(1): 1-50

Al-Omran AM, Falatah AM, Al-Matrood SS. 2005. Evaluation of irrigation well water quality in Riyadh region, Saudi Arabia. Journal of King Abdulaziz University, 16(2): 23-40

Al-Salamah IS, Ghazaw YM, Ghumman AR. 2011. Groundwater modeling of Saq Aquifer in Buraydah, Al Qassim for better water management strategies. Environ. Monit. Assess., 173: 851–860.

Aly A. 2001. Spatiotemporal monitoring and assessment of water resources in Siwa Oasis. MSc Thesis, Faculty of Agriculture Alexandria University, Egypt

Aly AA, Abbas AA, Benaabidate L. 2011. Hydro-chemical and Quality of groundwater in Egypt, Case Study of Egypt Southern oases. NATO Science for Peace and Security Series C: Environmental Security. Springer

Aly AA, Benaabidate L. 2010. Salinity of water resources in the Siwa Oasis: Monitoring and diagnosis. In: Water-Rock Interaction (Brikle, Torres Alvaro, eds). Taylor & Francis Group, London, UK

Ayers AS, Westcot DW. 1985. Water Quality for Agriculture. Irrigation and Drainage Paper 29 (Rev.1). FAO, Rome, Italy

Baba A, Erees FS, Hicsonmez U, et al. 2008. An assessment of the quality of various bottled mineral water marketed in Turkey. Environmental Monitoring and Assessment, 139: 277-285

Bakiewicz W, Milne DM, Noori M. 1982. Hydrogeology of the Umm Er Radhuma aquifer, Saudi Arabia, with reference to fossil gradients. Quarterly Journal of Engineering Geology and Hydrogeology, 15: 105-126

Daoud D. 1995. Caractérisation géochimique et isotopique des eaux souterraines et estimation du taux d’évaporation dans le bassin de Chott Chergui (zone semi-aride) Algérie. Thèse Univ Paris Sud. Centre d’Orsay, France

JCC – Jeddah Regional Climate Center. 2012. Assessment of climate change on water resources in Kingdom of Saudi Arabia. First National Communication Water Resources. http://jrcc.sa/First_National_Communication_Water_Resources.php. Accessed on 1 Oct. 2012

Kingdom of Saudi Arabia Standard (KSA). 2003. General presidency of meteorology and environment protection. The General System of Environment and Regulations. Saudi Arabia

Kumaresan M, Riyazuddin P. 2006. Major ion chemistry of environmental samples around sub-urban of Chennai city. Current Science, 91(12): 1668-1677

Matiti SK. 2004. Handbook of Methods in Environmental Studies: Water and Wastewater Analysis. ABD Publishers, Jaipur, India

MAW - Ministry of Agriculture and Water. 1984. Water atlas of Saudi Arabia. Saudi Arabian Printing Company Ltd., Riyadh, Saudi Arabia

Mohammed A, Georg T, Christoph S, Randolf R. 2011. Challenges for an Integrated Groundwater Management in the Kingdom of Saudi Arabia. International Journal of Water Resources and Arid Environments, 1(1): 65-70

Parkhurst DL, Appelo CAJ. 1999. User's Guide to PHREEQC (version 2)-A Computer Program for Speciation, Batch-reaction, One-dimensional Transport, and Inverse Geochemical Calculations. U.S. Geological Survey Water-Resources Investigations Report 99-4259, USA

Piper AM. 1944. A graphic procedure in the geochemical interpretation of water analysis. Transactions American Geophysical Union, 25: 914-928

Richard LA. 1954. Diagnosis and Improvement of Saline and Alkali Soils. Agricultural Handbook 60. USDA, Washington, USA

Sayyed MG, Wagh GS. 2011. An assessment of groundwater quality for agricultural use: a case study from solid waste disposal site SE of Pune, India. Proceedings of the International Academy of Ecology and Environmental Sciences, 1(3-4): 195-201

Semerjian LA. 2011. Quality assessment of various bottled waters marketed in Lebanon. Environmental Monitoring and Assessment, 172: 275-285

Sharaf MA, Hussein MT. 1997. Groundwater quality in the Saq aquifer, Saudi Arabia. Hydrological Sciences - Journal- des Sciences Hydrologiques, 4(5): 683-696