Groundwater Quality in West Asia Region: Experiences of Bahrain, Kuwait and Saudi Arabia

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Abstract.

Groundwater quality in some GCC countries in West Asia Region was evaluated for its suitability for agricultural uses through determining the main physical and chemical properties in three agricultural areas in northern part of Bahrain, Wafra, southern Kuwait, and Al-Quseeh at Al–Qassim Region central Saudi Arabia. Samples were collected from 140 wells and analysed for major cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and anions (HCO_3^{-}, Cl^{-}, NO_3^{-}, SO_4^{2-}), Ec, pH and total dissolved solids TDS. *E. coli* and fecal bacteria content were also detected. The results showed that the quality of groundwater in most wells is admissible, poor to very poor. Na^{+}, and Cl^{-} are the main cation and anion in the groundwater, and salinization is the main threat to agriculture sustainability in the three studied areas. The study also showed that some shallow wells in the unconfined aquifer and those near the sanitary landfills or treated wastewater facilities, and animal's corrals contained *E. coli* bacteria and *fecal* bacteria. The suitability of groundwater for irrigation purposes based on IWQI indicated that irrigation water in the studied areas are of moderate to low suitability for irrigation purposes, thus it is not suitable for irrigation under ordinary conditions but may be used for salt tolerant plants on sandy soils through special agricultural and management practices.

Keywords:. Bahrain, Wafra, Al-Quseeh, IWQI, groundwater quality, sustainable agriculture.

1. INTRODUCTION

Most of the West Asia Region, especially the Gulf Cooperation Council (GCC) countries are of arid to extremely arid climate, with less than 100 mm/yr rainfall irregular in space and time; and high evaporation rates (>3000 mm/yr); and devoid of surface water resources. In order to meet water demands, the GCC countries depend mainly on fossil non-renewable groundwater. In the past three decades, the need for food security prompted decision makers to encourage agriculture through subsidy and incentive programs. Most farms use flood irrigation for the date palms, where as drip and sprinkle irrigation are common for vegetables and fodder crops respectively. High water requirement crops, poor irrigation practices, lack of monitoring of groundwater quantities consumed, lack of agricultural water tariffs, and conservation programs led to a majority of the water resources in most of GCC used in agriculture (Table 1), a sector that provides less than 5% of GDP [1] with low water efficiency (<40%) [2]. Table 1 . Percent of Water withdrawal by source and sector in some GCC countries[3].

Water withdrawal	% by source				% by sector		
	GW	DW	RTW	SW	I+L	M	I
Bahrain	66	29	5	0	45	49	6
Kuwait	45	46	9	0	54	44	2
Saudi	90.3	4.4	0.7	4.6	88	9	3

GW: Groundwater; DW: Desalinated water, RTW: Reused treated wastewater, SW: Surface water.; I+L: Irrigation + livestock; M: Municipalities; I: Industry

The overexploitation of groundwater led to drying of natural springs-if any-(Figure 1), degradation of its quality and consequently salinization of agricultural lands and eventual loss of their productivity[4]. The degradation of groundwater quantity and quality will undoubtedly impact the sustainability of both groundwater resources and the agricultural sector itself and put further pressure on ecosystems and biodiversity [5]. These water scarcity conditions are expected to continue due to the limited water resources, population growth, consumption patterns and food demand [6],which is expected to increase 60% globally by 2050 [7].

A. B.

Figure1. Natural Springs in Bahrain A: *Azahi Natural spring; B. Al-Safahiyah both in 50th s and 90th.*

On the other hand, water scarcity is expected to be aggravated in the GCC region by climate change [8] due to the expected reduction in precipitation and increase in temperature and evaporation and the invasive of seawater intrusion to the costal aquifer due to seawater level rise [9]. Moreover, water considered as a key for enhanced water and food security in the post-2015 sustainable development, Goal 3 and 6. The main objective of this study is to assess the water quality in three important production agricultural areas in the Kingdom of Bahrain, Kuwait and Saudi Arabia using a water quality index (WQI) which is a useful method for assessing water quality [10] and one of the most effective ways to communicate information on overall quality of water to the concerned citizens and policy makers.

2. MATERIALS AND METHODS

Groundwater samples were collected from Dammam Formation in the northern part of Bahrain (44 wells)[11]; Kuwait Group Formation in Alwafra area in southern Kuwait (76 wells) [12,13] and Saq and Tabuk Formations in Al-Quseeh center at Al–Qassim region in central KSA (33 wells) [14]. Groundwater samples were collected after pumping the sampled well for at least fifteen minutes and stored in clean, sterile polyethylene bottles of one liter capacity. Chemical analysis was carried out at the Arabian Gulf University, Bahrain; Environmental Authority, Kuwait and Labs of Agricultural ministry at Kuwait and KSA during 2010 and 2012. Standard methods from American Public Health Association [15] were followed for analysis. Most water samples were analyzed for pH, Electrical Conductivity (EC), Total Dissolved Solid (TDS), major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and major anions (Cl^{-}, HCO_3^{-}, SO_4^{2-}). *E. coli* and fecal bacteria were detected also and compared with the national standards for drinking purposes. Results were georeferenced and mapped using ArcGIS. Quality of groundwater and their suitability were assayed according to Richard [16]; Ayers & Westcot [17] and Simsek and Gunduz [18].

3. RESULTS AND DISCUSSIONS

3.1. **Bahrain** Despite the small land area of the Kingdom of Bahrain (765 km^2) natural water springs and agriculture were the main causes of its ancient civilization, i.e. Delmon, Tylos and Awal [19]. The overexploitation of the limited water resources result in the lowering of water levels, increase of salinity, (Figure 2) and drying of natural springs(Figure 1). Consequently, the agricultural area in Bahrain decreased by 70%, from 71.40 km^2 in 1998 to 21.6 km^2 in 2008 [20]. The pH value of the studied sample varied from 7.6-8.2, indicating a slightly alkaline nature. The electrical conductivity (EC) of water samples collected in the study area varies from 4400 μS/cm to 19400 μS/cm with a average of 9790 μS/cm [11].

Figure 2. Relationship between Abstraction–water levels-Salinity in the Dammam Aquifer in Bahrain[21].

The spatial distribution of EC and Cl^{-} of groundwater samples (Figure 3) indicates a deterioration of water quality thattakes place gradually as the water flows from the northwest (KSA) to the southeast (BHN) in the Dammam aquifer. Saline intrusion in the eastern part of this coastal aquifer may occur due to seawater encroachment in eastern Bahrain. The order of abundance of the cations was Na^{+}> Ca^{2+}>Mg^{2+}>$K^{+}$and representing an average of 48.6% , 30.5%, 19% and 1.9% respectively. Among the major anions, the order of abundance is Cl^{-} >SO_4^{2-}>HCO_3^{-} contributing as an average of 74.7%, 20.9% and 4.4% respectively.

EC and TDS in most wells were more than the maximum permissible limits for irrigation, and based on water classification according to Richard [16], the studied water sample are poor C4-S2 (35%) to very poor C4-S3(28%);C4-S4(26%) and C5-S4(12%).

Figure3.Spatial distribution of EC and Na^{+} in Bahrain [11].

Pearson's correlation showed that the highest positive and significant (p< 0.01) correlation (r =0.8 to 0.9) exist between EC and TDS, Cl^{-}, Na^{+}, K^{+}, Mg^{2+}. Positive correlations at (p<0.1) was found between TDS and Cl^{-}, K^{+},Mg^{2+} and Na^{+}; between SAR and Na^{+}; between Cl^{-} and Na^{+}, Mg^{2+}, and K^{+} ; Ca^{2+} and SO_4^{2+}. These relationships clearly identify that these elements tend to increase as the salinity of the groundwater increase; in other words it is contributing to the groundwater salinity. Results shows that the bacterial contamination in ground water samples were found in the eastern part of the study area near Tubli central wastewater plant in Bahrain.

3.2. **Al-Wafra** is one of the most important agricu-ltural areas in Kuwait, it depends on the unconfined Kuwait group aquifer for irrigation. The area is about 199km^2 and contains 1719 farms, the residents about 11210, and doesn't have a wastewater drainage system. So the Kuwait group is exposed to pollution resulting from excess saline irrigation water and from a leaking wastewater drainage system[12,13]. The pH value of the studied sample varies from 7.6-8.2, indicating a slightly alkaline nature. The electrical conductivity (EC) of water samples collected in the study area varies from 4400 µS/cm to 19400 µS/cm with an average of 9790 µS/cm[12]. Results indicated that Na^+ and Cl^- are the dominant cation and anion in AlWafra groundwater. The results also showed an increase in total dissolved salts with time from 6984 ppm in 1989 and 7930 in 1998, reaching an average of 9211 by 2010. According to Simsek and Gunduz standard [21], the water can be considered moderately suitable for irrigation. According to Richard [16] standards the water is of type C4-S4 (highly saline and sodic). The salinity increased west of Alwafra agricultural area and reached upto 13000ppm due to the presence of evaporation lakes of the Wafra Oil field[22]. can be considered moderately suitable for irrigation according to Simsek and Gunduz standards[18]. According to Richard[16] standards the water is of type C4-S4 (highly saline and sodic) .

Figure 4. EC spatial distribution in AlWafra area[12].

Another kind of pollutant threat to water quality in the Alwafra area is bacterial contamination. The majority of the contaminated wells with Ecoli and Fecal Coliform bacteria were located at a distance less than 60 meters from septic tanks which has been drilled in an unconfined Kuwait Group Formation [13] .

Fig 5. Soil salinization and Soil profile showing Gatch layer in Alwafra area[12].

3.3. ***Al-Quseeh*** is small agricultural center in Al–Qassim Region which is considered as one of the most important agricultural areas in the kingdom of Saudi Arabia. Result [14] shows that groundwater in 60% of the wells is of admissible quality (high salinity –low SAR, C3-S1), while 36% of the wells have water of poor quality (high salinity with moderate SAR, C4-S1). Identification of water Facies indicated that the groundwater of Al-Quseeh center had $Na^+ > Mg^{2+} > Ca^{2+}$, whereas for anions $Cl^- > SO_4^{2}$ (Table 2). The study also showed that 49% of the wells located in farms with residential buildings contained E. coli bacteria and 13% of these wells contained fecal bacteria. Most of the contaminated wells are shallow (depth of less than 200m). The suitability of groundwater for irrigation purposes based on Ayers and Westcot [17] indicated that irrigation water in Al-Quseeh center is of moderate suitability for irrigation purposes.

Table 2. Analysis of water Quality in Al-Quseeh [14].

mg/L	Min	Max	Average	St Dev
TDS	775	4890	2142	1921
Na^+	85	269	626	972
Ca^{++}	63	683	189	27
Mg^{++}	6	919	87	36
K^+	73	331	938	113
Cl^-	975	1657	773	367
SO_4^{--}	83	1538	355	867
HCO_3^-	195	639	157	33

4. Conclusions

Although GCC countries are located in an arid region, the non-renewable groundwater still contributes to most of their total water demands. The expansion of agricultural areas, combined with low water use efficiency and the governmental subsidies to agricultural sector, led to excessive pressure on groundwater resources, and consequently deterioration of water quantity and quality. This will not only impact the sustainability of groundwater resources in the GCC countries, but also the sustainability of the agricultural sector itself. On the other hand, shallow groundwater aquifers in the region are also susceptible to bacterial contamination due to infiltration or leakage from unlined septic tanks through the unconfined aquifers, or because of the proximity of water wells to animal corrals and wastewater collection and treatment facilities. To secure water quality, the study recommends encouraging the adoption of modern agriculture techniques, expanding the use of treated waste water, and to promote sustainable agricultural [6]. It is also recommended to establish a network of a geo-referenced hydrochemical databases for ground- water wells in all GCC countries, regular/ periodical monitoring of water quality, and integrated assessment and reporting of water resources in order to review and analyze water state, pressures, trend, and policies and consequently to secure the sustainability of water resources in term of water quantity and quality.

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