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Hydrogeology and Evaluation of High Saline Groundwater Quality in the Wadi Al-lusub Basin, Western Saudi Arabia

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Abstract: A study was carried out to assess the quality of high saline groundwater and hydrogeology in the Al-Lusub Basin, Western Saudi Arabia using drinking water suitability and IWQ parameters. The groundwater level is generally less than 50 mbgl and deep wells are existed in the center of the study region. Groundwater flows from northeastern part to central region and then towards North West. Groundwater quality is brackish (71%, n = 52) and alkaline in nature. Spatial distribution patterns of EC, TDS, major cations and anions follow groundwater flow direction. Drinking water quality assessment suggests that the groundwater is not recommendable for drinking without proper treatment. According to sodium adsorption ratio (SAR), Kelly's ratio (KR), Na% and residual sodium carbonate (RSC), 83%, 54%, 85% and 100% of wells, respectively, they are suitable for irrigation. Moreover, groundwater is suitable only for salt-tolerant crops and soil with good drainage and permeability. This work would help for proper management and planning of aquifer for future water need.

Key words: Groundwater quality · High saline · Irrigation · Lusub Basin · Saudi Arabia

INTRODUCTION

Water resources management is a complex process in arid and semi-arid regions due to limited water availability, accessibility, irregular rainfall pattern and high evaporation [1]. In these regions, periodic groundwater quality monitoring is an important task to protect available groundwater resources. Natural processes and human activities affect the aquifer and make the groundwater unfit for regular uses such as drinking, domestic and agriculture. Further, vast agricultural activities, rapid urbanization and extensive pumping are serious concern in groundwater quality.

As the Saudi Arabia (KSA) experiences arid and semi-arid climatic condition, water management is a critical task. The amount of groundwater in KSA is around 500 km^3 and 2.2 km^3/year is renewable groundwater resources [2]. Despite, rainfall is also contributing well in the water storage (~ 2045 MCM/year) [3]. Numerous studies reported the existence of groundwater contamination in the KSA [4, 5, 6, 7]. Irrigation return flow, dumping sites and sewage systems are common contamination sources, which leads to multiple contaminants in the groundwater [8, 9, 6, 7]. The present study was carried out in Al-Lusub Basin, Western Saudi Arabia. Few studies were carried out in this basin to assess the groundwater potential, impact of pumping rate and aquifer sustainability [10-13]. There is no detailed studies related to groundwater quality assessment in this basin. The primary objective of this study is to evaluate the quality of high saline groundwater and its suitability for drinking and irrigation uses. Spatial distribution maps were also employed to explain the groundwater flow direction and to interpret the water quality visually.

Study Area: Wadi Al Lusub, one of the main basins in Wadi Usfan, lies between 39° 0' and 40° 20' latitude and between 39° 0' and 40° 20' longitude (Figure 1) and occupies an area of about 2497 km^2. The sub-basins are Madrarkah, Hishah, Alaq, Sima, Hada Al Sham and Usfan. Rainfall ranges from 70mm to 120mm and more rainfall is recorded in the eastern part of the study region. Geologically, the study area is characterized by Precambrian, Tertiary and Quaternary formations (Figure 1). Wadi Al-Lusub basin is a part of the Western Arabian Shield, which is composed of metamorphic and plutonic rocks (Figure 1). The downstream of the basin is composed of sedimentary rocks (Tertiary) which overlaid by sheets of basaltic lava. The sedimentary formations are classified into two groups namely Usfan and Shumaysi

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formations. Sandstone, shale, marls and fossiliferous carbonate wedges are in the Usfan formations whereas Shumaysi formation consist of sandstone, siltstone and oolitic ironstone bands [14, 15].

MATERIALS AND METHODS

A detailed survey was performed to locate the existing wells in the Al-Lusub basin because numbers of wells are low, which are sporadically distributed. Based on the wells availability and accessibility, water samples were collected from 52 operating wells (Figure 1). pH, EC and temperature were measured during water sampling in the field using portable meters (SevenGo Duo SG23, Mettler Toledo).

Depth to groundwater level was measured in 84 wells using water level indicator. Groundwater samples were collected from bore wells after at least 10 minutes of pumping to remove standing water in the casing and ensure the water freshness. Water samples were preserved at 4°C until analysis. Water samples were filtered using 0.45 µm Millipore membrane filters. Analyses were conducted at the Center of Excellence in Environmental Studies (CEES) laboratory, King Abdulaziz University, Jeddah, Saudi Arabia. Bicarbonate and carbonate were analysed by titration [16]. Major ions and minor ions were analysed by Ion chromatography (Thermo scientific, ICS 5000+). The precision and measurement repeatability of each analysis were < 2 % and the ion balance error is ±5 %.

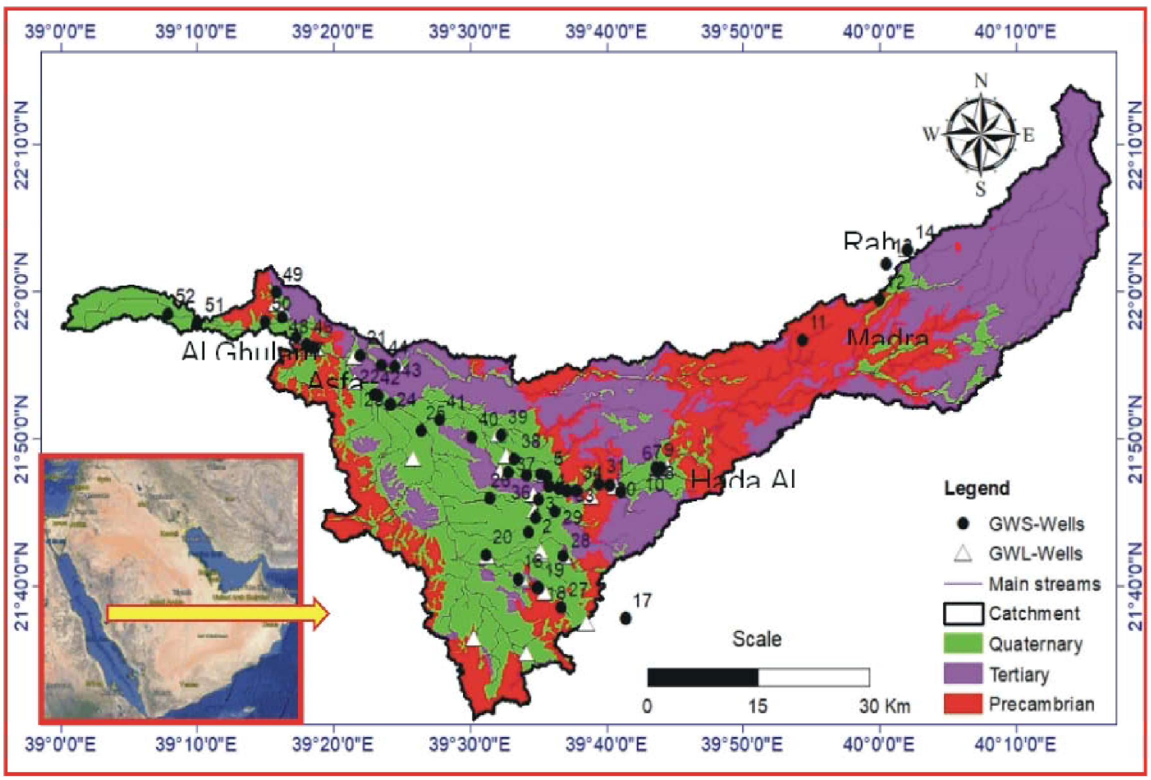

Fig. 1: Location map with sampling wells and other features. GWS – Groundwater sampling and water level measured wells. GWL-Groundwater level measured wells.

Table 1: Irrigation water quality parameters calculation

Parameter	Equations (All ions in meq/l)
Sodium adsorption ratio (SAR)	$SAR = Na^+/\{(Ca^{2+}+Mg^{2+})/2\}$^0.5
Residual sodium carbonate (RSC)	RSC (meq/l) = $(CO_3^- + HCO_3^-) - (Ca^{++} + Mg^{++})$
Kelly's ratio (KR)	Kelly's ratio (KR) (meq/l) = $Na^+/(Ca^{2+}+Mg^{2+})$
Magnesium hazard (MH)	MH (%) = $\{Mg^{2+}/(Ca^{2+}+Mg^{2+})\}*100$
Sodium percentage (Na%)	Na% = $\{(Na^++K^+)/(Na^++K^++Ca^{2+}+Mg^{2+})\}*100$.

Water quality data were employed for various calculations to assess the suitability of water for domestic and irrigation. Irrigation water quality (IWQ) parameters were calculated to evaluate the water suitability for irrigation applications. ArcGIS v10.2 and Surfer v10 were applied to prepare suitability and surface maps.

Irrigation Water Quality (IWQ) Parameters: IWQ parameters namely sodium adsorption ratio (SAR), residual sodium carbonate (RSC), bicarbonate hazard (BH), Kelly's ratio (KR), magnesium hazard (MH) and sodium percentage (Na %) were calculated (Table 1).

RESULTS AND DISCUSSION

Hydrogeology and Groundwater Flow: Quaternary deposits represent the main shallow aquifer in the Al-Lusub basin, which is composed of gravel, sand and sandstone with some intercalations of shale. Aquifer thickness varies from few meters at the upstream to >100 m at the middle and downstream of the basin. Previous study documented the existence of unconfined (up to 65m) and semi-confined/confined aquifer (thickness 200 – 250m) in this basin [17]. Hydraulic conductivity of the upper unconfined aquifer is 0.03 m/min [18, 19]. In the lower aquifer, the permeability and transmissivity are 1.7 m/day and 383 m^2/day, respectively [19].

In this study, groundwater levels in the Al-Lusub basin were surveyed in 84 wells and it ranges from 5 mbgl to 50 mbgl except three wells (61, 95 and 125 mbgl in the well no. 35, 49 and 2B). Groundwater level is generally shallow in the upstream and downstream regions and deep in the central region (Figure 2). Wells with groundwater level > 50 m bgl occurred in the central region. Groundwater flows from northeast to central region and then towards northwest (Figure 2). Central part of the study area is looking like valley.

General Groundwater Quality: Groundwater quality in the Al-Lusub basin is generally brackish and the electrical conductivity (EC) ranges from 1291 to 25700 (µS/cm) with an average of 9780 (µS/cm) (Table 2). Total dissolved solids (TDS) also shows that the water is brackish to saline in nature (646 -12860 mg/l; mean =4892 mg/l). The groundwater samples can be classified into fresh (n = 4; 8%), brackish (n = 37; 71%) and saline (n = 11; 21%) based on TDS [20]. TDS is greater than 1500 mg/l in the 75% of samples, which are not suitable for drinking (Table 3). Around 56% of samples, TDS is greater than 3000 mg/l and are not usable for irrigation as well [21]. In this study, pH is greater than 7 (n = 39; 75%) and the water is alkaline in nature. Major cations and anions are in the order of Na>Ca>Mg>K and Cl>SO4>HCO_3>NO_3, respectively. In the study region, CaMgCl and NaCl water types are noticed. Table 2 depicts that the mean value of most of the parameters are higher than median values, which suggests that the water quality is not homogenous in the study region.

Spatial distribution maps are useful tool to demark the contamination free zones and visual interpretations. Spatial distribution maps depict that EC and TDS follow similar trend and increased all along the groundwater flow direction (Figure 2). Low EC and TDS are noticed in the northeastern side and very high values are observed in the western and northwestern side. Similar pattern is observed in the Na as well. Further, 90% of the groundwater wells are unsuitable for drinking due to high Na concentration (Na > 200 mg/l) [22] (Table 3). Drinking water with high sodium causes hypertension, circulatory and cardiac. Like Na, the potassium concentration exceeds WHO recommended limit (K > 12 mg/l) in 54% of samples. The distribution pattern indicates that K increased from center to the west and northwest region like Na. The spatial distribution patterns of Ca and Mg follow similar trend and high concentrations are recorded in the western side. Table 3 depicts that 98% and 87% of samples exceeded the drinking water limits of Ca (75 mg/l (highest desirable limit (HDL)) and 200 mg/l (maximum allowable limit (MAL)), respectively, recommended by WHO. In the case of Mg, 90% and 52% of samples exceeded the HDL and MAL, respectively, which are not palatable (Table 3). Drinking water with high calcium creates health issues namely kidney or bladder stones and irritation in urinary passage for users [23].

The spatial distribution of Cl and SO_4 also behave like major cations and both increased from northeast to center and then to west and northwest. The concentrations of Cl and SO_4 range from 72 to 8434 mg/l and from 117 to 5254 mg/l with a mean value of 2716 mg/l and 2067 mg/l, respectively (Table 2). Around 94% and 71% of samples exceeded the HDL and MAL of Cl recommended by the WHO (Table 3). Likewise 96% and 90% of samples exceeded 200 mg/l and 400 mg/l of SO_4, respectively, which are not palatable. Water with high Cl and SO_4 affects the human health and causes hypertension, stroke, diarrhea, dehydration and gastrointestinal irritation [24, 25].

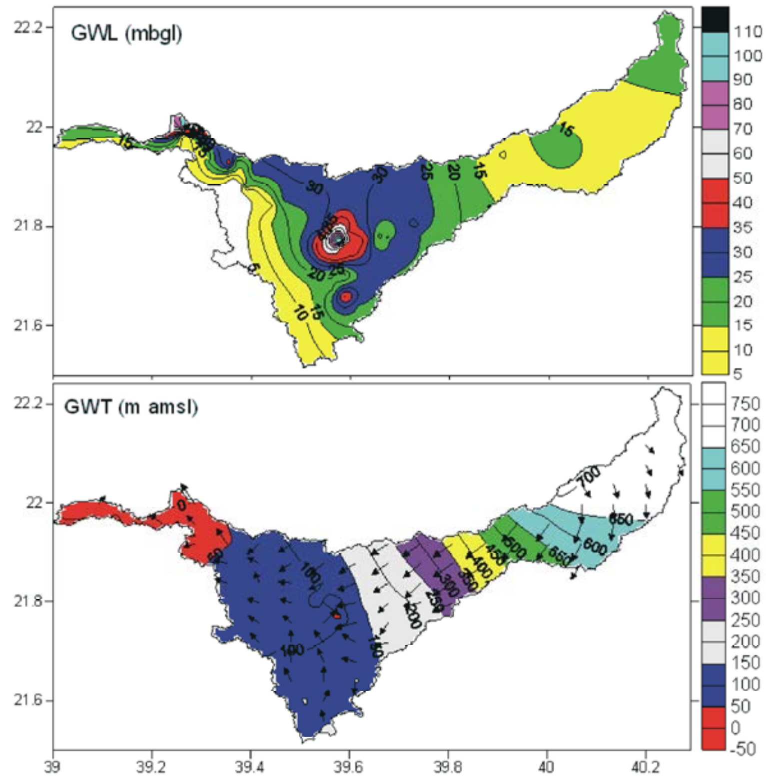

Fig. 2: Groundwater level and flow direction

Table 2: Descriptive statistics of analyzed parameters in the groundwater

Parameters	Min	Max	Average	Median	STD
pH	6.6	7.8	7.2	7.2	0.3
EC	1291	25700	9780	7050	8030
TDS	646	12860	4892	3520	4018
TH	258	6676	2655	2042	1947
Na	68	4036	1347	821	1277
K	1	53	19	15	14
Ca	59	1729	638	477	469
Mg	16	792	258	180	216
Cl	72	8434	2716	1583	2746
HCO3	57	659	196	169	96
SO4	117	5254	2067	1571	1505
NO3	6	810	149	97	169
F	0.1	8.1	1.2	0.8	1.3
Br	0.4	118	20	8.5	25
PO4	0.2	13	5.1	4.5	3.7

Unit: mg/l except pH and EC (µS/cm)

Spatial distribution maps and drinking water suitability assessment

The spatial distribution pattern of the HCO_3 is different from the other ions and high concentration is found in the central and northeastern side of the basin. Groundwater HCO_3 concentration varies from 57 to 659 mg/l with a mean value of 196 mg/l. The spatial distribution of PO_4 also behaves like major ions and elevated values are observed in the western side. Spatial distribution of fluoride illustrates that it is less than 1.5 mg/l in most of the region and varies from 1.5 to 3 mg/l in the coastal region. Wells situated in the coastal and northwestern side exceeded the drinking water limit (Table 3). High fluoride in the drinking water causes fluorosis for consumers and it affects the teeth and bones.

The concentration of nitrate varies from 6 to 810 mg/l with an average of 149 mg/l. There is a difference between the mean and median values and six wells have higher nitrate concentration (NO_3 > 300 mg/l) in this region (Table 2). The standard deviation (169 mg/l) of nitrate is also higher than the average concentration (Table 2), which indicates that nitrate is derived from multiple sources like domestic sewage, septic tank effluents and agriculture activities. According to WHO, around 71% of samples exceeded the drinking water limit (NO_3>45 mg/l) (Table 3). Earlier study also reported high nitrate (1.1 to 884 mg/l, n = 1060) in groundwater based on a survey conducted in 13 regions of KSA [6].

Irrigation Water Suitability Assessment: Groundwater suitability for irrigation was assessed using irrigational water quality parameters such as SAR, BH, RSC, Kelly's ratio, MH and Na% (Table 1). In addition, EC, bicarbonate and USSL classifications are also used for

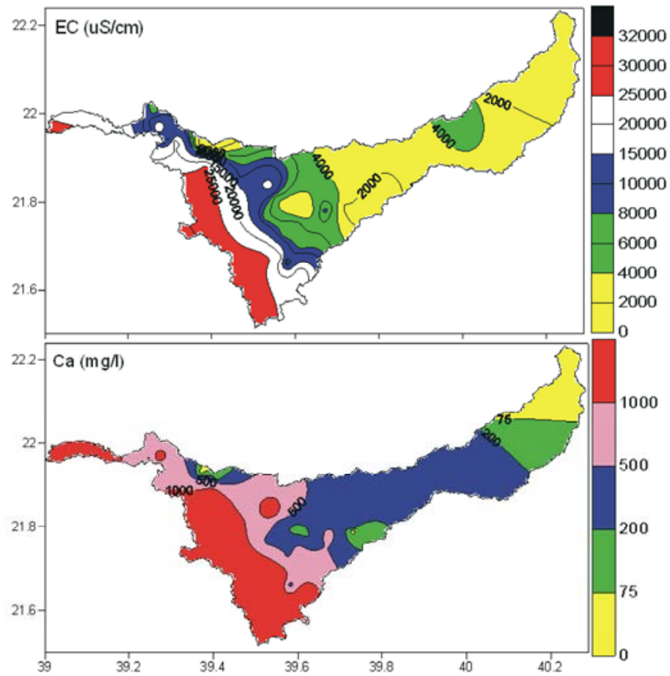

Fig. 3: Spatial distribution pattern of EC and Ca.

Table 3: Groundwater suitability for drinking purpose

	WHO (2011)			
Parameter	Highest desirable limit (HDL)	Maximum allowable limit (MAL)	No. of samples (%) exceeded HDL	No. of samples (%) exceeded MAL
pH	6.5-7.5	6.5-9.2	43 (83)	0
TDS	500	1500	52 (100)	39 (75)
TH	100	500	52 (100)	47 (90)
Ca	75	200	51 (98)	45 (87)
Mg	50	150	47 (90)	27 (52)
Na	-	200	-	47 (90)
K	-	12	-	28 (54)
Cl	200	600	49 (94)	37 (71)
SO4	200	400	50 (96)	47 (90)
NO3	45	-	37 (71)	-
F	-	1.5	-	14 (27)

Table 4: Groundwater suitability for Irrigation

Parameters	Range	Suitability	No. of samples (%)
EC (μS/cm)	<250	Excellent (C1)	0
	250-750	Good (C2)	0
	750-2250	Fair (C3)	5 (10)
	2250-5000	Poor (C4)	13 (25)
	>5000	Unsuitable (C5)	34 (65)
SAR	<10	Excellent (S1)	30 (58)
	10-18	Good (S2)	13 (25)
	18-26	Fair (S3)	9 (17)
	>26	Poor (S4)	0
Na%	<20	Excellent	0
	20-40	Good	16(31)
	40-60	Permissible	28(54)
	60-80	Doubtful	8(15)
	>80	Unsuitable	0

this assessment. Table 4 shows that 65% of samples are unsuitable for irrigation based on EC (> 5000 µS/cm). Remaining 35% of samples come under fair to poor classes. High salinity will reduce water and nutrients absorption by plant and changes soil chemical and physical properties as well as plant growth. In contrast, SAR shows that 83% of samples are excellent (S1) to good (S2) classes and suitable for irrigation (Table 4). Further, 17% of samples are classified as fair usage. In the study area, the calculated SAR varies from 2 to 24 with a mean value of 10. Based on bicarbonate concentration, irrigation water is classified into suitable (HCO_3 < 1.5 meq/l), moderately suitable (8.5 > HCO_3 > 1.5 meq/l) and unsuitable (HCO_3 > 8.5 meq/l) [26]. According to this classification, 92% of samples are not recommended for irrigation, which causes problem to soil properties.

On contrast, all samples are suitable for irrigation according to RSC classification [27]. In this study, RSC is less than 1.25 meq/l in all wells and suitable for irrigation. Kelly's ratio (KR) indicates that 54% of samples (KR < 1) are suitable for irrigation in the study area [28]. Similarly, 87% of samples are suitable for irrigation according to Mg hazard (MH < 50%). High sodium in the water increases ion exchange process and affects soil properties like texture and permeability. According to Wilcox [27] classification, 31%, 54% and 15% of samples fall in good, permissible and doubtful classes, respectively (Table 4).

Using SAR and EC, U.S. Salinity laboratory [29] evaluated the water suitability for irrigation, which indicates that 37 samples (69%) plotted in the C5S3 (n = 8), C4S1(n = 7), C5S4(n = 7), C3S1(n = 5), C4S2 (n = 4), C5S2(n = 4), C4S3 and C4S4 (diagram not shown). Remaining 15 samples have EC > 10000 µS/cm. USSL classification indicates that the water samples have very high salinity. Likewise, samples plotted in the low sodium (S1, n = 12), medium sodium (S2, n = 8), high sodium (S3, n = 9) and very high sodium (S4, n = 8) classes. Irrigation water with very high salinity is only suitable for soil with good drainage and permeability as well as salt-tolerant crops whereas medium sodium water is suitable for coarse textured soil with high permeability. S3 and S4 waters cause exchangeable sodium in the soil and are unsuitable for regular irrigation practices. Overall, the assessment of water suitability for irrigation suggests that most of the wells are usable for irrigation based on SAR, KR, MH, RSC and Na% whereas reverse is true based on EC, bicarbonate and USSL classification.

CONCLUSIONS

In Al-Lusub basin, groundwater quality is generally brackish (71%) and alkaline in nature. The depth to groundwater level is mostly <50 mbgl and groundwater flows from northeastern part to central region and then towards North West. Spatial distribution patterns of EC, TDS, major cations, Cl and SO_4 illustrate that the concentrations increased all along the groundwater flow direction. Drinking water suitability assessment indicates that around 95% of wells are not suitable for human consumption, which exceeded the WHO drinking water guideline values. Groundwater suitability for irrigation was evaluated using irrigational water quality parameters. According to SAR, RSC, KR and Na%, 83%, 100%, 54% and 85% of the wells, respectively, are suitable for irrigation. Likewise, 65% and 92% are unsuitable for irrigation based on EC and BH classification. On the other hand, USSL classification indicates that 36 samples (69%) are suitable only for good drainage and highly permeable soils as well as saline-tolerant crops. In Al-Lusub basin, 95% of wells have been used for agricultural water requirement and water usage is restricted due to the high salinity. Further, this study will aid to locate places that are suitable for groundwater development and sustainability.

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Conflict of Interest: The authors declare that they have no conflict of interest.

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