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Assessment of Groundwater Quality and its Suitability for Drinking and Agricultural Use in *Batinah* Coastal Plain, Sultanate of Oman

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Abstract: The Batinah coastal aquifer, situated in northwestern Sultanate of Oman, is the principal source of water for agricultural, municipal and industrial activities due to lack of surface water resources. The overexploitation of this aquifer, since 1970s, let to the depletion of groundwater quantity and deterioration of quality through seawater intrusion. Available water chemical data from southern part of Batinah aquifer was evaluated using graphical and statistical technics to understand natural and anthropogenic processes controlling mineralisation. A significant increase in the degree of water mineralisation was observed in the direction of groundwater flow from south to north. The chemical relationships in Piper's diagram suggest that groundwater is enriched mainly with chloride and sodium and that groundwater chemistry is regulated by distinct processes such as mineral dissolution in the highland part and saline water and ion exchange in the coastal part. PCA revealed that the predominant processes controlling the groundwater chemistry are seawater intrusion, mineral dissolution, ion exchange and extensive use of chemical fertilizers. Calculated saturation indices show that nearly all water samples are saturated and supersaturated with respect to carbonate minerals and under saturated with respect to sulfate minerals. Wilcox's and US Salinity Laboratory's diagrams suggest that the majority of the groundwater samples are not suitable for irrigation under ordinary conditions.

Key words: Groundwater quality · Seawater intrusion · Saturation index

INTRODUCTION

Groundwater is often the main resource of fresh water in many coastal cities located in arid and semi-arid regions. In these cities, the increasing demand of this resource for municipal, agricultural and industrial purposes has induced the decrease of the groundwater level and the deterioration of its quality. Degradation of groundwater quality in coastal regions may be the consequence of natural and anthropogenic processes. The natural processes include seawater intrusion, interaction of groundwater with brines and sedimentary formations like marl and sebkha and upcoming of saline water [1, 2]. Anthropogenic contamination can be induced by the high nitrate content derived from irrigation return flown, farm manures, fertilizers, domestic sewage, animal wastes and landfill and septic tank influent [3].

Sultanate of Oman is an arid country with low rainfall (100 mm/year) and very high evapotranspiration (3,000 mm/year). Under these harsh climatic conditions, groundwater resources are especially important as they supply more than 93% of the demand for fresh water and play a great role in the socio-economic development [4]. Since groundwater represents the main source of irrigation water, the aquifer has been massively pumped during the last three decades to meet the growing needs of municipal, agricultural and industrial activities. This has resulted in the decline of groundwater level and in seawater intrusion. Consequently, the groundwater was contaminated by salts and large agricultural lands have become unusable.

Various approaches were used to investigate the problem of seawater intrusion and its impact on groundwater quality. [5] studied the salinisation

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expansion in the aquifer of Korba in Tunisia using a statistical approach. Results showed that there was a strong relation between sample composition and seawater composition. [6] presented spatial and temporal assessments of the groundwater quality in the coastal aquifer of Wadi Ham located in northeastern part of UAE. Results indicated that seawater intrusion from the Gulf of Oman is not the main source of brackish water in several parts of the aquifer. [7] investigated the seawater intrusion predication in the Salalah coastal aquifer in Oman using an integrated approach. The simulation study predicted that by the year 2020 the groundwater level would decline by about 216% from their levels in 2006 and the seawater will move by 3 km inland. [8] used DRASTIC index method in GIS environment Assessment of groundwater vulnerability in Barka coastal region in Sultanate of Oman. DRASTIC vulnerability maps of 1995 and 2004 indicate that the northern part of this region is more vulnerable to pollution than southern and central parts of the same region. [9] used an analytical Dupuit-Forchheimer model to develop for the Batinah explicit expressions for the water table, sharp interface location and stored volume of fresh water. Results showed that the seawater intrusion could be mitigated by the pumping of salt water from the intruded part of the aquifer. [10] used geophysical methods to estimate the rate of seawater intrusion in Al Khabourah area, Sultanate of Oman. They showed a prominent recession in the saline plume and suggested an average annual recession rate of 120 m. [11] studied the interface dynamic between fresh and saline groundwater in south Chennai coastal aquifer. Results showed that the interface is moving towards the inland due to the over exploitation of groundwater.

The main objective of this study is to assess the groundwater quality and its suitability for drinking and irrigation purposes in the southern part of Batinah region using available ionic data.

MATERIALS AND METHODS

Study Area: The study region, encompassing an area of 1634 km^2, lies between 57°11’36’’ and 57°14’12’’E Longitudes and 23°35’30’’ and 23°37’24’’N Latitudes (Fig. 1). It is a coastal plain which extends 90 km along the Gulf of Oman, from Al Suwyq wilayat in the west to Barka wilayat in the east. This region is bounded by Jabal Al Akhdar in the south and by the Gulf of Oman in the north. It comprises three wadis (Al-Maawil, Bani Kharus and At Taww) that drain the western mountains slopes of Jabal and the coastal plain. The altitude ranges from 100 m at the piedmont to 0 m (sea level) at the coast. The average annual rainfall is 100 mm. Rainfall takes place mostly during the cool winter months from December to April. During the summer months from May to October the weather is hot, with temperatures up to 48°C.

The Quaternary-aged Alluvium and Neogene-aged Upper Fars Group are the main geological units in the study area with a total thickness of about 650 m [12]. These two geological units are significant for groundwater availability because all the wells in the coastal plain mostly tap from the Alluvium aquifer.

The quaternary alluvium is formed by the weathered products of limestone and ophiolite. It comprises loose gravels interbedded with clay (Fig. 2). The thickness of this layer reaches a maximum of 300 m. The alluvium aquifer is having horizontal transmissivity values within the range from 0.9 - 16,900 m^2/day. The lowest horizontal transmissivity was associated with cemented, clayey sands, while the highest values were associated with uncemented sands and gravels. The Fars Group, underlying the Alluvium formation, can be divided into three main formations viz Upper Fars Formation, Middle Fars Formation and Lower Fars Formation. The Upper Fars comprises of cemented gravels/conglomerates interbedded with brown and pink dolomitic and chalky limestone, clay and silt. The thickness of this layer is varying between 565 and 582 m. For the Upper Fars, the horizontal transmissivity is varying from 17 to 468 m^2/day. The Middle Fars Formation comprises claystone interbedded with thin cemented gravels. The thickness of this formation reaches up to 146 m. The Lower Fars Formation comprised calcareous shale interbedded with silty limestone. The thickness of these formation ranges between 8 m and 133 m.

The Alluvium and Upper Fars aquifers are considered as a single hydrogeological unit under water table conditions with two layers, the alluvium layer (Layer 1) and the Upper Fars layer (Layer 2). The middle Fars is generally impermeable and is considered an aquitard that forms the base of the groundwater aquifer. This aquifer is recharged by water flowing from Jabal Al Akhdar, local infiltration from local rivers and irrigation return to the aquifer.

Figure 3 shows the regional distribution of groundwater level and flow direction in the study area. It illustrates that the groundwater flow generally towards the northern direction. This hydraulic gradient follows the topography gradient and shows that the groundwater flow direction is from the foothills towards the coast.

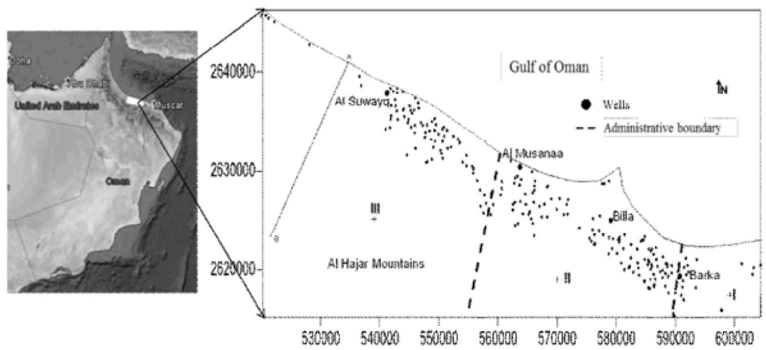

Fig. 1: Map shows the location of monitoring wells. Line A-B is cross section explained in Fig. 2

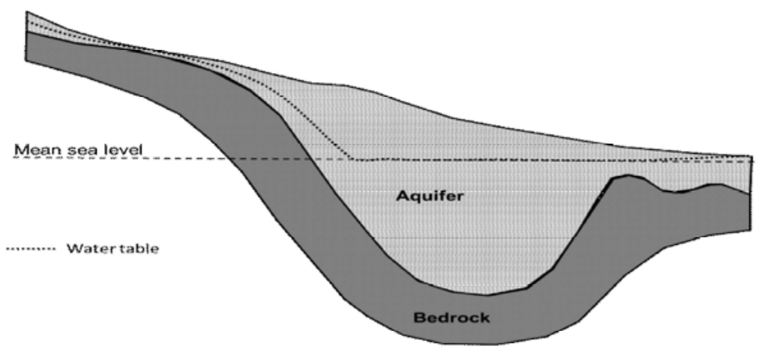

Fig. 2: Geological cross-section of Alluvium aquifer in Wadi Al Maawil of the southern Batinah (CACE, 2004)

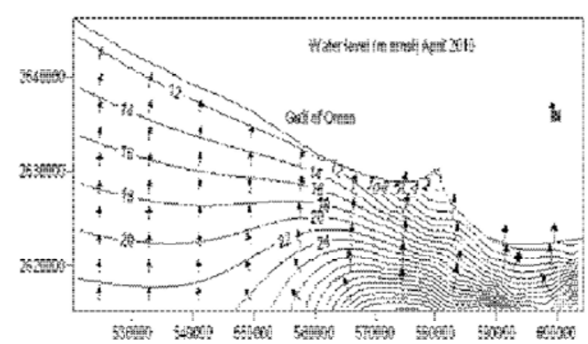

Fig. 3: Map shows the regional variation in water table level (meter above mean sea level) and groundwater flow direction in the study area

The total groundwater abstraction in the study area for the year 1995 was 170 Mm^3/year [13]. About 97% (165 Mm^3) of the groundwater abstraction was used in agriculture and for livestock and the remaining 3% (5 Mm^3) for municipal and industrial uses.

Analysis of Data: The study has utilised existing data of physical and chemical groundwater properties from the Ministry of Regional Municipalities and Water Resources (MRMWR), Oman. Analyses of pH, electrical conductivity (EC), anions and cations for a set of 224 groundwater samples collected during spring 2010 were carried out in the Food and Water Laboratories Center. Parametric statistical methods were used to provide useful generalisations about the water quality of the study area, such as the average concentration of a constituent and the expected variability. Surfer 9.0 software was used to create integrated groundwater quality maps and to display the areal distribution of dissolved constituents throughout the study area. The Piper diagram was used to identify hydro-chemical facies in that area. The geochemical modelling program PHREEQC [14] was used to calculate the distribution of aqueous species and mineral saturation indices. Principal component analysis (PCA), a multivariate statistical technique, was applied to interpret the multidimensional groundwater quality data into a lower dimensional format. The statistical software package XLSTAT 2012 for Windows was used to calculate the basic descriptive statistics and to perform the PCA.

Irrigation Water Quality: The effects of irrigation water on crop production and soil quality can be described using the following characteristics: (i) total soluble salt content; (ii) relative proportion of sodium to calcium and magnesium ions; (iii) carbonate and bicarbonate concentrations; (iv) specific ions concentrations such as chloride, boron, sulfate and nitrate. These have been termed as the salinity hazard, sodium hazard, alkali hazard and chloride hazard. The most influential water quality guideline on crop productivity is the water salinity hazard as measured by electrical conductivity. The higher the EC, the less water is available to plants. Soils with high sodium content are known for having a poor soil structure. In the past the sodium hazard has been assessed using the percentage of sodium content (Na%) which is the ratio of sodium to the total cations, namely, sodium, potassium, calcium and magnesium. Na% is calculated using the following equation:

$$Na\% = \frac{Na \times 100}{Ca + Mg + Na + K} \quad (1)$$

where the quantities of Ca, Mg, Na and K are expressed in milliequivalent per litre. Na% is plotted against EC, which is designated as a Wilcox diagram [15].

A better measure of the sodium hazard for natural waters is sodium adsorption ratio (SAR). The SAR defines sodicity in terms of the relative concentration of sodium (Na^+) compared to the sum of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in a sample. The SAR is calculated using the following equation:

$$SAR = \frac{Na}{\sqrt{\frac{(Ca+Mg)}{2}}} \quad (2)$$

where units are expressed in milli-equivalent per liter. The diagram of US Salinity Laboratory Staff is used widely for assessing irrigation waters [16], where SAR is plotted against EC.

RESULTS AND DISCUSSION

Water Chemistry: Table 1 shows major constituents of the groundwater in the study area with minimum, maximum, mean and standard deviation (STD) values. The pH of the groundwater samples vary from 6.5 and 8.7 with an average value of 7.7. At this pH, bicarbonate (HCO_3^-) is the predominant carbonate species. [17] recommends a pH range between 6.5 and 9.2 in waters used for public supply. Generally, the groundwater in the study area is alkaline (pH > 7 units). The action of carbon dioxide in water on carbonate rocks such as limestone and dolomite, carbonate and bicarbonate may produce an alkaline environment. The electrical conductivity (EC) of groundwater samples ranges from 631 to 31,460 µS/cm with a mean value of 7,560 µS/cm. These values indicate the brackish nature of the groundwater aquifer, which is possibly attributed: (i) in the upstream area to the nature of the alluvial deposits which are rich in soluble minerals and (ii) in downstream area to irrigation return flow that causes leaching of soluble salts precipitated in the root zone under the high evaporation rate and to mixing with the underlying dense salt water mostly caused by over-pumping.

The maximum limit of EC in drinking water is 1,300 µS/cm. Ninety-four percent of the groundwater samples in this study are higher than this threshold value. The EC increases in the direction of groundwater flow from south to the north (Fig. 3). The low mineralised water (EC < 1,300 µS/cm) was found at the piedmont of Jabal Al Akhdar, whereas high-mineralised water was identified in the coastal part of the study area. Groundwater samples in Barka are extremely affected by salinisation because the average EC (8,409 µS/cm) is very high compared to that calculated in Al Suwayq and Mussanna. Generally, Na^+ and Mg^{2+} are the major cations and Cl^- and SO_4^{2-} are the major anions in groundwater. In fact, cation chemistry indicates that 75% of the samples are Na^+ □ Mg^{2+} □ Ca^{2+} □ K^+, while the remaining 25% of samples are Na^+ □ Ca^{2+} □ Mg^{2+} □ K^+. The concentrations of Na^+, K^+, Ca^{2+} and Mg^{2+} ions range from 63.8 to 4687.0, 4.2 to 232.1, 26.7 to 1392.9 and 40.2 to 1467.2 mg/l with an average value of 969.7, 29.0, 292.6 and 344.6 mg/l, respectively. Among the cations, only the mean potassium concentration (K^+) in all samples is lower than the WHO allowable potassium concentration of 200 mg/l. As expected, the groundwater aquifer in Barka has high average calcium and magnesium levels relative to Suwayq and Mussanna (Fig. 4). In addition to the seawater intrusion, the source of magnesium and calcium in the groundwater could be limestone and dolomite in the sedimentary rocks. Anion chemistry indicates that 78% of samples are Cl^- □ SO_4^{2-} □ HCO_3^- □ NO_3^-, while the remaining 22% are Cl^- □ HCO_3^- □ SO_4^{2-} □ NO_3^-. The dissolved anions such as Cl^-, SO_4^{2-}, HCO_3^- and NO_3^- vary from 62.7 to 11256.5, 39.5 to 3731.0, 66.0 to 599.8 and 0.0 to 674.0 mg/l with an average value of 2426.0, 547.6, 210.1 and 24.1 mg/l, respectively. Among the anions, only the mean concentration of chloride exceeds guideline value set by WHO (Table 1). Fig. 4 shows that the bicarbonate concentration is decreasing from Al Suwayq to Barka. The first wilayat could be affected by infiltration of irrigation water originating from surface contaminations sources, which causes dissolution of carbonate and silicate minerals indirectly. The nitrate concentration indicates 7.6% of samples exceed 50 mg/l (drinking water standard for nitrate) and 45.5% of samples

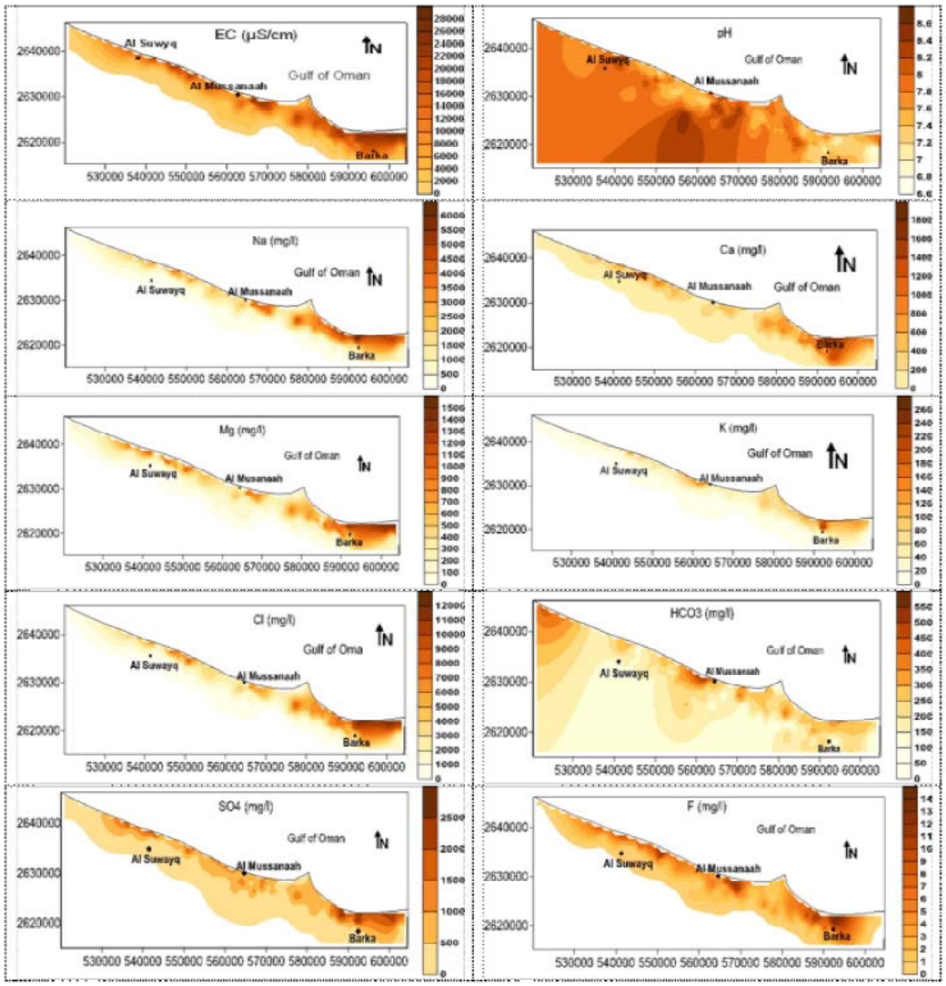

Fig. 4: Regional variations in pH, total dissolved solids, main anions and cations concentrations

Table 1: Statistical summary of groundwater quality data in Southern part of Batinah plain

	EC (µS/cm)	pH	Na	Ca	Mg	K	Cl	HCO_3	SO_4	NO_3	SiO_2	F
						Barka						
Min	1252	6.54	156.1	26	41.3	4.9	200.3	66.0	88.0	0.0	2.5	0.0
Max	25800	8.26	5875	1809	1379.5	379.1	11256.5	434.8	3457	255.1	269	13.6
Mean	8409	7.56	1386.9	401.9	385.8	35.7	2960.7	208.2	579.8	20.7	42.0	3.3
STD	6957.6	0.33	1314.7	402.9	367.7	46.5	2879.6	68.4	583.9	31.0	39.3	3.4
n	98	98	98	98	98	98	98	98	98	98	98	98
						Mussanaa						
Min	1560	7.10	156.9	40.4	51.0	5.1	193.4	76.8	135.3	0.0	24.6	0.6
Max	31460	8.7	4780.0	715.9	1186.3	214.5	8236.2	491.6	1720	674.0	57.0	12.7
Mean	6777.7	7.9	1034.7	173.1	255.9	20.2	1733.2	175.7	548.5	27.7	39.3	2.9
STD	6177.5	0.4	1072.4	143.9	225.7	28.6	1751	65.4	380.5	87.0	7.8	3.0
n	58	58	58	58	58	58	58	58	58	58	58	58
						Al Suwyq						
Min	631	7.2	63.8	26.7	40.2	4.2	62.7	90.0	39.5	0.0	3.9	0.0
Max	22900	8.7	4687.0	1392.9	1467.2	232.1	9922.9	455.3	3731	335.2	68.2	13.7
Mean	6990.8	7.8	969.7	292.6	344.6	29.0	2238.4	209.3	500.0	25.8	32.7	3.5
STD	6381.2	0.3	1079.3	307.0	384.2	35.0	2497.7	70.4	626.1	55.4	12.7	3.5
n	68	68	68	68	68	68	68	68	68	68	68	68

Table 1: Continue

	EC (µS/cm)	pH	Na	Ca	Mg	K	Cl	HCO_3	SO_4	NO_3	SiO_2	F
						Total						
Min	631	6.54	63.8	26.0	40.2	4.2	62.7	66.0	39.5	0.0	2.5	0.0
Max	31460	8.69	5875.0	1809.6	1467.2	379.1	11256.5	599.8	3731	674.0	269	13.7
Mean	7559.9	7.74	1170.1	309.9	339.8	29.7	2426.0	210.1	547.6	24.1	38.5	3.2
STD	6634.4	0.36	1205.4	338.2	347.1	39.7	2571.8	72.3	555.2	57.6	27.6	3.3
n	224	224	224	224	224	224	224	224	224	224	224	224
						Guideline values						
WHO (2004)	1,300	6.5-9.2	200	200	150	200	250	240	250	50		1.5
Seawater	57100	8.18	10012	410	1,350	520.7	19,000	142	2797	0	0	7.3

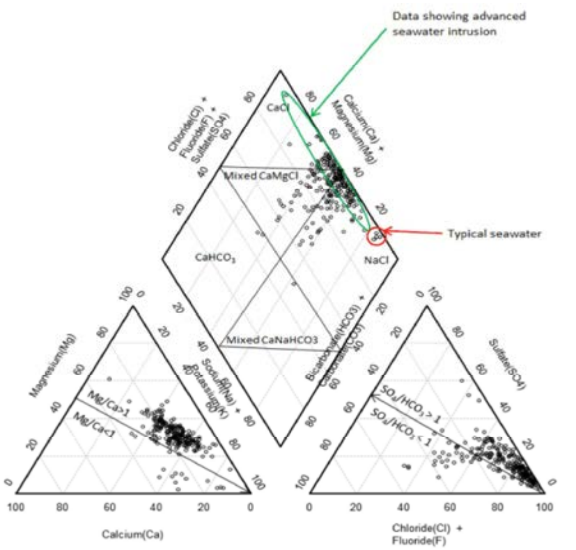

Fig. 5: Piper plot of groundwater h/ydrochemical data in the study area

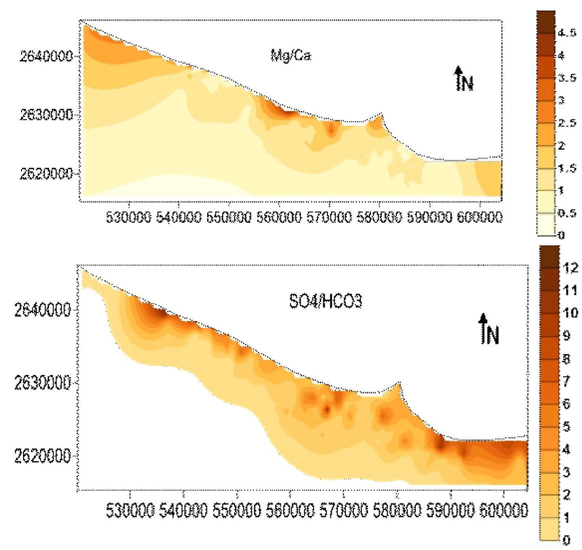

Fig. 6: Spatial distribution of Mg/Ca and SO4/HCO3 ratios in the study area

lie between 10 and 50 mg/l. The high concentrations of nitrate in Mussanaa imply the influence of anthropogenic sources, since several agricultural activities are practiced in this wilayat. According to the criteria developed by [18], nitrate concentration in the range 3.1-10 mg/l may represent elevated concentrations due to human activities.

Groundwater Quality: Figure 5 shows that groundwater samples are classified as various chemical types on Piper diagram. The dominant water types are in the order of NaCl > mixed CaMgCl > CaCl > $CaHCO_3$ > mixed $CaNaHCO_3$. However, most of the samples are clustered in NaCl, CaMgCl and CaCl segments. This indicates that samples are enriched with sodium and chloride followed by calcium and magnesium. This result shows that seawater intrusion and surface contamination sources such as irrigation return flow play a major role in controlling the groundwater chemical in the groundwater aquifer. Three wells are falling in facies NaCl, indicating the influence of seawater intrusion. However, $CaHCO_3$ and mixed $CaNaHCO_3$ water types express mineral dissolution and recharge of freshwater.

Seawater solutes are characterised by Mg^{2+} greatly in excess of Ca^{2+} (Mg^{2+}/Ca^{2+} = 5.4 in the case of Gulf of Oman). Therefore, the Mg^{2+}/Ca^{2+} ratio can be a good indicator for delining the sea-freshwater interface [19], [20]. Figure 6 indicates that magnesium dominates over calcium and Mg^{2+}/Ca^{2+} (molar ratio) is greater than one in most of the samples. This indicated an abundance of Mg^{2+} over Ca^{2+} in the study area. The Mg^{2+}/Ca^{2+} ratio increases from the piedmont to the coastal area and from the east to the west. Groundwater samples with Mg^{2+}/Ca^{2+} □ 4.5 justify the impact of saline sources, especially in Al Suwayq wilayat. Besides, SO_4/HCO_3 ratio suggests that

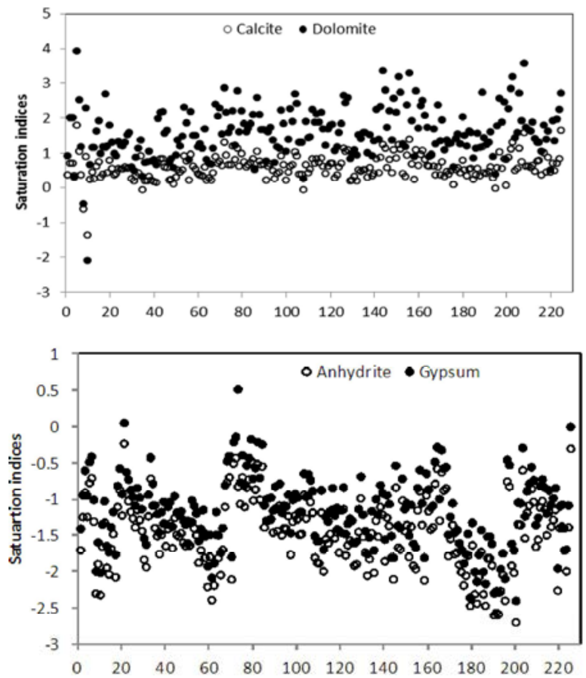

Fig. 7: Variation of saturation index with respect to well numbers

samples in the piedmont of Jabal Al Akhdar are predominantly influenced by mineral dissolution ($SO_4/HCO_3 < 1$).

Effects of Mineral Dissolution: The geochemical modeling program PHREEQC was used to investigate the influence of rock-water interaction on groundwater chemistry. The mineral reaction mode (dissolution/precipitation) was constrained by the saturation indices (SI) for minerals. For this purpose, specific calculations were performed for carbonate (calcite, dolomite) and sulfate (gypsum, anhydrite) minerals. Simulation results show that nearly all water samples in the study area are saturated and supersaturated with respect to carbonate minerals (Fig. 7) and under-saturated with respect to sulfate minerals. This result reveals that influence of sulfate minerals is not significant on groundwater chemistry. The explanation lies in the absence of geological formations containing sulfate minerals in the study area. Saturation indices of sulfate minerals indicate that wells existing in the piedmont of Jabal Al Akhdar, are highly under-saturated; while near saturation is observed close to the sea. Sulfate minerals may be derived mostly from saline water and anthropogenic sources such as irrigation return flow, specific tank effluents, domestic sewage and landfill. In fact, application of gypsum (fertilizer) in the irrigation field may contribute sulfate content in groundwater through irrigation return flow.

Principle Component Analysis: In this study, a correlation analysis and PCA was performed on 13 physico-chemical parameters determined on 224 groundwater samples. The correlation matrix between 13 variables is given in Table 2. Significant correlation over 0.78 was found between EC, Ca^{2+}, Mg^{2+}, Na^+ and Cl^-. The strong correlation among these variables suggests that they are strongly influenced by the same factor. Table 3 shows the eigen values of the extracted PCs, the loadings and the percentage variance explained by each PC.

Based on the eigenvalues, three principal components (PCs) were extracted to represent the hydrogeochemical process of the groundwater, without the loss of significant information. The three PCs cumulatively explained 78.65% of the data variance. The first PC, which has the highest eigen value accounts for 59.56% of the total variance usually, represents the most important process or mix of processes controlling the hydrochemistry of groundwater [21]. The PC1 shows the high positive loading for EC, Ca^{2+}, Mg^{2+}, Na^+, Cl^- and F^- and moderate positive loading for K^+ and SO_4^{2-}. The dominance of these parameters revel that seawater intrusions has affected the groundwater quality in this coastal area [22]. However, high positive loading of EC revealed that other hydrogeochamical process also involved in groundwater chemistry of the study area. High positive loadings for EC on PC1 most likely represents a combination of processes, including the dissolution of halite (NaCl) and high rates of evapotranspiration typical of arid climates, which concentrates groundwater constituents, resulting in increased EC [23]. PC2, accounting for 11.89% of the total variance, is mainly characterized by high positive loadings of NO_3^- and a moderate positive loading for HCO_3^-. The high positive loading of NO_3^- associated with chemical fertilizer used in this agricultural area. A large amounts of fertilizer; such as urea and commercial composite have been applied in this study area. Under favorable oxic conditions, the main component of fertilizer, NH_4^+, is oxidized to NO_3^- by the nitrification process [24], [25]. Therefore, NO_3^- is enriched in groundwater. On the other hand, the moderate positive loading for HCO_3^- suggests dissolution reactions involving carbonate minerals. The dissolution of carbonate minerals such as calcite and dolomite may result in the predominance of bi-carbonate ions in this study area [26]. The third

Table 2: Correlation matrix among the 13 physico-chemical variables of groundwater

Variables	EC	pH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SiO_2	Cl^{-}	NO_3^{-}	SO_4^{2-}	F^{-}	HCO_3^{-}
EC	1	-0.302	0.851	0.896	0.952	0.638	0.386	0.971	-0.038	0.718	0.824	0.214
pH		1	-0.413	-0.314	-0.252	-0.228	-0.153	-0.354	0.074	-0.150	-0.251	-0.040
Ca^{+}			1	0.846	0.785	0.578	0.433	0.892	-0.108	0.596	0.757	0.088
Mg^{2+}				1	0.843	0.578	0.341	0.893	-0.017	0.642	0.741	0.141
Na^{+}					1	0.653	0.441	0.938	-0.010	0.716	0.773	0.265
K^{+}						1	0.541	0.668	0.424	0.630	0.570	0.351
SiO_2							1	0.436	-0.119	0.473	0.396	0.208
Cl^{-}								1	-0.071	0.694	0.786	0.172
NO_3^{-}									1	0.051	0.024	0.286
SO_4^{2-}										1	0.673	0.353
F^{-}											1	0.170
HCO_3^{-}												1

Values in bold are different from 0 with a significance level alpha=0.05

Table 3: Eigenvalues of the extracted PCs, the loadings and the percentage variance explained by each PC

Groundwater Parameters	PC1	PC2	PC3
EC	0.963	-0.095	-0.059
pH	-0.362	0.245	0.488
Ca^{+}	0.891	-0.229	-0.098
Mg^{2+}	0.901	-0.136	-0.137
Na^{+}	0.942	-0.021	0.019
K^{+}	0.751	0.467	-0.037
SiO_2	0.533	0.095	0.602
Cl^{-}	0.967	-0.135	-0.056
NO_3^{-}	0.017	0.819	-0.461
SO_4^{-}	0.794	0.191	0.229
F^{-}	0.851	-0.039	-0.024
HCO_3^{-}	0.278	0.669	0.177
Eigenvalue	7.74	1.55	0.94
Variability (%)	59.56	11.89	7.19
Cumulative %	59.56	71.46	78.65

component (PC3) is mainly influenced by SiO_2. The predominant processes represented by PC3, may be a reflection of the importance of weathering reactions involving silicate minerals [27].

Evaluation of Groundwater Quality: Generally, Na% should not exceed 60% in irrigation waters [28]. The Na% of groundwater samples ranges from 22.6 to 85.3 with a mean value of 51.5. The Na% indicates that the groundwater is excellent to permissible for irrigation in 16% of samples and unsuitable for irrigation in 68.3% of samples (Fig. 8).

The SAR values vary from 1.64 to 44.0 with a mean value of 10.1. Fig. 9 shows that 29.3% of the samples fall in the C4S2 (very high salinity with medium sodium), 27.1% of the samples fall in the C4S4 (very high salinity with very high sodium), 18.2% of the samples fall in the C3S1 (high salinity with low sodium,) 14.7% of the samples fall in the C4S3 (very high salinity with high sodium), 7.6% of the samples fall in the C4S1

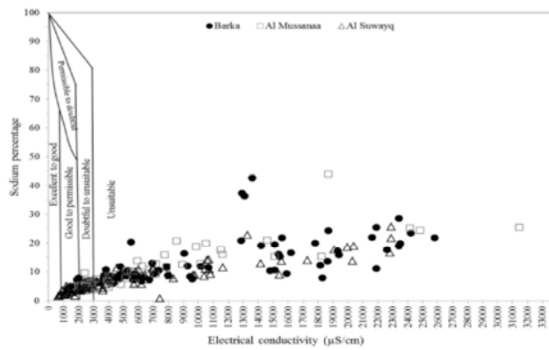

Fig. 8: Wilcox diagram for well waters

(very high salinity with low sodium), 2.2% of the samples fall in the C3S2 (high salinity with low sodium) and 0.9% of the samples fall in the C2S1 (Medium salinity with low sodium). Generally, the groundwater samples show high to very high salinity hazard with medium to very high alkali hazard, but most of the groundwater samples fall in very high salinity with medium sodium. These results show that most of the groundwater samples are not suitable for irrigation under ordinary conditions, but these samples may be used occasionally under the following conditions: the soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide leaching and very salt tolerant crops should be selected.

Classification of groundwater based on salinity hazard (EC) and SAR was presented in Table 4. It was found that only two samples are good.

Overall, groundwater suitability map for irrigation purpose for the study area was produced based on water quality parameters such as EC and SAR (Fig. 10). This map was plotted based on the same classification like USSL classification: good (C1S1, C2S1), suitable (C1S2, C2S2, C3S1, C3S2), Doubtful (C1S3, C1S4, C2S3, C2S4,

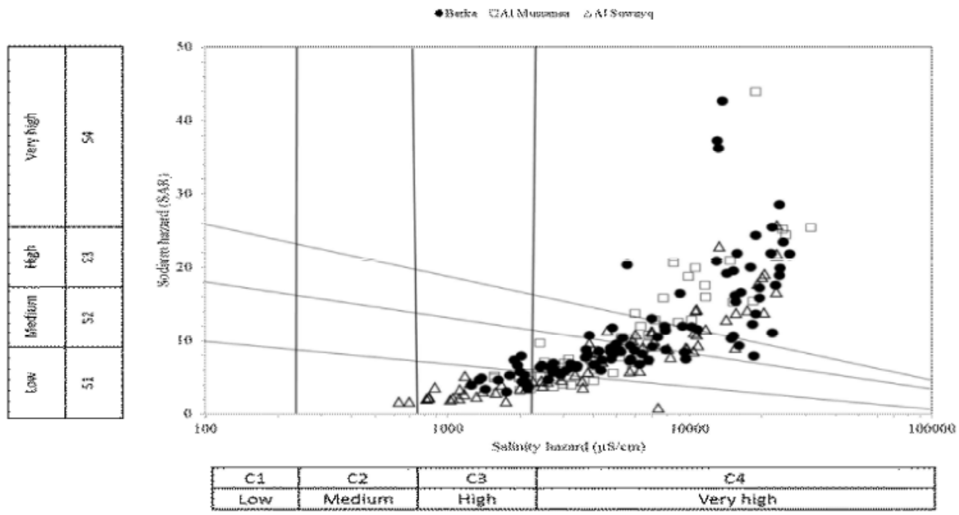

Fig. 9: US Salinity Laboratory diagram for classification for well waters

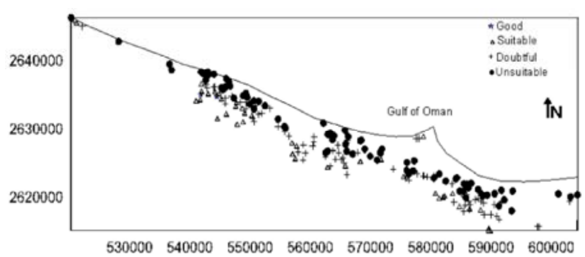

Fig. 10: Integrated groundwater suitability map for irrigation water in the study area.

Table 4: Classification of the groundwater quality according to the USDA method

Sodium hazard		Salinity hazard			
		Low C1	Medium C2	High C3	Very high C4
Low	S1	0	2 (0.9%)	41 (18.2%)	17 (7.6%)
Medium	S2	0	0	5 (2.2%)	66 (29.3%)
High	S3	0	0	0	33 (14.7%)
Very high	S4	0	0	0	60 (27.1%)

C3S3 and C3S4) and unsuitable (C4S3, C4S4). Fig. 10 shows that the most of the groundwater samples fall in the field C4S2 and C4S4 indicating high salinity and high to medium sodium, which is not suitable for irrigation under ordinary conditions. Wells located in the south of the study area fall under good to suitable water.

CONCLUSION

Deterioration of groundwater quality due to seawater intrusion is common occurrence in coastal aquifers. This study was conducted to evaluate factors regulating groundwater quality in southern part of Batinah coastal plain in Sultanate of Oman. Results suggest that, in 75% of groundwater samples, sodium and chloride are the predominant cation and anion, respectively in the study area. Further, Piper plot also indicates that NaCl and mixed CaMgCl water types are dominant in the study area. These results show that the groundwater quality in the study area is influenced by mineral dissolution, ion exchange and evaporation. Chloride and nitrate concentrations express the impact of surface contamination sources such as domestic and agricultural activities and 45.5% of samples have elevated nitrate content (> 10 mg/l as NO_3^-). Influence of mineral dissolution was evaluated by PHREEQC software and suggests that mineral dissolution, especially carbonate minerals, regulates groundwater chemistry. The predominant processes controlling the groundwater chemistry revealed by PCA were seawater intrusions, mineral dissolution and extensive use of chemical fertilizers in the study area. Groundwater suitability for drinking usage was evaluated by WHO standards and suggests that 94% of samples are not suitable for drinking because their EC is higher than 1,300 µS/cm and that 7.6% of samples are not suitable for drinking because the nitrate concentration is higher than 50 mg/l. Likewise, irrigation suitability of groundwater was evaluated using quality parameters, e.g. EC, Na%, SAR, Wilcox diagram and USSL classification. Results showed that 68.3% samples are not fit for irrigation under ordinary conditions. Groundwater suitability map for irrigation was also produced based on salinity and sodium hazard and express that wells located in the highland part of the study area have good to suitable water, whereas those located in the coastal part are not suitable for irrigation.

REFERENCES

1. Afroza, R., Q.H. Mazumder, C.S. Jahan, M.A.I. Kazi, M.A. Ahsan and M.A. Al-Munsur, 2009. Hydrochemistry and Origin of Salinity in Groundwater in parts of Lower Tista Floodplain, Northwest Bangladesh. J. Geological Soc. of India, 74: 223-232.
2. Arslan, H., 2013. Application of multivariate statistical techniques in the assessment of groundwater quality in seawater intrusion area in Bafra Plain, Turkey, Environ Monit Assess, 185: 2439-2452.
3. Zghibi, A., J. Tarhouni and L. Zouhri, 2013. Assessment of seawater intrusion and nitrate contamination on the groundwater quality in the Korba coastal plain of Cap-Bon (North-east of Tunisia). African Earth Sciences (2013), doi: http://dx.doi.org/10.1016/j.jafrearsci.2013.07.009.
4. Zekri, S., 2008. Using economic incentives and regulations to reduce seawater intrusion in the Batinah coastal area of Oman. Agricultural Water Management, 95: 243-252.
5. Kouzana, L., A. Mammou and M. Felfoul, 2009. Seawater intrusion and associated processes: Case of the Korba aquifer (Cap-Bon, Tunisia), C. R. Geoscience, 341: 21-35.
6. Sherif, M., M. Mohamed, A. Kacimov and A. Shetty, 2011. Assessment of Groundwater Quality in the Northeastern Coastal Area of UAE as Precursor for Desalination. Desalination, 273: 436-446.
7. Shammas, M.I., 2007. Sustainable management of the *Salalah* coastal aquifer in Oman using an integrated approach, PhD. Thesis, Department of Land and Water Resources Engineering, Royal Institute of Technology (KTH), Sweden.
8. Jamrah, A., A. Al-Futaisi, N. Rajmohan and S. Al-Yaroubi, 2008. Assessment of groundwater vulnerability in the coastal region of Oman using DRASTIC index method in GIS environment. Environ. Monit. Assess., 147: 125-138.
9. Kacimov, A.R., M.M. Sherif and J .S. Perret and A. Al-Mushikhi, Control of sea-water intrusion by salt-water pumping: Coast of Oman. Hydrogeology Journal, 17: 541-558.
10. Osman, A.E.A., A. Mubarik, H. Khalifa, H. Al-Zidi, I. El-Hussain and S. Al-Hinai, 2010. Rate of seawater intrusion estimated by geophysical methods in an arid area: Al Khabourah, Oman. Hydrogeology Journal, 18: 1437-1445.
11. Bhuvana, J.P. and K. Ramesh, 2012. Deciphering Fresh and Saline Groundwater Interface in South Chennai, Coastal Aquifer, Tamil Nadu, India. Int. J. Res. Chem. Environ. 2(3): 123-132.
12. Ashworth, J.M., 2006. Drilling and aquifer testing project in Northern *Batinah*. Final report. The Ministry of Regional Municipalities, Environment and Water Resources, pp: 44.
13. MAF and ICBA, 2012. Oman salinity strategy. Assessment of Salinity Problem. pp: 185.
14. Parkhurst, D.L. and C.A.J. Appelo, 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 , 312: 99-4259.
15. Wilcox, L.V., 1955. Classification and use of irrigation waters, vol. 969. U.S. Department of Agriculture Circular, Washington, DC, pp: l19.
16. USSL, 1954. Diagnosis and improvement of saline and alkali soils, handbook, vol. 60, USDA, Washington, pp: 147.
17. WHO, 2004. Guidelines for drinking water quality, 3rd edn. World Health Organization, Geneva.
18. Madison, R.J. and J.O. Brunett, 1984, Overview of the occurrence of nitrate in ground water of the United States, in National Water Summary 1984: U.S. Geological Survey, Water Supply, pp: 2275.
19. El-Moujabber, M., B. Bou Samra, T. Daewish and T. Atallah, 2006. Comparison of different indicators for groundwater contamination by seawater intrusion. Water Resources Management, 20: 161-180.
20. Mondal, N.C., V.S. Singh and V.K. Saxena, 2010. Determining the interaction between groundwater and saline water through groundwater major ions chemistry. J. Hydrol., 388: 100-111.
21. Yidana, S.M., B. Banoeng-Yakubo and T.M. Akabzaa, 2010. Analysis of groundwater quality using multivariate and spatial analysis in the Keta Basin, Ghana. Journal of African Earth Sciences, 58: 220-234.
22. Chen, K., J.J. Jiao, J. Huang and R. Huang, 2007. Multivariate statistical evaluation of trace elements in groundwater in a coastal area in Shenzhen, China. Environmental Pollution, 147: 771-780.
23. Salifu, A., B. Petrusevski, K. Ghebremichael, R. Buamah and G. Amy, 2012. Multivariate statistical analysis for fluoride occurrence in groundwater in the Northern region of Ghana. J. Contam. Hydrol., 140-141, 34-44.

24. Kim, R.K., J. Lee and H.W. Chang, 2003. Characteristics of organic matter as indicators of pollution from small-scale livestock and nitrate contamination of shallow groundwater in an agricultural area. Hydrol. Processes, 17: 2485-2496.
25. Kim, J.H., R.K. Kim, J. Lee, H.W. Chang, T.J. Cheong, B.W. Yum and H.W. Chang, 2005. Multivariate statistical analysis to identify the major factors governing groundwater quality in the coastal area of Kimje, South Korea. Hydrol. Process. 19: 1261-1276.
26. Acheampong, S.Y. and J.W. Hess, 1998. Hydrogeological and hydrochemical framework of shallow groundwater system in the southern Voltain Sedimentary Basin, Ghana. Hydrogeology Journal, 6(4): 527-537.
27. Ramakrishna, 1998. Groundwater hand book, India, pp: 556.