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Study The Seasonal Fluctuations of Groundwater Characteristics in Al-Raudhatain And Umm Al-Aish Depressions, North Kuwait

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ABSTRACT
The role of groundwater in north Kuwait is expected to be doubled in the near future. The fresh groundwater lenses in the Quaternary Aquifer in Al-Raudhatain and Umm Al-Aish Depressions (QARUAD) receive special attentions of the government and different investment authorities for agricultural development and construction new communities. Expanding the development of new communities within the limited low flat desert surfaces in north Kuwait has started to face the continuous growth of population. The specific objectives of this study were to detect the dynamics of groundwater level and salinity in wet and dry season; and to determine the relationships among the groundwater level, salinity content, and climate factors. The materials used in this paper *were collected through carrying out 12 field trips in* QARUAD *during the period 2015-17.* Moreover, network of 120 observation and dug wells was chosen for seasonally periodic recording of groundwater levels and hydrogeochemical routine analysis and cluster analysis. The results showed that the groundwater moves generally from the SW to the NE towards the Arabian Gulf. Direct recharge through the rainfall, faults and lateral flow from the adjacent aquifers are the acceptable source of the recharge to QARUAD. The change in groundwater salinity may attribute to the seasonal rainfall, lithologic composition and structural impacts. The relation between TDS and different major ions are statistically analyzed. Four principal components were extracted from chemical data to explain the major sources and processes responsible for chemical characteristics of groundwater. Cluster analysis showed that silicate weathering, agricultural runoff (fertilizer input), municipal wastewater infiltration play a vital role in the enrichment of ionic constituents. It is concluded that that the majority of the samples are good to permissible for drinking purpose which reflects a good chance for agriculture and urbanization development. An integrated water management to the most fresh upper zone of QARUAD and detailed subsurface study before any reclamation activities are recommended.

Keywords: Hydrogeology, Geochemical processes, Al-Raudhatain and Umm Al-Aish, north Kuwait.

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I. INTRODUCTION

Kuwait is situated in an arid coastal region characterized by high temperatures, low humidity, sparse precipitation rates, and high evaporation and evapotranspiration rates with no rivers or lakes. Therefore, Kuwait has always relied on other sources to secure freshwater to meet its growing demands. Furthermore, the groundwater accumulations below the surface depressions in north Kuwait, particularly the fresh groundwater lenses of Quaternary Aquifer in Al-Raudhatain and Umm Al-Aish Depressions (QARUAD), constitute a strategic natural resource in the arid, water starved environment of Kuwait. A substantial part of the study area also contains usable groundwater in the topmost part of the Quaternary aquifer. The seasonal runoff generated during occasional rainstorms is conveyed by wadis (dry channels) to surface depressions to form temporary playa lakes. The infiltration of this accumulated water over thousands of years has given rise to the formation of freshwater lenses below these depressions and brackish water reserves surrounding them (Amitabha Mukhopadhyay et al. 2016). Human interventions in the study area started from the 1970s through the development of the freshwater fields, exploration and production of oil and the establishment of agricultural farms in Al-Abdaly area (Fig. 1). Nowadays, the areas in northern Kuwait is subjected to anthropogenic activities, including reclamation agricultural activities, on a grand scale beside further exploration for oil, and other developmental activities were taken up in this area. These activities are expected to bring about changes in the quantity and quality of groundwater resources, recharge locations, rates and quality of the groundwater recharge with significant effects on the freshwater bodies in the aquifers of northern Kuwait. In this study, the effect of the seasonal rainfall on the quantity and quality of groundwater in the groundwater aquifers in northern Kuwait was assessed by conducting a comprehensive survey of all the productive wells in QARUAD and the adjacent development areas. Moreover, quantitative and qualitative analysis of 120 samples of the mentioned wells was carried out before and after seasonal rainfall to determine the impact of seasonal rainfall on the quantity and quality of groundwater.

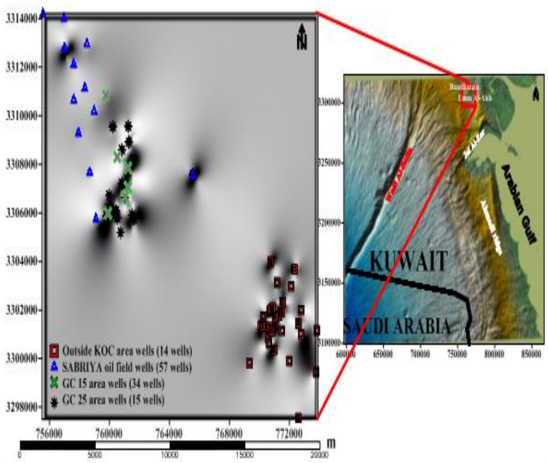

Fig. 1: Location map of QARUAD showing the location of the different productive and observation dug wells

1.1-Site description and climate

The study area is located in the northern part of Kuwait state. It lies far from Kuwait city by about 55 Km in NW direction and west of Arabian Gulf by about 25 Km (Fig.1). It is limited between latitudes 3260000 and 3315000 due North and longitudes 750000 and 780000 due East with an area of 1650 Km^2. Al-Jahra table land area bounds QARUAD from south while from the east, Arabian Gulf forms the northern boundary Iraq-Kuwait border represents the northern boundary. The climate of north Kuwait can be divided into two main seasons, hot with temperature ranges between 46 ^oC and 50 ^oC during summer months and from 20 ^oC to Zero ^oC during winter months (November through March). The mean annual precipitation was about 101.02 mm, and the monthly average 9.6 mm while the mean daily Pan-A evaporation rate varied from 4.7 mm in January to 31 mm in July, with an average mean daily rate of 16.6 mm (Safar 1985). Moreover, the annual evaporation rate ranges between 8.8 mm and 9.8mm while the relative humidity ranges from 31.1% to 38.7% with mean value of 34.66% (Table 1).

Table 1: Meteorological records of north Kuwait area

S. N.	Year	Rainfall (mm)	Evaporation (mm)	Humidity (%)
1	2012	126.70	9.40	31.1
2	2013	117.90	9.50	33.9
3	2014	73.70	9.50	38.7
4	2015	97.80	8.80	37.1
5	2016	89.00	9.80	32.5
Mean	-------	101.02	9.4	34.66

1.2 Geomorphological setting

To delineate the geomorphological setting of the study area, the TM images and other maps were rectified to the Universal Transverse Mercator (UTM) zone 38 projection and co-ordinate system, using a second order polynomial resampling scheme and bilinear interpolation (Lillesand & Kiefer, 1994). The shaded relief of the study area was generated from the DEM data and TM images (Fig. 2). The resulted shaded relief represents elevations ranging from 0 to 300 m above mean sea level. The highest elevations occur in the SW with a gradual eastward decline towards the Gulf. The extracted geomorphological features in the study area include the NE-SW trending Wadi Al-Batin, an ancient riverbed (Al-Sarawi, 1980; Al-Sulaimi, Pitty, 1995 and A. Y. Kwarteng et al. 2000), and the sand corridor. Otherwise, several geomorphological features with implications for groundwater exploration are readily observed. The most prominent include the Jal Al-Zor escarpment, the Ahmadi ridge, the Wadi Al-Batin valley, the Raudhatain and Umm Al-Aish, and Abdali depressions, and the sand corridor.

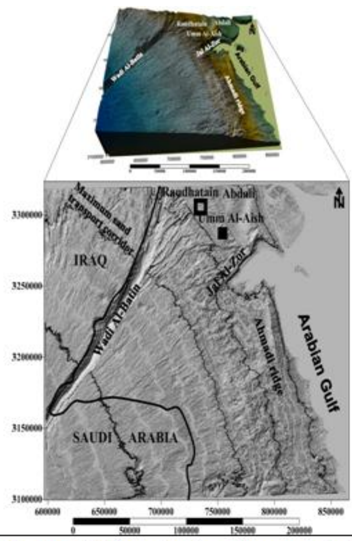

Fig. 2: Shaded relief map showing the geomorphological

1.3 Geological setting

The details of the geology of rock units of Kuwait have been presented by Owen and Nasr (1958), Milton (1967), Fuchs et al. (1968), Burdon and Al-Sharhan (1968), Omar et al. (1981), Clarke (1988), Al-Sulaimi (1988), Amer et al. (1989), Al-Sulaimi and Pitty (1995), Mukhopadhyay et al. (1996), Al-Sulaimi and Mukhopadhyay (2000), Al-Sulaimi and Al-Ruwaih (2004) as well as the geologic maps and landsat images (El-Baz & Al-Sarawi 2000) in addition to field investigation (Fig.3). Based on these studies, the main lithostratigraphic units forming the bedrock of Kuwait are unconsolidated to semi-consolidated clastic sediments of the Kuwait Group (post-Eocene Age), which unconformably overlies the dolomitic Dammam Formation of the Eocene Age. The surface of Kuwait is predominantly covered by Quaternary sediments which include Pleistocene gravel and sand of the upper member of the Dibdibba Formation and Holocene sediments including marine sand deposits, beach rocks, sabkha deposits, desert floor deposits, alluvium and aeolian sands.

In addition, the paleo-drainage channels in QARUAD, which were formed in the Pleistocene (Al-Sulaimi et al., 1997), are carved in the Upper and Lower Dibdibba and the undifferentiated Fars and Ghar formations. Presently, they are filled with gravel and sand and are not readily observed on flat terrain where they are only manifested as micro-relief with the surroundings. Moreover, the relative abundance of paleo-drainage channels in the north and south-west is due to the underlying hard calcretic and gypcretic gravelly deposits of the Dibdibba Formation. Conversely, the paucity of wadis in the south is due to the friable sandstone of the Undifferentiated Fars and Ghar Formation, which was not as ideal for developing and preserving the drainage channels. The south-west-north-east trending drainage pattern closely follows the present relief variations (Al-Senafy et al. 2013).

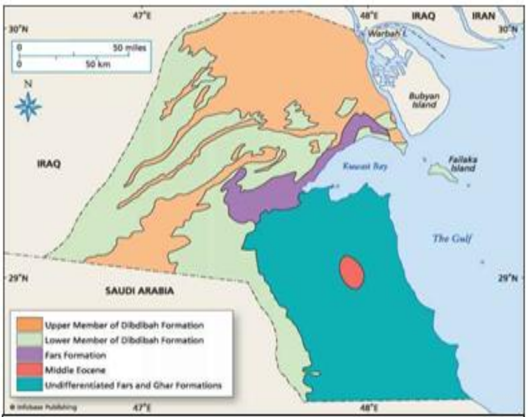

Fig. 3: Geological map of Kuwait (modified after HGG 1981)

1.4 Hydrogeological setting

There are two major aquifers in Kuwait. The upper one, known as the Kuwait Group aquifer, consists of silty, gravelly sand; and the lower one, known as the Dammam Formation, consists of chalky and dolomitic limestone (Fig. 4). The Kuwait Group aquifer is generally in an unconfined state, whereas the Dammam Formation is confined. Moreover, that the Kuwait Group aquifer is poor in hydraulic properties. The porosity ranges from 5% to 20% and hydraulic conductivity ranges from 17 to 71 m/day while the highest estimated transmissivity reaches 1998 m^2/d and storativity reaches 0.00018 (GII, 2010). The groundwater table varies from approximately 90 m above mean sea level in the SW, and decreases to zero at the Gulf coast.

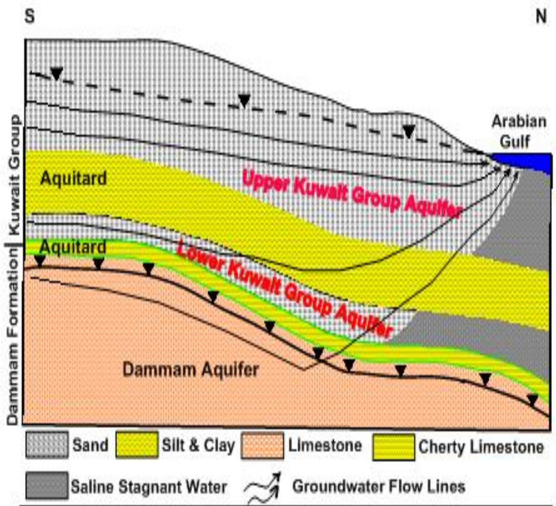

Fig.4: Hydrogeological cross section of the study area

The flow of groundwater is from SW to NE. In general, the groundwater quality varies from brackish in the SW to highly saline in the NE region. Brackish groundwater with TDS of less than 3000 mg is extracted and used for irrigation and landscaping. The majority of the groundwater wells extracting brackish groundwater exist in the central and SW regions of Kuwait. Beyond the brackish groundwater fields, groundwater quality deteriorates rapidly with TDS exceeding 10,000 mg/1 and reaching levels as high as 100,000 mg/l in the northern and NE regions (Kwarteng et al. 2000).

On the other hand, in the north, the groundwater of QARUAD which was accidentally discovered in the early 1950s (Parsons Corporation, 1964), freshwater lenses of TDS less than 1000 mg/1 are found floating on saline groundwater of TDS more than 100,000 mg/1. The boundary between the freshwater and saline water is diffuse, however, the density difference between the two results in stable configuration of the lenses. Extensive investigations were carried out in the early 1960s by Parsons Corporation (1964). The investigation concluded that fresh groundwater in QARUAD existed as lenses that were formed by infrequent infiltration of rainwater. The study estimated the total volume of freshwater in Al-Raudhatain basin to be approximately 68,130 Ml. Senay (1977) estimated the safe yield from Al-

Raudhatain field to be about 6.8 Ml/day. Fresh groundwater from the lenses has been extracted for potable purposes and to produce bottled mineral water since the 1960s. Freshwater extraction for potable purposes from these fields was discontinued after 1977 because of the development of large desalination plants. Presently, groundwater extraction is for bottling purposes only. Accordingly, the study of seasonal changes of groundwater characteristics in QARUAD is very important for sustainable development. In this study, the effect of the seasonal rainfall on the quantity and quality of groundwater in QARUAD was assessed by conducting a comprehensive survey of all the productive wells in the QARUAD. A quantitative and qualitative analysis of 120 samples of the mentioned wells was carried out before and after seasonal rainfall to detect the effect of seasonal rainfall on groundwater regime in QARUAD.

II. MATERIALS AND METHODS

To study the seasonal fluctuations of groundwater characteristics in QARUAD, 12 field trips in QARUAD during the period 2015-17 were carried out. During these field trips, 120 groundwater samples were collected in August, 2016 (pre-monsoon) and January, 2017 (post-monsoon) from dug-wells and bore-wells and locations were fixed by GPS (Oregon 600). Samples were taken in properly rinsed 250 ml polyethylene bottles (presoaked in acid wash for 24 h. and rinsed several times with distilled water). General parameters such as pH, EC, TDS and depth to water table were measured immediately at the time of sampling using a multi parameter ion meter (pH/Cond 340i SET 1). Moreover, the groundwater samples were analyzed at NAPESCO Environmental Laboratory in Kuwait, which is approved with KEPA for conducting all baseline sampling and analysis. NAPESCO laboratory has a fully fledged Quality Management System (QMS) with ISO 17025:2005 accreditation.

The physicochemical parameters were determined using the standard analytical methods (APHA 2005): hardness, alkalinity, Ca, CO_3, HCO_3 and Cl were analyzed with titrimetric method and Mg was determined with calculation method. Na and K was analyzed using flame photometer (Elico Model CL 378). F was estimated using ion analyzer (Thermo scientific Orion-4 star) with an ion-selective electrode. SO_4, NO_3 and PO_4 were determined by spectrophotometry method (UV 3200 double beam spectrophotometer, Labindia).

The analytical precision for the accurate measurements of ions was determined by calculating electrical neutrality (EN %) which is acceptable at ±5 % (Appelo and Postma 1999). All the samples have EN % values within ±5 % in pre- and post-monsoon.

Electrical Neutrality = Σ Cation + Σ Anion / Σ Cation - Σ Anion X 100………………...1

The analytical data obtained were processed for detailed geochemical and statistical analysis. Statistical analysis was carried out by Stat Soft STATISTICA 10 and Microsoft Excel-2010. Salinity mapping and hydrogeochemical facies distribution maps were prepared by Golden software Surfer 13. Total hardness and various water indices used to classify groundwater suitability for irrigation and industrial purposes are calculated using the formula:

Total Hardness = 2.5 Ca + 4.1 Mg (mg/l as $CaCO_3$)………………………………………2

As a general, in the laboratory, the water samples were filtered through 0.45 μm to separate suspended particles. Acidification (pH < 2) with concentrated nitric acid was performed on the filtered samples for heavy metals analysis using ICP (Inductively Coupled Plasma) at NAPESCO laboratory. The acid titration method was used to determine the concentration of bicarbonate HCO_3^- (APHA, 1995). Trace elements (Fe and Mn) were analyzed using ion chromatography (Dionex DX-600). The routine analysis of 40 samples was carried out and the results are given in Table 2.

Table 2: Physical and inorganic parameters concentration of the QARUAD groundwater samples

Well No.	pH	Condu-ctivity µS/cm	TDS mg/l	Na mg/l	K mg/	Ca mg/l	Mg mg/l	NH_3 mg/l	Cl mg/l	Brm g/l	SO4 mg/l	F mg/l	NO3 mg/l	PO4 mg/l	Fe mg/l	Mn mg/l
NP01	7	1090	742	196	4.4	62	0.45	0.28	275	0.22	55	0.17	2.4	0.09	--	--
P08	7.5	1290	920	172	9	88	58	0.5	232	0.15	204	0.68	0.3	0.05	--	--
NP03	7.4	4941	3755	1025	9	49	2.1	1.52	1220	2.2	322	0.56	3	0.53	ND	ND
P07R	7.6	3370	2516	579	5	174	33.9	0.69	762	1.22	659	0.2	0.3	0.1	ND	ND
P06R	7.1	4958	3720	688	5	241	62.2	0.45	1120	2.32	688	0.54	2.4	0.09	ND	ND
P05R	7.5	4931	367	693	16	420	82.6	0.3	112	3.	922	0.38	1.7	0.38	ND	ND

			2						6	66						
P04R	7.9	1315	917	130	14	136	13.7	0.7	210	0.04	170	0.17	2.1	0.02	ND	ND
P03R	7.8	1450	920	244	7	13	6	1.25	255	0.06	194	0.28	0.6	0.02	ND	ND
P02R	7.5	581	415	99	5	6	9.55	0.63	124	0.02	15.2	0.1	0.7	ND	ND	ND
P01R	7.6	840	572	136	9.2	11.2	4.5	0.56	175	0.06	18	0.32	1.2	0.23	ND	ND
P09R	7.7	1220	892	243	9	13	11.6	0.68	290	1.22	122	0.41	0.5	0.21	ND	ND
P68RA	7.5	476	327	45	5.6	36.6	5.78	1.28	119	0.07	4.2	0.5	2.5	0.09	ND	ND
P68RB	7.6	842	902	121	18	59	2.8	0.56	142	0.06	102	0.05	2.1	0.06	ND	ND
P68RC	7.7	423	276	53	10	31.2	12.6	0.79	89	0.04	56	0.03	1.5	0.09	ND	ND
P30UB	7.5	854	560	92	8.8	34.5	6.7	0.5	102	0.13	72	0.7	3	0.41	ND	ND
P30U	7.4	753	596	89	14	66	12.8	0.45	122	0.52	96	0.68	3.2	0.32	ND	ND
P31UB	7.5	903	618	102	23	34	5.9	0.68	132	1.02	66.9	0.95	3.8	0.07	ND	ND
P31U	7	2415	1642	277	7.1	108	43.8	0.44	451	1.32	109	0.88	4.1	0.09	ND	ND
P24U	6.8	8253	6120	668	22	1220	65.6	0.89	2836	6.32	90.7	0.59	1.8	0.09	ND	ND
P62U	7.6	1650	1045	126	4.2	129	1.8	0.66	176	2.32	182	0.63	1.7	0.06	ND	ND
P18	7.0	5644	3520	890	15	120	19	0.56	1320	3.21	220	0.43	0.5	0.04	ND	ND
P27U-1	6.8	9364	5216	1042	22	620	156	0.59	1864	1.32	962	0.08	0.7	0.12	ND	7.5
P27U	6.9	11998	6154	1245	21	857	130	0.38	2375	3.62	1422	0.92	1.6	0.09	0.11	7.5
P28UA	7.1	1272	890	143	12	69	34.2	0.2	195	2.3	163	0.5	0.5	0.08	ND	ND
P28UB	10	2955	1672	352	68	210	4.3	1.7	851	2.11	244	0.48	0.1	0.08	ND	ND
P28UC	7.7	3295	1762	535	15	63.8	30	1.08	612	1.4	242	0.41	0.1	0.05	ND	ND
P33U	7.6	4028	2230	485	14	220	31	0.55	842	2.32	302	0.3	0.1	0.08	ND	ND
P33UA	7	3072	2340	702	11	130	24.5	0.32	962	3.21	291	0.75	3.1	0.01	ND	5.8
P33UB	7.4	2685	2032	510	8	63	14	0.5	722	2.65	142	0.63	2.1	0.09	ND	ND
P32U	7.2	1953	1473	253	12	143	24.3	0.75	284	1.52	247	0.38	1.5	0.01	ND	ND
P32UB	7	2408	1760	220	11	204	41.8	0.81	514	1.32	95	0.44	0.7	0.05	ND	ND
P19	7.1	1591	1105	188	13	126	23	0.92	252	1.22	236	0.59	1.1	0.13	ND	ND
P58UB	7.2	2196	1560	183	12	169	38.8	0.49	575	0.62	74	0.32	2.1	0.09	ND	ND
P58UA	7.2	1765	1340	275	6.1	81	4.7	1.44	422	1.22	144	0.61	1.5	0.38	ND	ND
P59UB	7.3	1605	1094	322	12	47	49.5	0.48	342	0.09	92	0.92	0.9	0.05	ND	ND
P59UA	7	1532	1120	287	4.2	36.9	18.6	0.2	409	0.01	88	0.68	1.3	0.1	0.05	ND
P60UA	6.9	1563	1075	163	8.9	75	18.6	0.56	282	0.12	141	0.56	1.2	0.21	ND	ND
P60UP	7.1	2193	1549	476	7.6	29	1.41	1.49	632	0.21	56	0.79	2	0.01	ND	ND
P61UP	7.3	2051	1503	356	6.5	120	2.7	1.08	423	2.11	223	0.71	0.9	0.12	ND	ND
P61UA	6.9	1852	1304	287	4.2	48	0.88	1.23	412	1.32	90	0.81	1.5	0.01	ND	ND

In addition, the results of the seasonal fluctuations of groundwater quality and some trace elements concentration are given in (Table 3) while the seasonal fluctuations of groundwater level (amsl) pre and post the rainwater season were
given in (Table 4).

Table 3: Physical and inorganic parameters concentration of the groundwater samples before and after rainfall in mg/l and the difference between them (MEW, 2017)

S.N	Well N.	Area	Na	Na"	Diff	Cl	Cl"	Diff	F	F"	Diff	$CaCO_3$	$CaCO_3$'	Diff	SO4	SO4"	Diff	PO_4	PO_4"	Diff
1	P30UB	SABRIYA	92	69	-23	102	169	67	0.7	0.54	-0.16	125	66	-59						
2	P30U		89	135	46	122	192	70	0.68	0.41	-0.27	105	110	5						
3	P31UB		102	63	-39	132	96	-36	0.95	0.78	-0.17	175	135	-40						
4	P31U		277	184	-93	451	450	-1	0.88	1.24	0.36	222	110	-112						
5	P24U		668	1418	750	2836	3113	277	0.59	0.43	-0.16	159	260	101						
6	P62U		126	229	103	176	374	198	0.63	0.91	0.28	210	60	-150						
7	P61UA		287	213	-74	412	367	-45	0.81	0.73	-0.08	245	190	-55						
8	P61UB		356	69	-287	423	173	-250	0.71	0.05	-0.66	116	160	44						
9	P60UB		476	169	-307	632	285	-347	0.79	0.05	-0.74	240	180	-60						
10	P60UA		163	309	146	282	425	143	0.56	0.28	-0.28	180	290	110						
11	P59UA		287	301	14	409	409	0	0.68	0.51	-0.17	156	240	84						
12	P59UB		322	105	-217	342	272	-70	0.92	0.37	-0.55	272	130	-142						
13	P58UA		275	310	35	422	448	26	0.61	0.21	-0.4	120	80	-40						
14	P58UB		183	142	-41	575	238	-337	0.32	0.38	0.06	152	200	48						
15	P19U		188	195	7	252	177	-75	0.59	0.12	-0.47	110	410	300						
16	P32UB		220	175	-45	514	461	-53	0.44	0.21	-0.23	213	110	-103						
17	P32U		253	337	84	284	1099	815	0.38	0.31	-0.07	210	160	-50						
18	P33UB		510	1842	1332	722	3600	2878	0.63	0.71	0.08	170	290	120						
19	P33UA		702	1836	1134	962	3100	2138	0.75	0.93	0.18	110	270	160						
20	P33U		485	496	11	842	1120	278	0.3	0.05	-0.25	202	100	-102						
21	P28UC		535	553	18	856	920	64	0.41	0.35	-0.06	198	70	-128						
22	P28UB		352	419	67	851	755	-96	0.48	0.05	-0.43	166	75	-91						
23	P28UA		143	120	-23	195	177	-18	0.5	0.17	-0.33	134	310	176						
24	P27U		1245	1231	-14	2375	1960	-415	0.92	1.17	0.25	273	410	137						
25	P27U1		1042	1007	-35	1864	1820	-44	0.08	0.05	-0.03	349	380	31						
26	P18U		890	893	3	1320	1725	405	0.43	0.27	-0.16	170	210	40						
27	P26U		146	111	-35	91	189	98	0.68	0.57	-0.11	109	150	41						
28	P29U		360	404	44	547	761	214	0.5	0.18	-0.32	134	120	-14						
29	P63U		935	1690	755	1702	2463	761	0.72	0.5	-0.22	167	60	-107						
30	P49UA1		487	563	76	975	1276	301	0.17	0.08	-0.09	213	190	-23						
31	P49UA		715	665	-50	1276	1271	-5	0.09	0.02	-0.07	256	30	-226						
32	P49UB		852	1553	701	2233	2478	245	0.8	0.3	-0.5	135	160	25						
33	P25UB		625	2015	1390	1152	4325	3173	0.3	0.28	-0.02	273	120	-153						
34	P25UA		532	427	-105	780	836	56	0.71	0.54	-0.17	295	130	-165						
35	P20U		328	309	-19	332	488	156	0.47	0.34	-0.13	130	110	-20						
36	NP10		262	259	-3	320	322	2	0.71	0.6	-0.11	124	90	-34						
37	P23U		1010	1389	379	1772	2410	638	0.68	0.75	0.07	156	60	-96						
38	P50UB		###	9232	###	1320	1725	405	0.64	0.79	0.15	210	70	-140						
39	P50UA		###	###	4302	91	189	98	0.05	0.05	0	236	70	-166						
40	P50UA1		###	9636	###	547	761	214	0.11	0.02	-0.09	190	60	-130						
41	P51UA		1720	1853	133	957	1099	142	0.29	0.33	0.04	175	190	15						
42	P51UB		846	1108	262	1065	1612	547	0.01	0.02	0.01	175	100	-75						
43	P52UA		471	361	-110	407	473	66	0.36	0.21	-0.15	125	110	-15						
44	P52UB		288	498	210	494	1117	623	0.01	0.02	0.01	217	90	-127						
45	NP12		430	258	-172	525	342	-183	0.92	0.48	-0.44	258	120	-138						
46	NP13		346	263	-83	563	325	-238	0.3	0.22	-0.08	181	140	-41						
47	NP14		370	245	-125	425	345	-80	0.48	0.19	-0.29	166	120	-46						
48	NP11		652	239	-413	835	384	-451	0.55	0.2	-0.35	150	90	-60						
49	NP15		110	56	-54	98	76	-22	0.11	0.05	-0.06	212	140	-72						
50	NP16		51	53	2	63	29	-34	0.05	0.05	0	109	120	11						
51	NP17		114	61	-53	173	90	-83	0.28	0.1	-0.18	109	160	51						
52	P53UB		233	131	-102	159	120	-39	0.26	0.17	-0.09	210	130	-80						
53	P53UA1		102	147	45	124	355	231	0.29	0.35	0.06	170	42	-128						
54	P53UA		485	765	280	1320	1488	168	0.33	0.17	-0.16	228	130	-98						
55	NP18		299	157	-142	332	242	-90	0.09	0.22	0.13	140	130	-10						
56	P17UB		112	36	-76	159	122	-37	0.38	0.15	-0.23	84	160	76						
57	P17UA		75	124	49	119	210	91	0.22	0.09	-0.13	122	208	86						
58	P47RB	GC 25	582	591	9	376	821	445	0.05	0.09	0.04	202	120	-82	683	225	-458	0.11	0.24	0.13
59	P47RA		720	609	-111	177	978	801	0.28	0.12	-0.16	135	120	-15	1201	103	-1098	0	0.09	0.09
60	P48RA		749	683	-66	421	355	-66	0.07	0.02	-0.05	110	210	100	929	890	-39	0.25	0.39	0.14
61	P48RB		655	600	-55	301	837	536	0.21	0.1	-0.11	167	200	33	1007	311	-696	0.37	0.42	0.05
62	NP02		325	283	-42	375	386	11	0.13	0.05	-0.08	149	190	41	145	36	-109	0.04	0.06	0.02
63	P11R		652	230	-422	835	358	-477	0.55	0.08	-0.47	150	190	40	340	89	-251	0.11	ND	ND
64	P10		230	209	-21	185	322	137	0.09	0.05	-0.04	212.3	160	-52.3	179	40	-139	ND	ND	ND
65	P46RA		595	156	-439	886	455	-431	0.2	0.09	-0.11	75	20	-55	315	1705	1390	0.21	0.11	-0.1
66	P46RA		174	153	-21	230	236	6	0.29	0.17	-0.12	110	200	90	97	226	129	0.08	ND	ND
67	P46RB		144	129	-15	176	193	17	0.11	0.28	0.17	166	140	-26	232	348	116	0.07	ND	ND
68	P46RC		117	122	5	138	167	29	0.3	0.19	-0.11	185	140	-45	208	344	136	0.09	ND	ND
69	P14		182	220	38	157	325	168	0.78	0.26	-0.52	210	120	-90	141	12	-129	0.12	0.17	0.05
70	P55RA		371	351	-20	210	160	-50	0.49	0.2	-0.29	193	170	-23	297	572	275	0.06	0.02	-0.04
71	P55RB		730	538	-192	522	825	303	0.76	0.53	-0.23	445	100	-345	382	326	-56	0.09	0.08	-0.01
72	P47RA		569	581	12	823	830	7	0.12	0.09	-0.03	146	110	-36	623	354	-269	0.14	0.09	-0.05

Na: Sodium conc. before, Na": Sodium conc. after rain (mg/l), diff:difference (After-Before), Cl: Chloride conc. before, Cl": Chloride conc. after (mg/l), diff: difference (After- Before) and so

Table 4: Groundwater level records pre- and post rainwater season in QARUAD (MWE,

S.N	Well N.	Area	WT-Pre (m)	WT-Post (m)	Diff. (m)	S.N	Well N.	Area	WT-Pre (m)	WT-Post (m)	Diff. (m)
1	NP01	Outside KOC	9.33	8.38	-0.95	61	NP14	Sabriya Oil Field	35.55	35.57	0.02
2	P08R		8.07	7.98	-0.09	62	NP11		27.33	27.26	-0.07
3	NP03		13.5	13.35	-0.15	63	NP15		9.38	9.35	-0.03
4	P07R		4.34	3.94	-0.4	64	NP16		12.91	11.66	-1.25
5	P06R		7.17	7.05	-0.12	65	NP17		11.94	12.16	0.22
6	P04R		6.95	6.43	-0.52	66	P53UB		22.87	22.75	-0.12
7	P05R		11.1	10.65	-0.45	67	P53UA1		27.23	27.06	-0.17
8	P01R		16.56	32.61	16.05	68	P53UA		6.87	6.75	-0.12
9	P02R		9.35	9.3	-0.05	69	NP18		18.75	18.57	-0.18
10	P09R		21.11	20.99	-0.12	70	P17UB		29.97	30.02	0.05
11	P03R		3.16	1.51	-1.65	71	P17UA		10.08	10.03	-0.05
12	P68RA		17.17	13.12	-4.05	72	P39R	GC 15	1.58	1.6	0.02
13	P68RB		8.25	16.35	8.1	73	P38RA		14.62	14.72	0.1
14	P69RC		32.2	40.06	7.86	74	P38RA1		4.67	4.55	-0.12
15	P30UB	Sabriya Oil Field	10.72	10.64	-0.08	75	P38RB		30.62	30.52	-0.1
16	P30U		19.98	21.12	1.14	76	P57R		2.35	2.15	-0.2
17	P31UB		30.97	30.99	0.02	77	P44RA		6.73	6.53	-0.2
18	P31U		10.46	10.4	-0.06	78	P44RB		28.08	25.72	-2.36
19	P24U		5.43	5.6	0.17	79	P64RA		10.13	9.95	-0.18
20	P62U		18.43	18.11	-0.32	80	P64RB		8.82	8.78	-0.04
21	P61UA		4.24	4.15	-0.09	81	P54RB		23.08	22.85	-0.23
22	P61UB		3.82	3.39	-0.43	82	P54RC		11.31	11.1	-0.21
23	P60UB		36.44	36.38	-0.06	83	P54RA		26.27	26.12	-0.15
24	P60UA		13.38	13.36	-0.02	84	P40RB		42.58	42.15	-0.43
25	P59UA		4.36	4.37	0.01	85	P40R		5.87	7.1	1.23
26	P59UB		21.6	21.53	-0.07	86	P41RA		13.57	14.32	0.75
27	P58UA		6.29	5.87	-0.42	87	P41RB		21.18	21.04	-0.14
28	P58UB		21.68	21.6	-0.08	88	P41RC		40.68	40.73	0.05
29	P19U		34.78	34.7	-0.08	89	P65RA		7.01	7.35	0.34
30	P32UB		6.46	6.32	-0.14	90	P65RB		30.5	30.6	0.1
31	P32U		4.13	4	-0.13	91	NP06		8.21	8.1	-0.11
32	P33UB		20.03	19.63	-0.4	92	NP05		20.67	20.36	-0.31
33	P33UA		5.4	5.27	-0.13	93	NP04		8.71	8.45	-0.26
34	P33U		18.63	18.51	-0.12	94	NP09		20.5	20.25	-0.25
35	P28UC		16.42	15.95	-0.47	95	NP08		36.58	36.6	0.02
36	P28UB		32.17	32.06	-0.11	96	NP07		9.8	9.5	-0.3
37	P28UA		27.27	27.15	-0.12	97	P34RB		4.9	4.65	-0.25
38	P27U		7.2	7.07	-0.13	98	P34R		16.21	15.85	-0.36
39	P27U1		16.75	17.71	0.96	99	P35R		21.94	21.54	-0.4
40	P18U		1.67	1.62	-0.05	100	P35RB		11	10.9	-0.1
41	P26U		5.99	5.93	-0.06	101	P67RA		12.1	12.45	0.35
42	P29U		15.88	15.84	-0.04	102	P67RB		30.79	31.14	0.35
43	P63U		0.81	0.87	0.06	103	P66RA		5.1	4.05	-1.05
44	P49UA1		2.8	5.8	3	104	P66RB		1.68	1.5	-0.18
45	P49UA		14.76	14.81	0.05	105	P56R		4.78	4.65	-0.13
46	P49UB		10.4	10.47	0.07	106	P47RB	GC 25	20.85	20.65	-0.2
47	P25UB		15.89	15.53	-0.36	107	P47RA1		4.88	4.68	-0.2
48	P25UA		4.52	4.43	-0.09	108	P48RA		14.71	14.61	-0.1
49	P20U		33.4	33.32	-0.08	109	P48RB		0.65	0.57	-0.08
50	NP10		2.13	2	-0.13	110	NP02		1.8	3	1.2
51	P23U		6.94	6.77	-0.17	111	P11R		10.69	10.44	-0.25
52	P50UB		14.22	14.17	-0.05	112	P10		27.68	27.2	-0.48
53	P50UA		8.46	8.76	0.3	113	P46RA		4.12	3.82	-0.3
54	P50UA1		23.84	23.51	-0.33	114	P46RA1		11.8	11.75	-0.05
55	P51UA		9.68	10.01	0.33	115	P46RB		5.46	5.36	-0.1
56	P51UB		21.36	21.38	0.02	116	P46RC		16.33	16.3	-0.03
57	P52UA		9.54	9.18	-0.36	117	P14		16.26	16.43	0.17
58	P52UB		18.51	18.42	-0.09	118	P55RA		14.83	13.7	-1.13
59	NP12		11.04	10.92	-0.12	119	P55RB		40.75	39.6	-1.15
60	NP13		19.82	19.69	-0.13	120	P47RA		9.77	9.27	-0.5

WT-Pro: Water table pre-monsoon (amsl), WT-Post: Water table post-monsoon (amsl), Diff.: Difference between WT-Post and WT-Pre

All the hydrogeochemical analyses data recorded in tables 2 and 3 were used in mapping the studied physical and inorganic parameters of the groundwater in QARUAD by applying Golden software Surfer 13 (Fig.5 to Fig. 10).

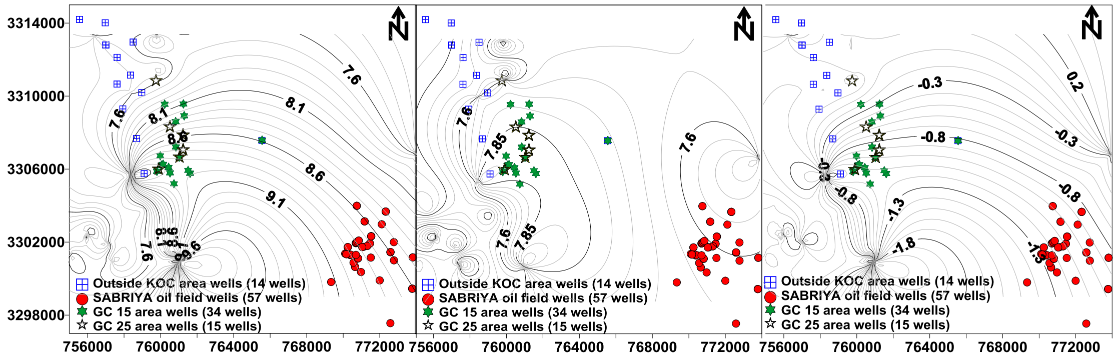

Fig. 5: pH contour maps before (left map), after rainfall (middle map) and the difference (right map).

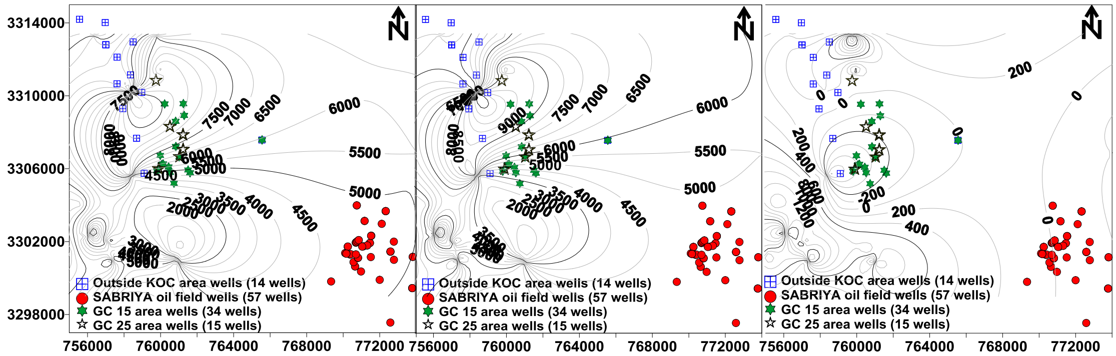

Fig. 6: TDS contour maps before (left map), after rainfall (middle map) and the difference (right map).

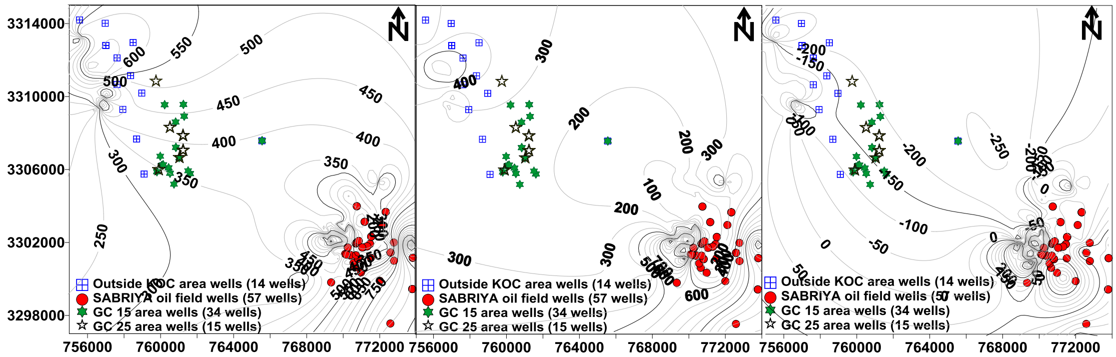

Fig 7: Na contour maps before (left map), after rainfall (middle map) and the difference (right map).

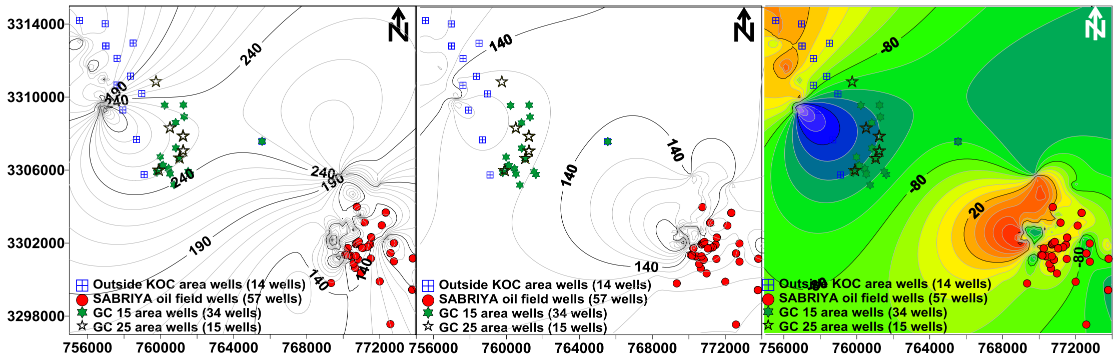

Fig.8: CO_3 contour maps before (left map), after rainfall (middle map) and the difference (right map)

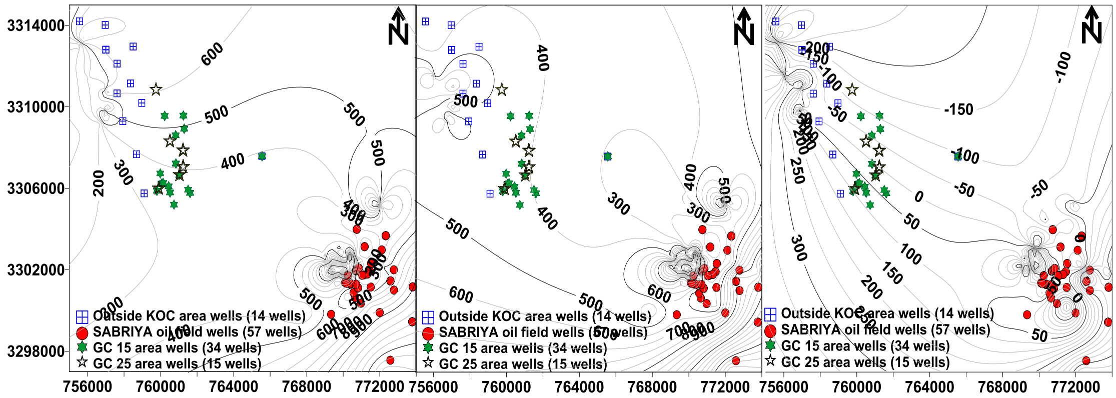

Fig 9: Cl contour maps before (left map), after rainfall (middle map) and the difference (right map).

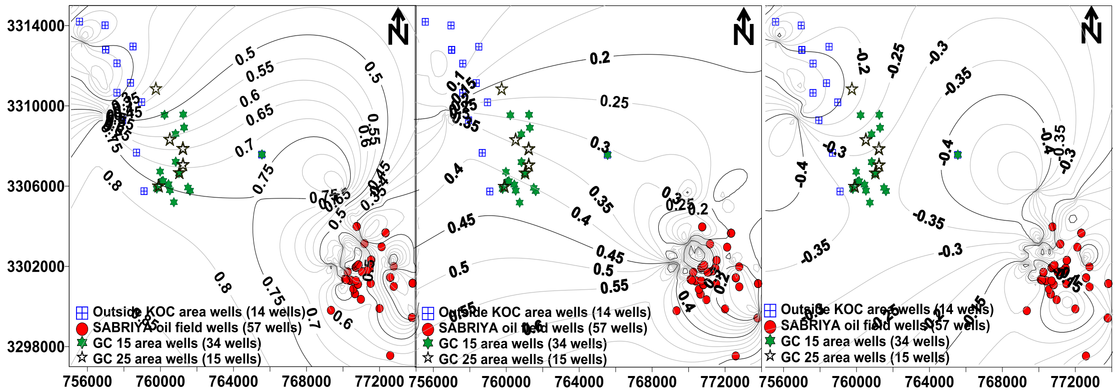

Fig 10: F contour maps before (left map), after rainfall (middle map) and the difference (right map).

Moreover, the groundwater level records before and after rainfall season and the difference between them were used in construction of seasonal change contour map (Fig. 11). All these maps were constructed based on the records of the wells in Outside KOC area, Sabriya Oil Field area, GC 15 area and GC25 area respectively (MEW, 2017-Table 4).

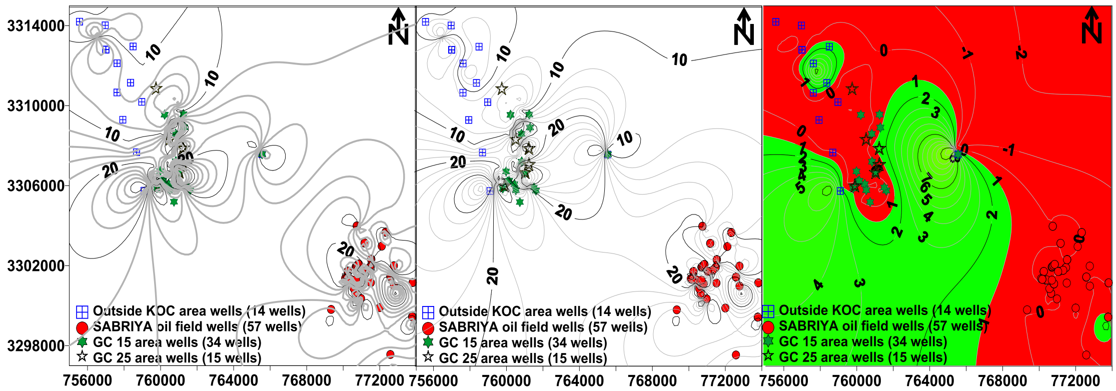

Fig.11: Groundwater level contour maps in (masl) before (left map), after rainfall (middle map) and the difference between them (right map).

In addition, Cluster analysis was used in this study, as it comprises of a series of multivariate methods which are used to find true groups of data related to basic hydrogeochemical analysis results (Table 2). In clustering, the objects are grouped such that similar objects fall into the same class (GAD 2001 and Danielsson et al., 2013). One of the benefits of the hierarchical method of cluster analysis, which is used in this study, is the advantage of not demanding any of prior knowledge of the number of clusters, which the nonhierarchical method does. A review by Sharma 1996 suggests Ward's clustering procedure to be the best, because it yields a larger proportion of correct classified observations than do most other methods (Davis, 1986, Gardner et al., 1990: Prethvivaj and Prakash, 1990). As a distance measure, Euclidean distances method is used in this study. The cluster analysis was carried out with single linkage and Euclidean method, firstly on the non-transformed input data matrix of all records. The results are given as R-mode dendrograms as shown in (Fig. 12).

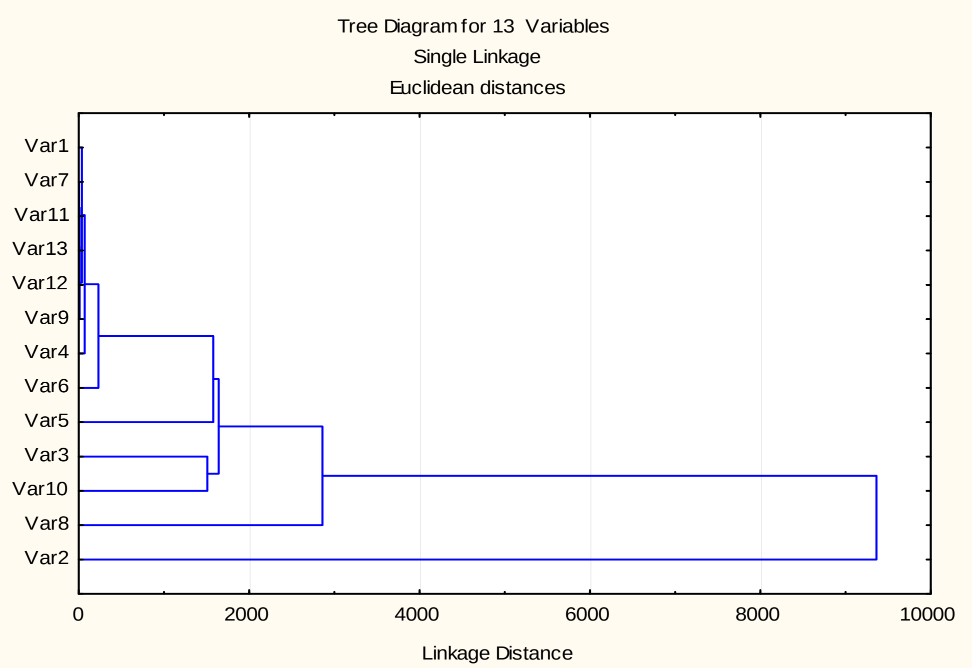

Fig.12: Horizontal hierarchical tree plot (R-mode dendrograms)

III. RESULTS AND DISCUSSIONS

Physico–chemical parameters were analyzed for groundwater samples have been summarized in Table 2&3. These parameters include pH, EC in situ, TDS, major cations and major anions (Table2). In general, pH is a measurement of activity of the free, un-complexed hydrogen ion which may lead to precipitation, co-precipitation and sorption processes that alter the chemical composition and reaction rates. pH ranges 6.4–10 (mean 7.73) in pre and 6.1–9 (mean 7.3) for post-monsoon. The pH resultant contour map (Fig.5 right map) showed that pH of the groundwater in Sabriya wells decreased by range 0.8-1.3 mg/l and by 0.3-0.8mg/l for the other three localities. This depicts slightly alkaline nature of groundwater due to the influx of HCO_3^- ions in the groundwater aquifer from percolation of rainwater through soil (Alam et al. 2011& Priyanka et al. 2016). All samples fall within the recommended limit (6.5 to 8.5) for human consumption (WHO, 2011**)** except sample No.P28UB was unsuitable for drinking purposes. Total dissolved solids (TDS) values range from 276-6154 mg/l (classified as 10% only fresh water, 38% classed as slightly saline groundwater and about 52 % moderately saline groundwater according to (Konikow and Reilly, 1999; Rhoades et al., 1992). The TDS resultant contour map (Fig.6 right map) showed that no change in TDS of the groundwater in Sabriya wells after rainfall season but decreased in the other three localities by 200mg/l. Total hardness (mg/l as $CaCO_3$) of groundwater is ranging from 75 to 445 (mean 179) for pre- and 20 to 410 (mean 150) for post-monsoon. TDS (mg/l) ranges 512.8–11570 (mean 4618.6) in pre- and 992–11790 (mean 4906.9) in post monsoon. The low TDS content in the groundwater of the study area could be either a result of short residence time with the underground rocks or the slow weathering of Dammam Formation limestone terrain (GAD 1995).

Among major analyzed cationic concentrations (mg/l): sodium is the dominating ion ranges 51–27700 (mean 1157.2) pre monsoon and ranges 36-16502 (mean 963.7) post monsoon and followed by calcium ranges 6–1220 (mean 159) and 18–234 (mean 93.7), magnesium ranges 0.45–156 (mean 27.74) and potassium ranges 4.2–68 (mean 12.22) and 0.3–200.7 (mean 10.1) in pre- and post-monsoon, respectively. Among cationic concentrations (meq/l), Na predominates by constituting 44 and 40 % of total cations followed by Ca constitute 32 and 25 %, Mg constitute 23 and 33 % and K constitute 2 and 1 % of total cations in pre- and post-monsoon, respectively. Moreover, Na resultant contour map (Fig.7 right map) showed that Na concentration decreased after monsoon by 50 mg/l in Sabriya groundwater samples while in the other three localities by 100 mg/l. In this groundwater system, Na is the dominant cation that exceeds the threshold of dominance (meq/l 50 %) in 31 and 23 % of the samples followed by Ca (5 and 2 %) and Mg (0 and 6 %) in pre- and post-monsoon, respectively. So, hydrogeochemistry reveals that the order of cation abundance is Na > Ca > Mg > K in both dry and wet seasons.

Among major analyzed anion concentrations (mg/l): carbonate is the dominant ion ranges 75 – 445 (mean 179.1) and 20 – 410 (mean 150). The CO_3 resultant contour map (Fig.8 right map) showed that the concentration of CO_3 in the groundwater of Sabriya depression increased by 20 mg/l after rainfall season while the other three localities samples decreased by 80 mg/l. Moreover, the chloride ion ranges 63 – 2836 (mean 626.7) and 29 – 4325 (mean 820.8) in pre- and post-monsoon, respectively. It is noticed from the resultant contour map of Cl (Fig.9 right map) that the concentration of Cl in groundwater of Sabriya wells increased after rainfall season by 50 mg/l but decreased in the other three localities by range 50-100 mg/l. Otherwise, sulphate ion (SO_4) ranges 179 – 1007 (mean 67.13) and 40 - 311 (mean 20.73) followed by phosphate ion (PO_4) ranges 0 - 0.37 (mean 0.02) and 0 - 0.42 (mean 0.028) while fluoride ranges 0.01–0.95 (mean 0.44) and 0.02–1.24 (mean 0.3) in before and after rainfall season samples respectively as shown in Table 3. Also, nitrate ion (NO_3) ranges 0.1 – 4.1 (mean 1.56).

Among the anionic concentrations (meq/l), Cl is the dominant anion that exceeds the threshold of dominance (i.e. meq/l 50 %) followed by HCO_3 in pre- and post-monsoon samples, respectively. Hydrogeochemistry reveals that the order of anion abundance is Cl > HCO_3 > NO_3 > SO_4 > CO_3 > F > PO_4 in pre- and post-monsoon. In general, mineral weathering, dissolution and base-exchange processes control the levels of ionic concentrations in groundwater. The spatial distribution of total hardness in the investigated area clearly shows that high levels of hardness confined mainly to extreme southwest and few patches are found in central and northeast part in both pre and post monsoon (Table 2&3). High Ca, Mg and Cl in groundwater are the probable reason for the hardness in basin. Nitrate spatial distribution shows wide variation in its concentration infers point and non-point sources (Priyanka Patel et al. 2016). High nitrate contamination is predominant in southwest part which consists of fast urbanizing area. Poor sewerage, leakage of human excreta from septic tanks and locally unmanaged solid waste disposal sites could have result in slug like motion of water during infiltration in groundwater (GAD et al. 2015). Few patches of nitrate pollution have also been observed in the central and northeast part of Umm Al-Aish might be due to high agricultural activities and domestic sewage. Application of N-fertilizers on irrigation land as crop nutrients along Abdali area may be responsible for nitrate pollution in the groundwater due to leaching by applied irrigation water.

Moreover, two main groups of ion relationships can be concluded. Group1 which have ion dominance Na > Ca > Mg and Cl > SO_4 > HCO_3, where rNa/rCl is less than unity. This group (92% from 40 samples) characterizes groundwater samples which were collected from Al-Raudhatain and Umm Al-Aish areas (Table2). Group2 which have ion dominance Ca > Na > Mg and Cl > SO_4 > HCO_3 for samples No. PO4R and P24U extracted from Outside KOC area while ion dominance of Ca > Na > Mg and SO_4 > Cl > HCO_3 is characterizing to sample No. P62U related to Sabriya area.

According to salinity level, the water type is mainly freshwater type. On the other hand, the hydrochemical features of this group in the QARUAD presents Outside KOC area and Sabriya area which indicates marine salts contamination from the marine deposits of the neighboring catchment area and aquifer matrices. There is also a possible contamination for the QARUAD in Sabriya area with marine salts from the underline fractured limestone aquifer. This is confirmed by the assemblages of hypothetical salts combinations. Otherwise, the water composition of the QARUAD consists of NaCl, $CaSO_4$, Na_2SO_4 and $CaCl_2$. Whereas $CaSO_4$ and NaCl are the predominant water types in the brackish groundwater fields (Al Ruwaih and Ben-Essa 2004), in the freshwater fields, the principal water types are $Ca(HCO_3)^2$ and $NaHCO_3$. According to Kwarteng et al., 2000, the difference in water types is due to cation exchange process whereby the water quality changes from NaCl to $CaCl_2$ water type. The interaction of freshwater with a marine aquifer results in the loss of Ca^{+2} and the formation of $NaHCO_3$ and Na_2SO_4 water types (GAD 1999).

Consequently, the origin of solutes was studied based on the Ca/Mg ratio. It is used to determine the sources of Ca and Mg into the groundwater. Ratio of 1, indicates dolomite dissolution, 1–2 indicate calcite dissolution dominance and >2 reflects an effect of silicate minerals (Raju et al. 2015). The Ca/Mg ratio varies 0.23–5.31(mean 1.63) and 0.16–2.73 (mean 0.86) (Table 2) in before and after rainfall season, respectively. 44 and 30 % groundwater samples depicts calcite weathering dominance, and 25 and 67 % shows dolomite weathering dominance in the study area in pre and post-monsoon season, respectively (Priyanka Patel et al. 2016). 31 and 3 % of the samples showing >2 Ca/Mg ratio which indicates silicate weathering is dominant process for the contribution of Ca and Mg ions in pre- and post-monsoon, respectively. P. Patel

As a general, the chemical inorganic pollutants in the groundwater is discussed through measurement of trace elements concentration including Fe with minimum value (0.01 in wells No. P51UB and P52UB in Sabriya area) and maximum value of 0.95 in well No. P31UB as shows in (Table 3).Compared to international standards (WHO, 2011) to assess high concentrations of trace elements that could affect human health in the hypothetical case that impact shallow groundwater used for drinking water purposes. It is worth to mention that the most cations and anions are decreased in concentration after rainwater season which reflects a good chance for agriculture and sustainable urbanization development.

In the other side, the main factors that affected groundwater interaction were the climate parameters (rainfall and evaporation demand). Precipitation infiltration was a key recharge source of shallow groundwater as well as the major recharge source of groundwater. During the wet season (November-March), frequent and sufficient rainfall led to large fluctuations in groundwater level and the shallowest water level was reached. During the dry season (April-October), the groundwater level fluctuated within a narrow range with low precipitation (GAD 2009). During a non rainfall period, the groundwater level exhibited a linear downward trend because of evaporation and then increased until the next precipitation occurred. The period from May to August is characterized by absence of rainfall, together with elevated temperatures and potential evapotranspiration; the longest non rainfall period during the wet season occurred. During this period, the groundwater level reduced. The groundwater level increased after the precipitation events and then decreased gradually with evaporation. The groundwater tables varied within the period from wet to dry seasons and showed seasonal variations because of the seasonal distribution of precipitation and evaporation. Also, the water table contour maps before and after rainfall season and the resultant maps (Fig.11, left, middle and right maps respectively) were constructed. The maps represent the same period of measurements to study precisely the groundwater flow as well as to through a light on the seasonal changes as a basis of recorded values. From these maps the followings can be concluded:

i-The water level lies above the mean sea level. It ranges between 3.16 -32.2 m pre monsoon (wells No. P03R and P69RC), between 1.51– 40.1m, after rainfall season (wells No. P03R and P69RC) with difference values of 16.1 and - 4.05 m in wells No. P01R and P68RA in Outside KOC area. Otherwise, it ranges between 0.81-36.4 m pre-rainfall in wells P36U and P60UB, between 0.87 – 36.4 m post-rainfall in wells No. P36U and P60UB with difference values of 3 and -1.25 m in wells P49UA1 and NP16 in Sabriya Oil Field area. Also, it ranges between 1.58 - 42.58 m before rainfall in wells P39R and P40RB, between 1.5 – 42.15 m after rainfall in wells No. P66RB and P40RB with difference values of 1.23 and -1.15 m in wells P40R and P55RB in GC 15 area. Finally, it ranges between 0.65 - 40.75 m pre-rainfall in wells P48RB and P55RB, between 0.57 – 39.6 m post-rainfall in wells No. P48RB and P55RB with difference values of 1.2 and -2.36 m in wells No. P02 and P44RB in the GC 25 area.

ii- The water table contours (equipotential lines) show a general trend more or less parallel to the central area. Moreover, their altitudes increase as they go far from them. This indicates that these areas represent a discharge front for the rainfall and it is considered the main factor of water table rise. The water table levels in this area are always lower than the water surface in surroundings indicating effluent conditions around these drainage natural systems (GAD 1995).

iii- The curvature of contour line 10 m representing the water table before and after rainfall bend downstream of Sabriya area. This express essentially upon the losing water condition (influent stream) (GAD, 1999). The same case is observed in contour line 20 m pre and post rainfall (Fig. 11).

iv- Equipotential lines of the central part are curved in an open trench with flow from all directions towards the central areas. This may attribute to the low topography of this area and/or concentration of dug wells in these parts of QARUAD with heavy uncontrolled pumping (about 120 production and observation dug wells) (GAD et al. 2015).

In addition, the identification and interpretation of Cluster analysis results (Fig. 12) were concluded. The rotated factor was also computed. Based on these steps, four statistical factors may be extracted as following (Fig. 12):

Factor 1: is the main factor and characterized by highly positive loading with Na, and SO_4. This may attributed to the water rock interaction and municipal wastewater discharge and presence of surface saline soils, evaporation, agricultural activity and wastewater.

Factor 2: is highly positive loading with pH, NH_3, F, NO_3 and PO_4 due to agricultural activity, fluoride and silica enrichment and wastewater.

Factor 3: is highly positive loading with K and Pr due to CO_3-pH relation and industrial wastes.

Factor 4: represented by TDS, Ca, Mg and Cl which are independent variables.

IV. CONCLUSION AND RECOMMENDATIONS

The groundwater of the study area are slightly alkaline in nature. Majority of the groundwater samples are moderately hard to very hard waters in both before and after the rainfall season. In this groundwater system, Na (31 % in pre- and 23 % in post-) and Cl (39 % samples in pre- and 55 % in post-) are dominant ion that exceeds the threshold of dominance (i.e. meq/l 50 %). Ca/Mg molar ratio signifies calcite weathering as dominant source in pre- and dolomite weathering in post-monsoon for the ionic constituent in the groundwater. The spatial distribution of hydrochemical facies shows that majority of the area is dominated by Na–Cl facies. Deep saline water of Dammam aquifer upconing and wastewater infiltration is the primary factors along with agricultural return flow and sea water intrusion which play momentous role in increasing salinity of the groundwater. According to Cl classification, brackish water is distributed all over the study area followed by the fresh brackish water. Four clusters were inferred from the principal component analysis noticeably infers the water rock interaction and municipal wastewater discharge in PC1, agricultural fertilizer input in PC2, CO_3-pH relation in PC3, Salinity and dolomite weathering beside silicate weathering is dominant process in PC4 as major factors in the groundwater system. These findings reveal that groundwater is less polluted with various natural and anthropogenic activities and majority of the samples are good to permissible for drinking purpose. The groundwater usage for domestic purposes has been limited due to the excessive permissible limit of TDS, TH, Na, HCO_3 and NO_3 in the study area.

The study area is suitable for agricultural and urbanization development in case of good planning especially with respect to the fresh groundwater lenses in QARUAD. Also, long-term monitoring of both groundwater levels and quality in the future will be required to assess the threat to groundwater reserves and to adopt appropriate mitigating actions. Also, the flow of oil from the oil wells in the vicinity, damaged during the 1991 Gulf War, and subsequent use of seawater for extinguishing the oil fire have contaminated the soil and infiltrating rainwater has carried these pollutants to the relatively shallow groundwater in these areas. It must be recommended that these environmental problems are badly in need of treatment through continuous projects as fast as possible.

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