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The Effect of Seasonal Rainfall on Groundwater Quality in North Kuwait

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ABSTRACT: *Water is substantial natural resources on earth which cater for all human endeavors. Groundwater is the most essential and reliable source of fresh water in arid zones like north Kuwait. This study evaluates the effect of rainfall precipitation on groundwater characteristics in north Kuwait. The representative samples of groundwater were collected from 50 water points, in addition to rain water and Arabian Gulf water samples. The chemical analyses of the collected water samples were performed in the Laboratories of the MEW. 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. The salinity change suggests that the fresh water–saline water interface, as defined by the 1500 ppm contour line, has moved towards the centre of the fresh water lens. In some areas up-gradient of the fresh water recharge by rainfall, the extent of the fresh water lens has actually increased slightly in the down-gradient areas. In addition, 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 groundwater pollution. It is concluded that the majority of the samples are good to permissible for drinking purpose. It is highly recommended that the environmental problems related to the damaged during the 1991 Gulf War are badly in need of treatment through continuous projects as fast as possible before any urbanization development or any integrated water management.*

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

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I. INTRODUCTION

Kuwait state 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. The acute lack of natural water resources of the country has created a unique water sector in Kuwait, that is, about 90% of the potable water production is coming from the unconventional resource of seawater desalination. Although this unusual situation has been maintained for decades and probably will continue into the foreseeable future, the complete dependence on a highly industrialized source for freshwater has serious drawbacks, one of which is the lack of secured strategic water reserve. As such, the usable water accumulation in northern Kuwait stands out as a potential sizable emergency reserve (Al-Senafy et al, 2013). The infiltration of the rainwater/runoff from the occasional rainstorms of Kuwait is known to produce freshwater lenses in the natural depressions of northern Kuwait (Parsons, 1964). 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). Nonetheless, freshwater accumulations are not confined to the depressions, but extend however in lesser volumes, to the formations underlying the wadis that carry the surface base flows. During the early exploration efforts, potential usable water accumulations, i.e., total dissolved solids (TDS) <5000 mg/l, of different volumes have been reported in many parts of northern Kuwait (Parsons, 1964). While the main two depressions (Raudhatain and Umm Al-Aish) have been evaluated extensively, most of the other identified/potential usable water accumulations have been given next to no attention. This was mainly due to their irrelevance in the pursuit of freshwater bodies large enough for economical exploitation. However, in the context of securing a strategic emergency reserve for the country, these relatively smaller accumulations are significant assets. The lack of information on the location, extent and TDS content of these accumulations as well as the recharge rates to the watershed are deficiencies that prevent preparation of emergency utilization plans for these resources. In this context to address these deficiencies, this study was conducted with the overall aim of exploring the effect of seasonal rainfall on groundwater quality of the Shallow Groundwater Resources in Northern Kuwait (SGRNK).

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).

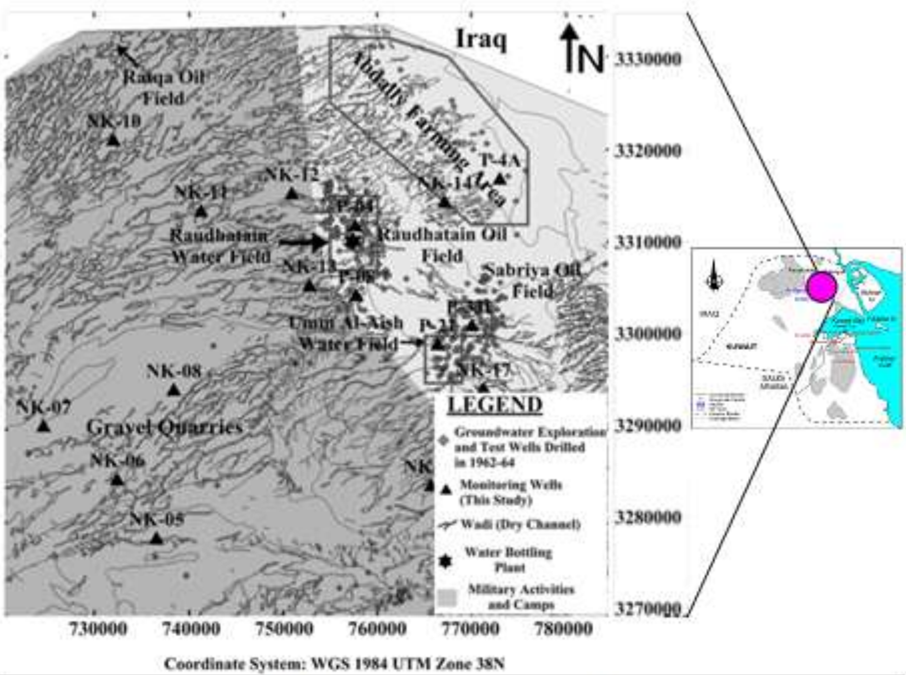


Fig. 1: Location map of the study area

It is limited between latitudes 3270000 and 3330000 due North and longitudes 725000 and 780000 due East with an area of 1650 Km^2. Al-Jahra table land area bounds SGRNK 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 ^{o}C and 50 ^{o}C during summer months and from 20 ^{o}C to Zero ^{o}C 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 9.4 mm (Safar 1985). Moreover, the annual evaporation rate ranges between 8.8 mm and 9.8 mm while the relative humidity ranges from 31.1% to 38.7% with mean value of 34.66% (Table 1).

Table 1: Climatic characteristics of the study area

Serial No.	Year	Rainfall in (mm)	Evaporation in (mm)	Humidity in (%)
1	2012	126.7	9.4	31.1
2	2013	117.9	9.5	33.9
3	2014	73.7	9.5	38.7
4	2015	97.8	8.8	37.1
5	2016	89	9.8	32.5
Mean		101.02	9.4	34.66

1.2 Geomorphological settings

Geomorphological features play a vital part in accumulation of rainwater and irrigated drainage water in low depressions and consequently affect the soil water quality. 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 re-sampling 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).

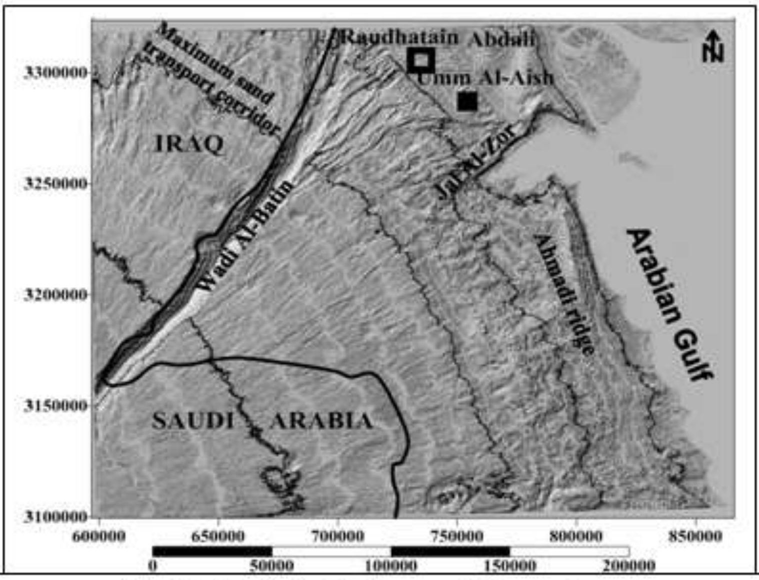


Fig. 2: Shaded relief map of the study area

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 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 Umm Al-Aish, and Abdali depressions, and the sand corridor.

1.3 Geological settings

The geology of Kuwait consists of recent (Quaternary age) deposits and sediments unconformably overlying sedimentary rocks (Tertiary age) which host the groundwater aquifers. The regional dip of strata is about 2 m per km towards the north-east and this regular dip is interrupted by anticlines and other small structures which are present at the Raudhatain oil field. The Dibdibba Formation, confined to the northern part of Kuwait, comprises sands and gravels with minor clay and gypsiferous sandy clay beds. 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) (Fig.3). In addition, the paleo-drainage channels in SGRNK, 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).

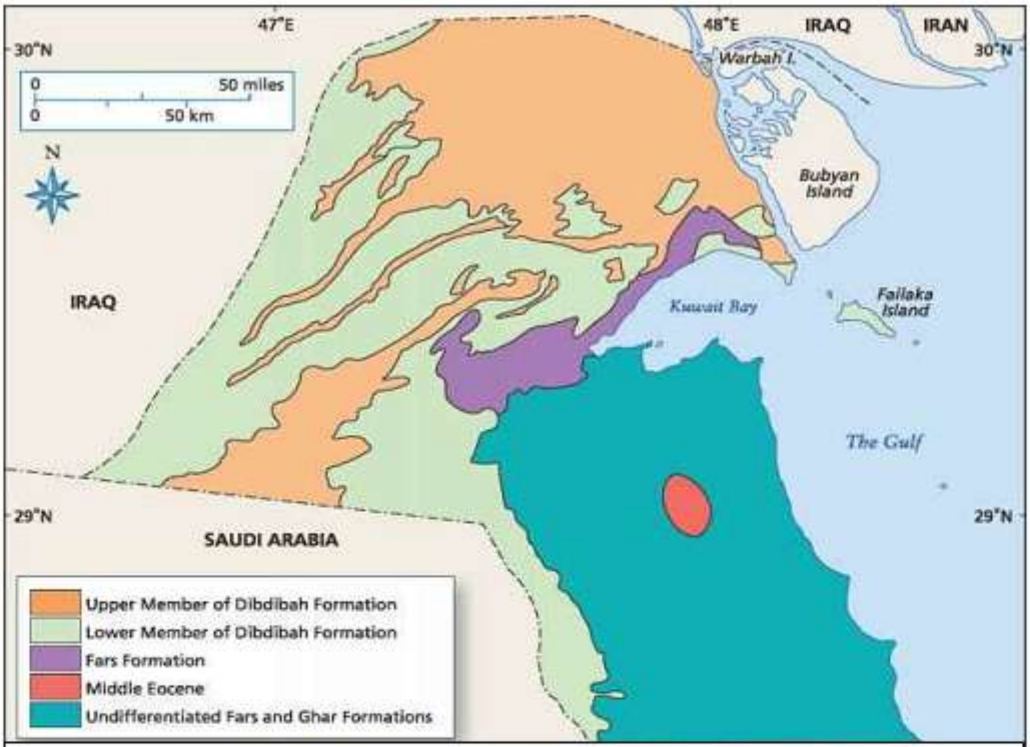


Fig. 3: Geological map of Kuwait (modified after HGG 1981)

1.4 Hydrogeological setting

Hydrogeologically, the two fresh water aquifers of interest are situated beneath the shallow, elongated depression of the Al-Raudhatain and Umm Al-Aish drainage system which consist of an extensive network of wadis and drainage lines (Yihdego and Al-Weshah 2016). The S-N hydrogeological cross-section shows that upper aquifer, 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.

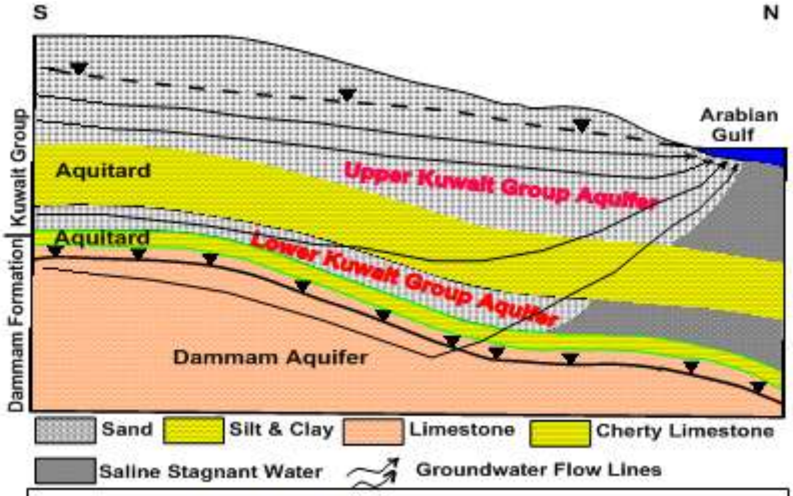


Fig.4: Hydrogeological cross section of the study area

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 SGRNK 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 SGRNK existed as lenses that were formed by infrequent infiltration of rainwater. The study estimated the total volume of freshwater in Raudhatain basin to be approximately 68,130 Ml. Senay (1977) estimated the safe yield from the 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 SGRNK is very important for sustainable development.

II. MATERIALS AND METHODS

To study the seasonal change of groundwater quality after seasonal rainfall in SGRNK, 12 field trips 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. SO4, 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 x100…………....(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 CaCO3)…………….…………………(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 comparison between salinity measurements at the end of the dry season (during September 2010) and in the middle of the rainy season (January 2011) is given in (Fig.5). In addition, the base case scenario of the groundwater quality in presented in the results of the routine analysis of 40 groundwater samples collected from SGRNK at 2016 (Table 2).

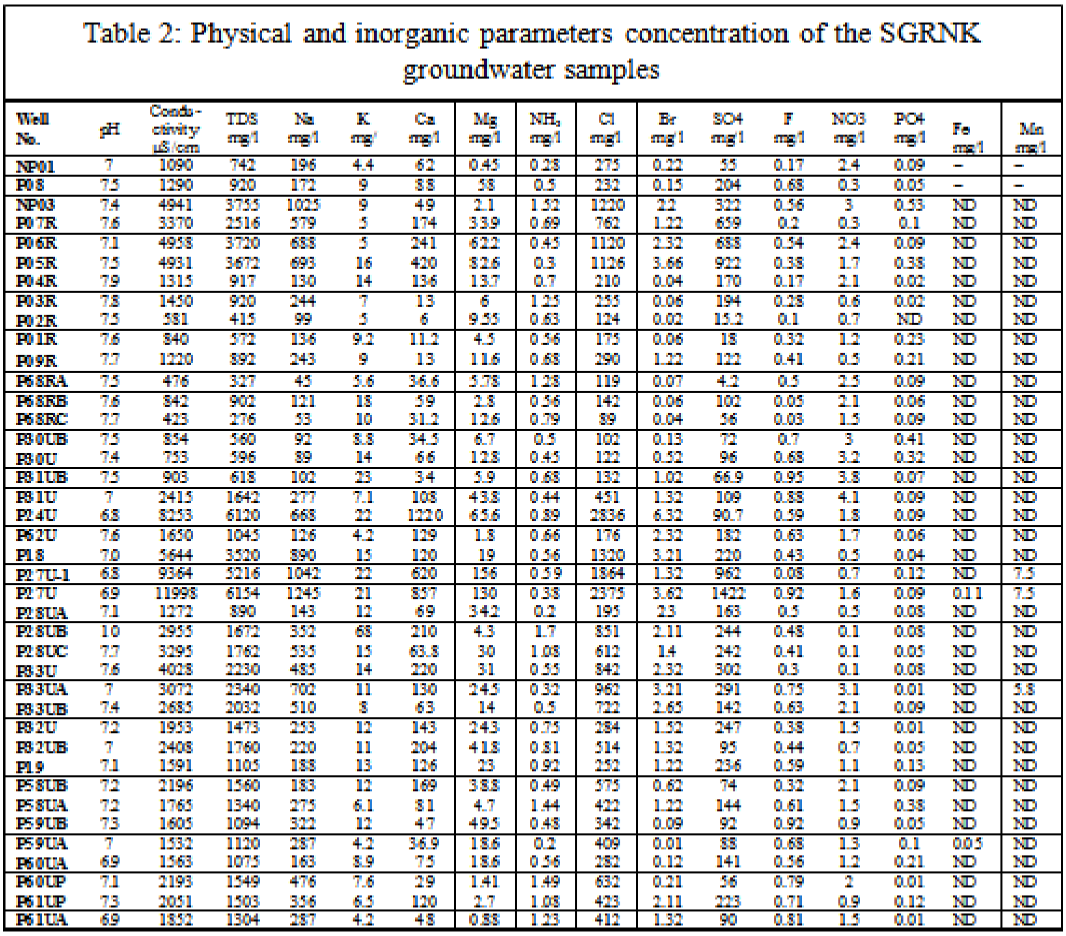


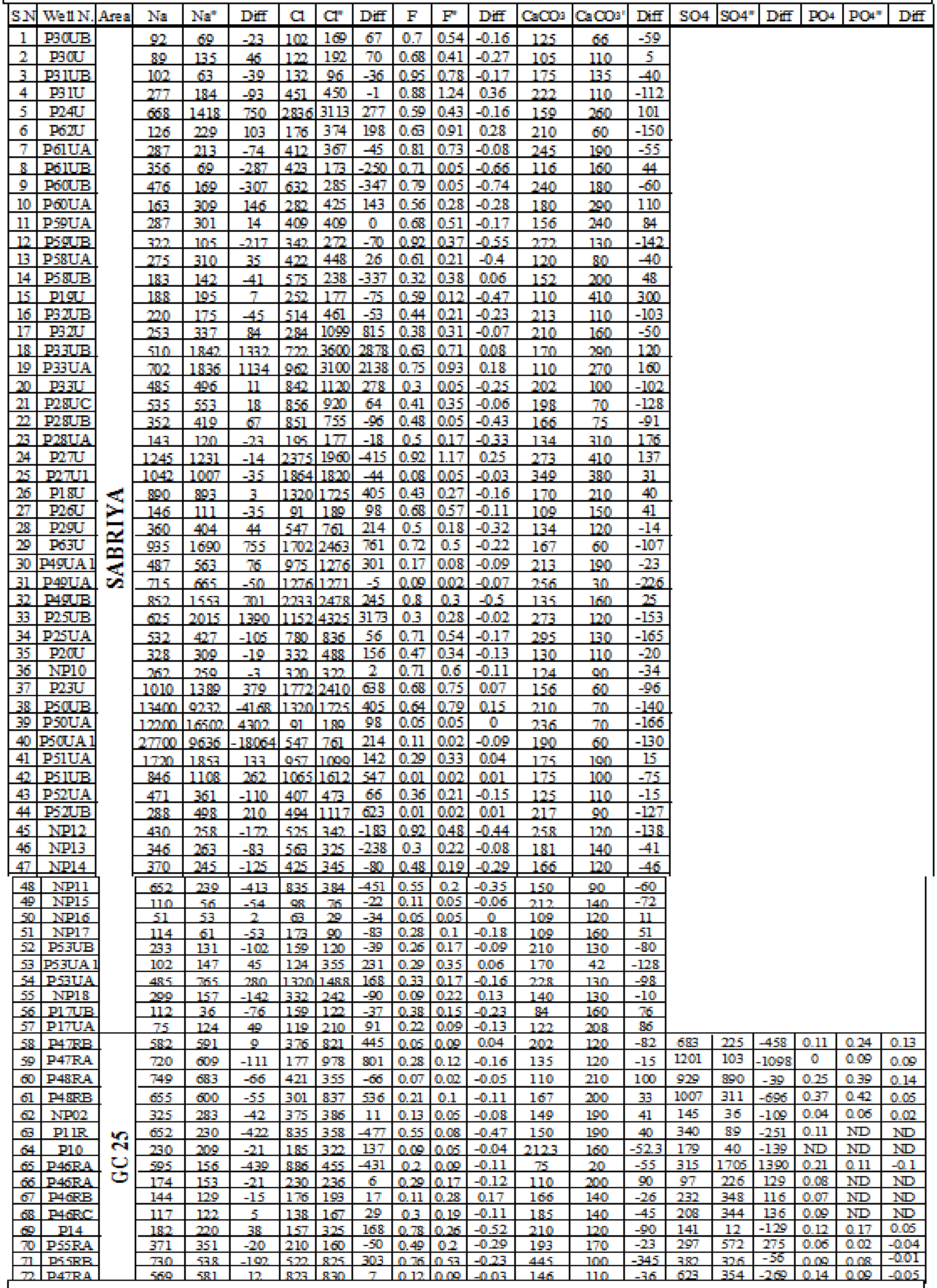
Table 2: Physical and inorganic parameters concentration of the SGRNK groundwater samples

Well No.	pH	Conductivity µS/cm	TDS mg/l	Na mg/l	K mg/	Ca mg/l	Mg mg/l	NH_3 mg/l	Cl mg/l	Br mg/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	22	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	3672	693	16	420	82.6	0.3	1126	3.66	922	0.38	1.7	0.38	ND	ND
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	23	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	14	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 changes of groundwater quality and some trace elements concentration pre and post the rainfall season are given in Table 3.

It is worth to mention that, 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.

Table 3: Inorganic parameters concentration of the groundwater samples pre and post 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	P49UA 1		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		13400	9232	-4168	1320	1725	405	0.64	0.79	0.15	210	70	-140						
39	P50UA		12200	16502	4302	91	189	98	0.05	0.05	0	236	70	-166						
40	P50UA 1		27700	9636	-18064	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	P53UA 1		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	2123	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. pre, Na": Sodium conc. post rain (mg/l), diff: difference (pre-post), Cl: Chloride conc. before, Cl": Chloride conc. after (mg/l), diff: difference (pre- post)……..and so on…………..

III. RESULTS AND DISCUSSION

3.3 Seasonality change in salinity

The seasonality change in groundwater salinity is illustrated in (Fig. 5). It shows a comparison between salinity measurements at the end of the dry season (during September 2010) and in the middle of the rainy season (January 2011). The results show that the dry season salinities are, on the average, ≈ 25% higher than the rainy season with a standard deviation of ≈ 5%. This quality change is important to be taken into consideration if this groundwater reserve is to be utilized for emergency purposes.

Moreover, 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.

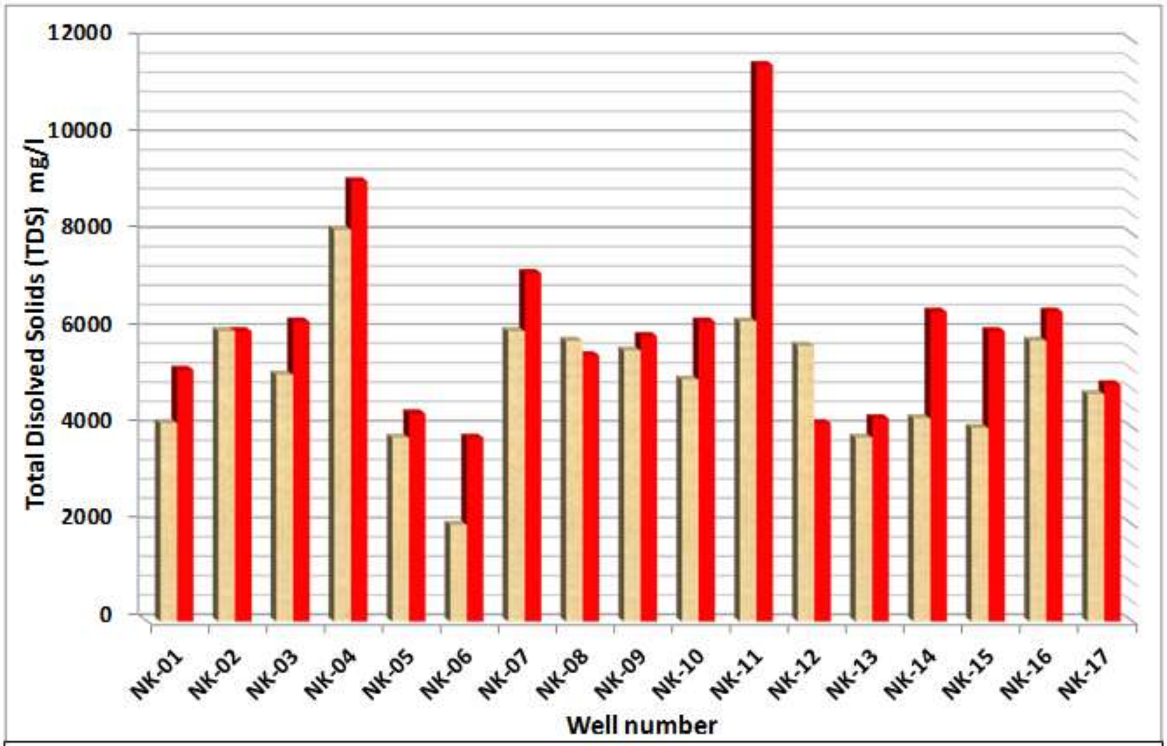


Fig. 5: Seasonal salinity variations of SGRNK during dry season (Sep 2010-yellow color) and rainy season (Jan 2011-Red color).

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). 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 SGRNK by applying Golden software Surfer 13 (Fig.6 to Fig. 11).

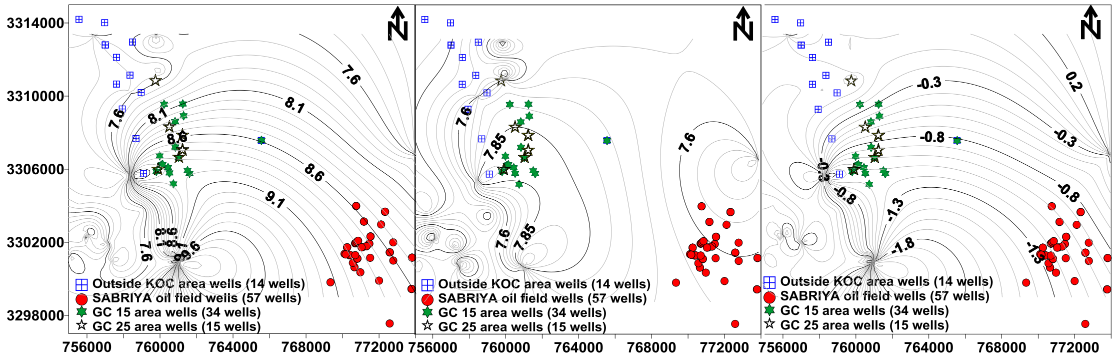


Fig. 6: pH contour maps before (left map), after rainfall (middle map) and the difference (right map).

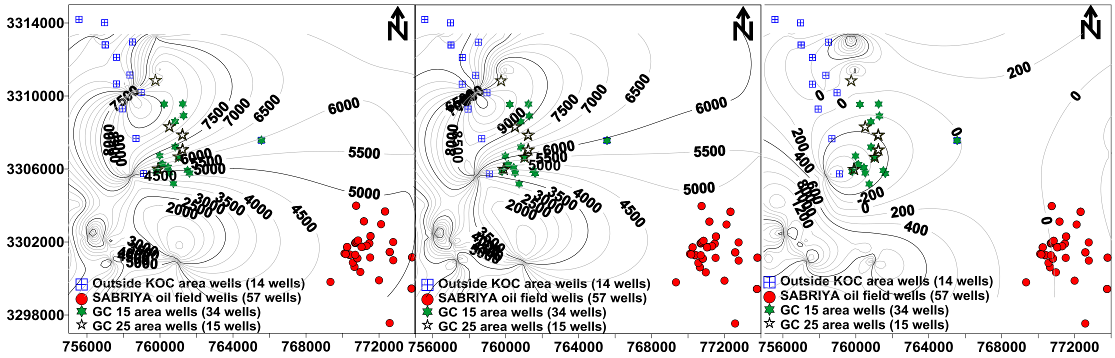


Fig. 7: TDS contour maps before (left map), after rainfall (middle map) and the difference (right map).

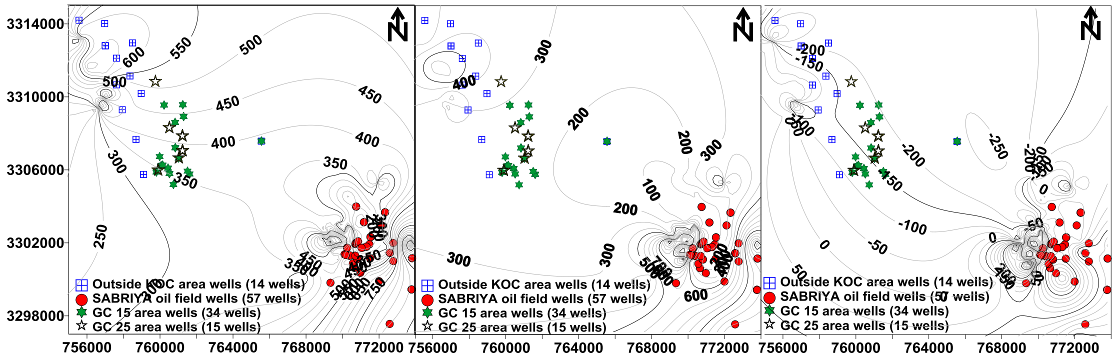


Fig 8: Na contour maps before (left map), after rainfall (middle map) and the difference (right map).

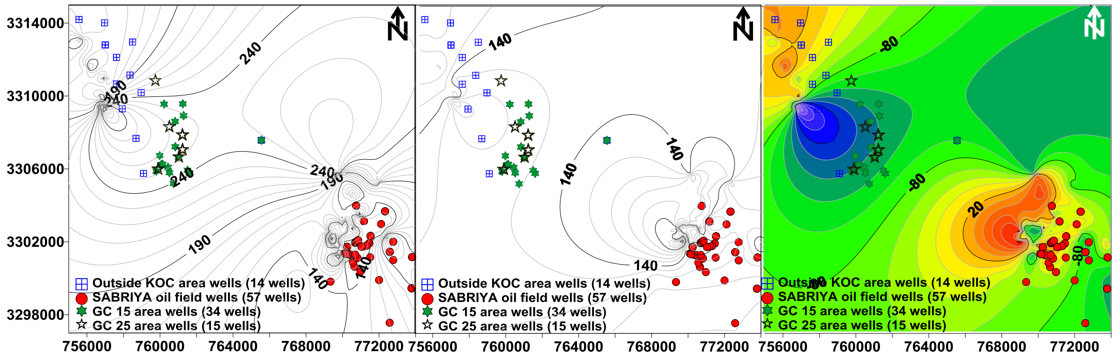


Fig.9: CO_3 contour maps before (left map), after rainfall (middle map) and the difference (right map)

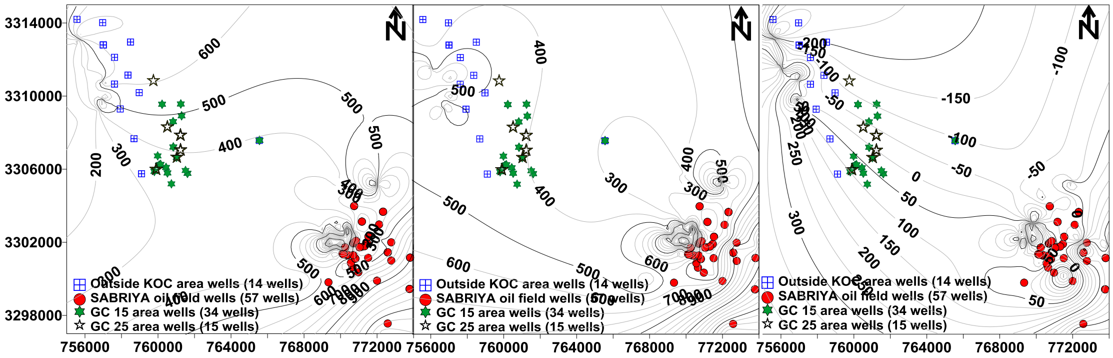


Fig 10: Cl contour maps before (left map), after rainfall (middle map) and the difference (right map).

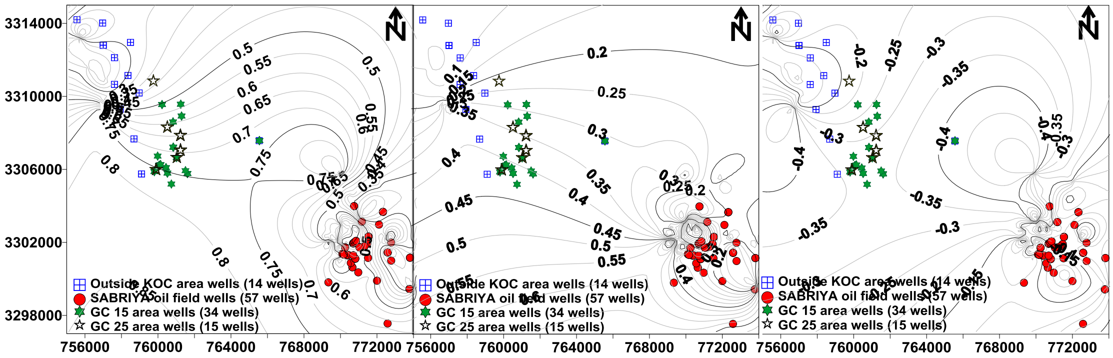


Fig 11: F contour maps before (left map), after rainfall (middle map) and the difference (right map).

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.8 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.10 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 SGRNK 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 SGRNK 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 SGRNK 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.

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 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):

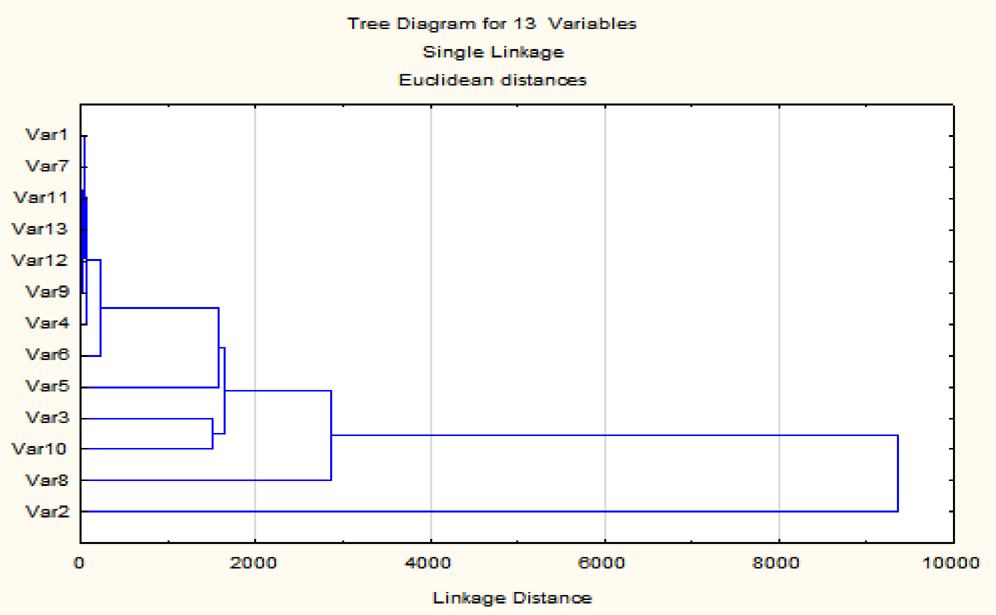


Fig.12: Horizontal hierarchical tree plot (R-mode dendrograms)

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 % of samples in pre- and 23 % in post-) and Cl (39 % of 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 SGRNK. 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 related to the damaged during the 1991 Gulf War are badly in need of treatment through continuous projects as fast as possible.

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