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Hydrogeology and Water Quality of Umm Alradhma Aquifer, Eastern Saudi Arabia

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Abstract

Umm Alradhma limestone aquifer represents the most important aquifers in Saudi Arabia. This aquifer is the largest groundwater reservoir in the Arabian Peninsula. It has high potential of groundwater with average saturated thickness of Umm Alradhma 270 m. the average transmissivity, hydraulic conductivity and effective porosity of Umm Alradhma limestone aquifer are 5800 m2/day, 33 m3/day and 30% respectively. The groundwater of the Umm Alradhma limestone aquifer exists under confined condition in the study area. The productivity of the wells reached 704000 m3/day and provided Riyadh City about 300,000 m3/day.

The hydrochemical analyses of 52 groundwater samples representing Umm Alradhma limestone aquifer reveal that the groundwater origin is meteoric. The presence of marine salts in groundwater is attributed to the effective leaching and dissolution processes through the flow path within the aquifer materials (limestone, dolomitic limestone and dolomite). The groundwater salinity of the Umm Alradhma limestone aquifer in the study area ranges between 1195-1429 ppm. This suggests that groundwater of Umm Alradhma limestone aquifer is acceptable for domestic, industrial and agricultural purposes.

Keywords: Umm Alradhma aquifer, Hydrogeology, Water Quality

Introduction

Groundwater represents the main source of water supply for the inhabitants in Saudi Arabia. Umm Alradhma aquifer is considered one of the most important and principal aquifers and represents the largest groundwater reservoirs in the Arabian Peninsula. Alhuni Well field is an additional water resource to supply Riyadh City. The drilling of this well field consists of 65 productive wells and 5 piezometers.

The study area is located about 220 km east of Riyadh City (Fig. 1). It covers more than 250 km2 and is confined between 25o 05`-25o 15` N and 48o 36`-48o 43` E. The study area lies in the typical arid region of Saudi Arabia. The average monthly temperature ranges between 15 o C in winter to 35 o C in summer. Rain occurs mostly in the months from October to April and rainfall varies from 49.4 mm/year to 80.12 mm/year. The evaporation intensity varies from 9.1 mm/day to 12 mm/day.

Umm Alradhma Formation was subjected to several hydrogeological and geological investigations (Wakuti company 1971; Dincer et al. 1974; BPGM 1977; GDC 1979; Al Bassam 1983; Annakhli 2005).

This study characterized the hydrogeological and hydrochemical characteristics of the Umm Alradhma limestone aquifer.

Geomorphological and Geological Setting.

Geomorphological Features

Geomorphologyically, the majority of the surface of study area is occupied by huge sand dunes (Fig. 1). The surface elevation of study area decreases towards the east direction and it ranges from about 180 m mean sea level (msl) in the east (at Al-Jafurah sand dune belt) to 1000 m (msl) in the west (at Jibal Tuwaqa plateau). Accordingly, the surface of study area slopes eastward and comprises the following units:

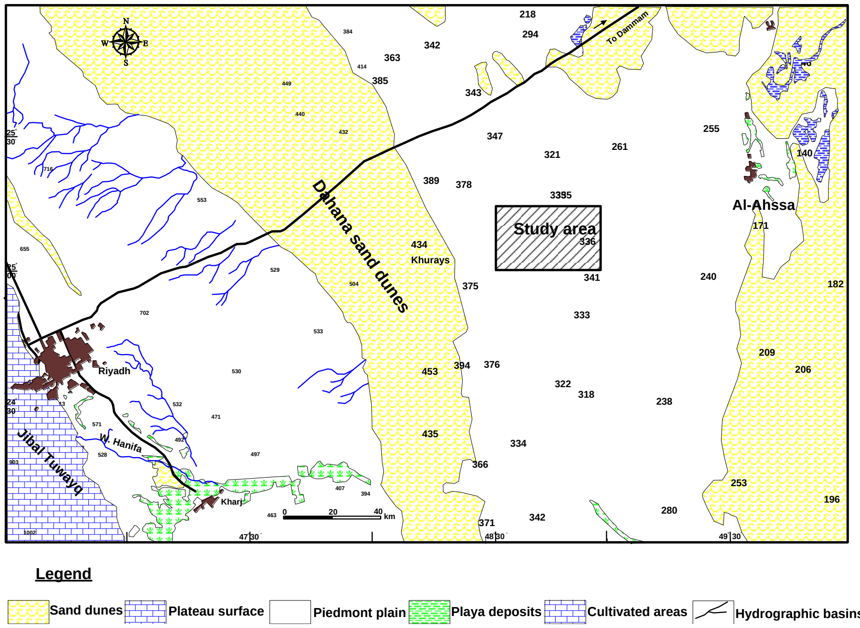

Figure (1): Location and geomorphologic unit's map of study area and its surroundings.

1- Sand dunes (collector area): they cover about 50 % the surface of study area. These dunes comprise of Dahana sand dune belt in the west and Al-Jafura in the east. They are parallel oriented in NNE-SSW. These dunes play an important role for feeding the Umm Alradhma limestone aquifer, through the rapid infiltration rate of the collected rainfall.

2- The high plateau (watershed area): the Jibal Tuwaqa represents the high plateau and are located in the west of the study area. This unit receives the rainwater and the surface of this unit is formed middle Jurassic limestone. The average altitude of this plateau attains 1000 m (msl).

3- Hydrographic basins: they are parallel and run in NW-SE direction. They drain the plateau and piedmont plain to the Dahana sand dunes.

4- Piedmont plain: this plain occupies the strip between foot slope of plateau. Its surface slopes towards the east direction.

5- Playa deposits: it is located in the northeast of study area.

6- Cultivated area: it concentrates along Wadi Hanifa.

Geological Setting

Neogene deposits cover the majority of the studied area (Fig. 2). Because there is no any rock exposures on the surface; the lithostratigraphic column in the study area is studied through 70-drilled wells. This column is discriminated into 5 lithologic units according to the well logs and reveals the following stratigraphic sequence:

Aruma Formation is mainly composed of limestone with subordinate dolomite and shale. This formation belongs to Late Cretaceous. Its thickness ranges from 30 m at northeast of study area to about 300 m at southwest of the investigated area. Generally, the thickness of this formation increases due southeast gradually to Ruba Alkhali basin. The concerned formation overlies the Wasia Formation and underlies the Umm Alradhma Formation. This formation represents the water bearing formation. Umm Alradhma Formation is exposed on the surface from south of Wadi Jabaliyah to north at the Iraqi-Saudi Arabian border, a distance of about 1200 km. This formation overlies the Aruma Formation and underlies the Rus Formation. The investigated formation is composed of limestone, dolomitic limestone and dolomite. It belongs to Paleocene age (Powers et al, 1966). Its thickness increases from 100 in the outcrop area to 400 m to the east. Rus Formation is made up of marls, chalky limestone and gypsum with chert and anhydrite. It is assigned to Early Eocene age. The thickness of this formation ranges from less than 15 m at northeastern part to more than 38 m at east of study area. This formation is detected as water bearing formation. Dammam Formation underlies the Neogene deposits and overlies the Rus Formation. It belongs to Eocene age and consists of limestone, dolomite marl and shale. Its thickness varies from less than 30 m at west to more than 180 m at southeastern part of the study area. Neogene deposits have several formations (Handrukh, Dam, Hofuf and Kharj Foramtions). They belong to Miocene and Pliocene age. These formations are composed of limestone, sandy limestone or marl, gypsum and gravel sometimes. The thickness of these formations increases from northwest (less than 60 m) to southeast (about 280 m). It is noticed that the majority of the pervious formations increases gradually from the outcrops area to the southeast towards the Rub-Alkhali basin. The study area is highly affected by folding processes, while the investigated area is located within syncline fold.

Hydrogeological Settings

1-Hydrogeological Conditions

The hydrogeological characteristics of the Umm Alradhma limestone aquifer in the study area are defined based on, the collected data of the available drilled water wells, surface geological information, borehole geophysical interpretations and analyses of pumping tests data.

Seventy wells are drilled by GDC, with their depths ranging between 450 m and 472 m (Table 2). They are totally penetrating the upper part of the Umm Alradhma limestone aquifer. The generalized explanatory hydrogeological section (Fig. 2) shows that the study area is represented by syncline fold. The concerned aquifer is composed of limestone, dolomitic limestone and dolomite. The average penetrated thickness of this aquifer attains 170 m. The groundwater in this aquifer is generally present under confined conditions (Fig. 2).

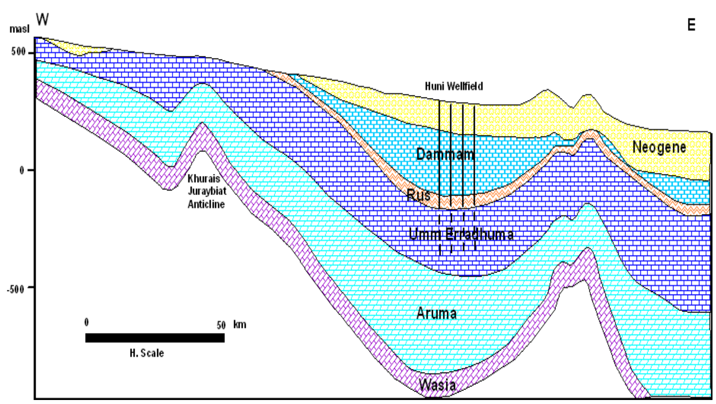

Fig. (2): Hydrogeological cross-section EW across the study area (modified after Annakhli, 2005).

The depth to water varies from 179.6 m (well no. 48) to 187.97 m (well no. 45) below ground surface. The constructed piezometric surface contour map for the Umm Alradhma aquifer is shown in Figure 3. This map reflects that the following results:-

● The piezometric levels of the concerned aquifer range between 162.37 (msl) in well no. 47 located at east of study area and 178.85 (msl) in well no. 7 located at west of study area.

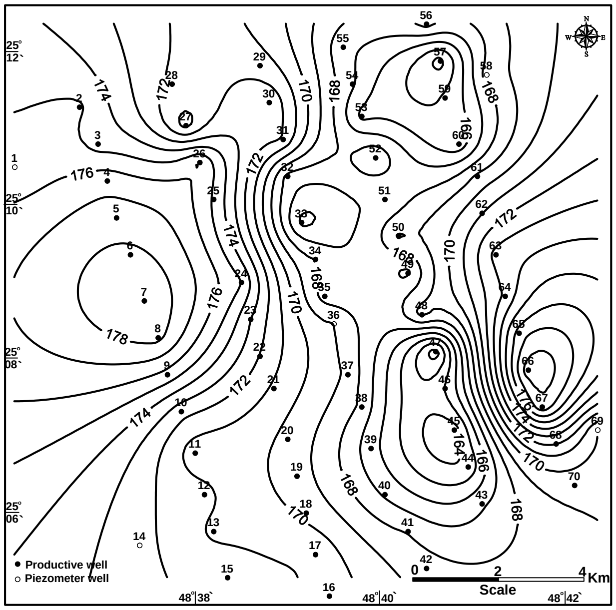

Fig. (3): Piezometric contour map of Umm Alradhma aquifer.

Table (1): Hydrogeological data of Umm Alradhma limestone aquifer

Well No.	Elevation (msl)	Total Depth (m)	Design (m)	Depth to water (m)	Water level (msl)	Salinity (ppm)
1	361.2	472	275-472	186.34	174.86	
2	359.5	467	275-467	184.34	175.16	
3	359	450	275-450	184.4	174.6	
4	359	450	277-450	182.4	176.6	
5	361.5	460	275-460	184	177.5	1285
6	363	462	275-462	184.81	178.19	1272
7	363.5	459	275-459	184.65	178.85	1308
8	363.1	471	275-471	184.8	178.3	1301
9	360.6	467	276-467	184.92	175.68	1273
10	357.7	467	276-467	185.3	172.4	1265
11	355	470	276-470	184.55	170.45	1265

12	353	467	275-467	181.68	171.32	1244
13	352.2	470	275-470	181.39	170.81	1319
15	353.6	462	275-462	182	171.6	
17	355.5	450	270-450	182.6	170.8	
18	353.4	450	270-450	182.25	169.75	
23	354.5	450	270-450	182.47	173.03	1218
24	355.5	450	272-450	181.7	175.1	
26	356.5	450	270-450	181.91	176.09	1264
27	358	450	270-450	187.23	170.57	1320
28	357.7	450	271-450	185.88	171.82	1288
30	355.2	462	277-462	182.35	172.85	1285
31	353.1	462	277-462	181.1	172	1272
32	350.6	461	274-461	182.9	167.7	1262
33	349	460	272-460	183.3	165.7	1262
34	350.1	460	272-460	182.15	167.95	1266
35	350.5	462	270-462	182.95	167.55	1250
36	350.5	461	270-461	181.61	168.89	1311
37	350.3	460	270-460	181.5	168.8	1295
38	350.1	459	271-459	182.3	167.8	1275
39	350.5	462	275-462	184.08	166.42	1254
40	351.2	460	277-460	184.34	166.86	1429
41	351.8	459	278-459	183.86	167.94	1306
43	351.5	450	275-450	184.88	166.82	1230
44	351.5	455	275-455	187.34	164.16	1195
45	351.4	455	275-455	187.96	163.44	1238
46	350.1	450	275-450	185.09	165.01	

47	349	455	275-455	186.63	162.37	1242
48	349	455	275-455	179.6	169.4	1249
49	350.1	450	275-450	183.36	166.74	1251
50	350.5	455	275-455	181.36	169.14	1231
51	350.8	455	275-455	183.82	166.98	1238
52	350.9	455	275-455	181.91	168.99	1267
53	351.7	455	275-455	185.95	165.75	1287
54	352.4	455	275-455	185.21	167.19	1308
55	353	455	275-455	185.66	167.34	1208
56	350.8	450	275-450	182.38	168.42	1269
57	350.2	450	275-450	186.63	163.57	1233
59	350	450	275-450	184.87	165.13	
60	349.8	450	275-450	184.52	165.28	1243
61	350.4	450	275-450	181.2	169.2	1267
63	353.8	450	275-450	180.5	173.3	1245
64	356.5	450	275-450	183.35	173.15	1241
65	361	450	275-450	184.58	176.42	1223
66	363	450	275-450	184.35	178.65	1266
67	362	450	275-450	184.2	177.8	1212
69	353	450	270-450	182.99	170.01	

The regional groundwater flow direction is mainly to the east, while the local groundwater flow directions are concentric to the center of the study area. This is attributed to the fact that Umm Alradhma aquifer in the study area is located within the trough of syncline fold, where the groundwater moves towards the syncline from all directions.

2- Groundwater Recharge:

Umm Alradhma aquifer is exposed on the surface in the west of the study area (Fig. 2). The investigated formation outcrop is largely overlain by the Addahna sand dunes. Umm Alradhma aquifer recharges during heavy rains by direct infiltration. Addahna sand dunes area store and collect the surface water and recharge the groundwater of Umm Alradhma aquifer. The estimated recharge of this aquifer reaches 970 mcm/year (GDC, 1979).

3- Hydrological Properties

The hydrologic properties of Umm Alradhma limestone aquifer in the study area are determined based on field and laboratory techniques. They comprise the following (Table 2):

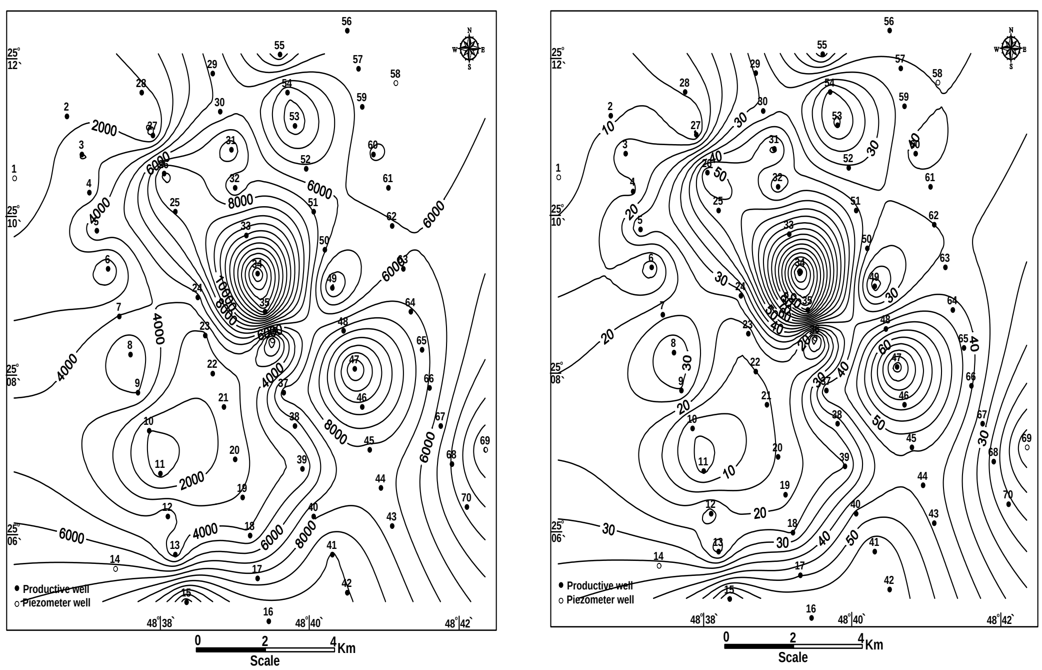

Fig. (4): Transmissivity contour map of Umm Erradhuma aquifer in Huni Wellfield.

Fig. (5): Hydraulic conductivity contour map of Umm Erradhuma aquifer in Huni Wellfield.

● The transmissivity of Umm Alradhma limestone aquifer is estimated by the analyses of the obtained data of pumping tests, which had been carried by Annakhli (2005). It is calculated from the recovery method (Theis, 1935). It varies from 600 m2/day (well no. 11) to 20172 m2/day (well no. 34). The high transmissivity is attributed to this well lies in trough of syncline fold of very high fractures. A transmissivity map is constructed for the aquifer (Fig. 4). It reveals an increment in transmissivity towards the middle of study area.

The hydraulic conductivity of the concerned aquifer ranges between 3.53 m/day (well no. 11) and 118.66 m/day (well no. 34). A distribution map of the hydraulic conductivity for Umm Alradhma aquifer is constructed (Fig. 5). It shows an increment in hydraulic conductivity towards the middle part of study area.

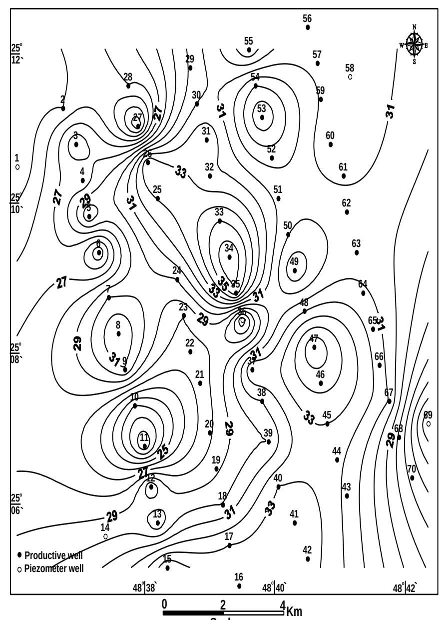

Fig. (6): Effective porosity contour map of Umm Erradhuma aquifer in Al-Huni Wellfield

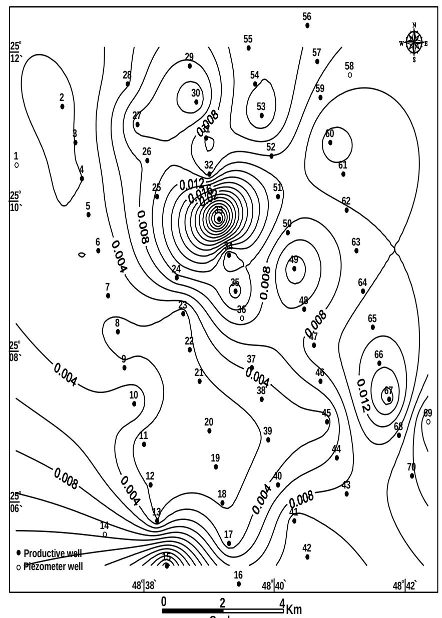

Fig. (7): Storativity contour map of Umm Erradhuma aquifer in Al-Huni Wellfield

The effective porosity of the concerned aquifer was calculated by using Marotz equation (1968), as follows:

$$\Phi eff = 0.462+0.045 \ Ln \ K$$

Where

Φeff: The effective porosity in decimal.

K: The regional hydraulic conductivity in cm/sec.

The effective porosity of the concerned aquifer ranges from 21% (well no. 11) to 37% (well no. 34) and increases due central of study area (Fig. 6).

The storativity of the studied aquifer reported by the (GDC, 1979) ranges between 6x10-2 to 8.7 x 10-5 for confined aquifer sties. The values of storativity of the concerned aquifer in study area varies between 0.0005 (well no. 11) and 0.0382 (well no. 33). Also, the storativity increases towards the middle part of study area (Fig. 7).

It is noticed that the hydraulic parameters of Umm Alradhma limestone aquifer increase due middle part of the study area. This is attributed to the increasing of fractures of Umm Alradhma limestone aquifer due the central of study area, which are located within of trough of syncline fold.

Table (2): Hydraulic parameters of Umm Alradhma aquifer

Well No.	Dtw (m)	Dynamic water level (m)	Drawdown (m)	T (m2/day)	K (m/day)	ϕ_{eff} (%)	S
1	186.34	188.23	1.89	1192	7.01	24	0.0033
2	184.34	194	10.16	1400	8.24	25	0.0012
3	184.4	189	4.6	3122	18.36	29	0.002
4	182.4	188.57	6.17	2300	13.53	27	0.0019
5	184	185.35	1.35	4953	29.14	31	0.0027
6	184.81	197.82	13.1	1071	6.3	24	0.0021

7	184.65	188.22	3.75	4016	23.59	30	0.0027
8	184.8	186.9	2.1	5978	35.22	32	0.0015
9	184.92	187.87	2.86	5138	30.23	31	0.0022
10	185.3	198.72	13.42	994	5.85	24	0.006
11	184.55	208	24.1	600	3.53	21	0.0005
12	181.68	185.07	3.39	4695	27.62	31	0.0018
13	181.39	186.33	4.94	3279	17.33	28	0.0019
15	182	182.8	0.8	14717	71.28	35	0.0275
17	182.6	184.02	1.07	8438	49.64	33	0.0026
18	182.25	184.45	2.14	4149	24.41	30	0.0018
23	182.47	187.11	4.64	2787	16.4	28	0.001
24	181.7	181.7	2.46	4581	26.95	30	0.0096
26	181.91	183.03	1.42	9330	54.88	34	0.0082
27	187.23	196.86	8.8	752	4.42	22	0.0109
28	185.88	191.51	5.63	1811	10.66	26	0.0056
30	182.35	184.65	1.26	5251	30.89	31	0.0142
31	181.1	182.9	1.8	8861	52.12	33	0.0058
32	182.9	186.2	3.25	6144	36.14	32	0.0068
33	183.3	184.37	1.07	11894	69.97	35	0.0382
34	182.15	182.78	0.63	20172	118.66	37	0.0077
35	182.95	183.52	0.57	16061	94.48	36	0.0134
36	181.61	182.54	0.93	1254	7.38	25	0.0038
37	181.5	184.2	1.7	7494	44.09	33	0.0043
38	182.3	185.15	1.85	5485	32.27	31	0.0029
39	184.08	188.67	4.59	4148	24.4	30	0.0022
40	184.34	186.03	1.69	7814	45.97	33	0.0048
41	183.86	185.21	1.35	10083	59.31	34	0.0109
45	187.96	190.78	2.81	7711	45.36	34	0.0032
47	186.63	188.04	1.41	14243	83.79	33	0.0093
49	183.36	186.28	2.82	2756	16.21	36	0.0023
53	185.95	192.25	5.81	2314	13.62	28	0.0019
54	185.21	189.44	4.23	3164	18.61	27	0.0043
55	185.66	187.42	1.41	9981	58.71	29	0.004
60	184.52	186.25	1.73	7153	42.08	34	0.0131
67	184.2	186	1.8	5509	32.41	32	0.0174
69	182.99	184.4	1.41	896	5.27	31	0.002

Abbreviation: Dtw: Depth to water **T:** transmissivity **K:** hydraulic conductivity

ϕ_{eff}**:** effective porosity **S:** Storativity

Similar results were recently obtained by Rosas et al. (2013) who determined hydraulic conductivity, porosity and grain-size distribution for different depositional environments in Saudi Arabia.

Hydrochemistry

The aim of this part is to study of the groundwater chemistry and determination of the chemical types and their relation to the prevailing geological and hydrogeological conditions. This study depends on the chemical analyses of 52 groundwater samples representing Umm Alradhma aquifer in Alhuni wellfield (Table 2). They will be discussed herein through the following:

• Groundwater salinity

The groundwater salinity of the studied aquifer reveals a great variation reflecting the effect of the facies changes and the structural effect and the hydrochemical processes. The groundwater salinity of this aquifer varies from 1195 ppm (well no. 44) to 1429 ppm (well no. 40). The constructed groundwater salinity for this aquifer reveals an increase of salinity due the center of the study area with flow direction (Fig. 8). This is related to the center of the study area represents syncline fold (This, which is related to the center of the study area, represents syncline fold) and the groundwater flows from all directions towards the syncline and increases the groundwater salinity with flow.

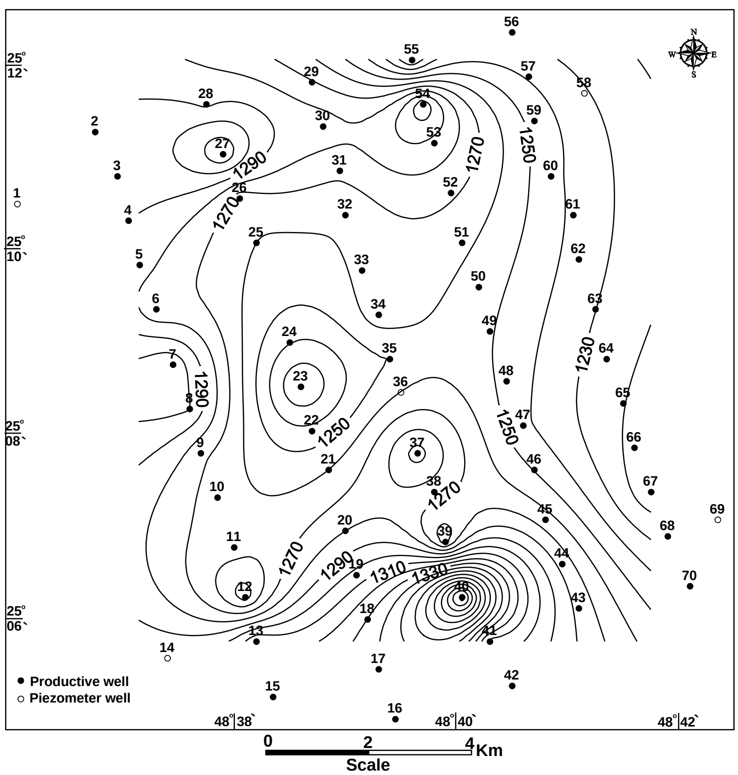

Figure 8. Groundwater salinity map of Umm Alradhma aquifer

• Hypothetical salts:

In Umm Alradhma limestone aquifer, two assemblages of hypothetical salt combinations are recognized in the groundwater of the concerned aquifer (Table 3):

Group 1; NaCl, $MgCl_2$, $CaSO_4$, $MgSO_4$ and Ca $(HCO_3)_2$. Such assemblage is recorded in the majority of groundwater samples of the studied aquifer. This assemblage reflects the main influence of marine beds (limestone, dolomitic limestone and dolomite of Umm Alradhma deposits) on the groundwater through the predominance of the marine salt (MgCl2), and absence of the terrestrial salts.

Group 2; NaCl, Na2SO4, CaSO4, MgSO4 and $Ca(HCO_3)_2$. This assemblage represents the groundwater samples 7,27,37,38,40,41,42,48 and 68. The presence of Na2SO4 in the groundwater reveals the dominance of meteoric origin.

Table (3): Chemical data of Umm Alradhma aquifer

Well	EC	pH	TDS	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{--}	Cl^{-}
1	2200	7	1320	158	56	225	12.1	182	350	428
5	2100	7.4	1285	145	52	225	11.3	170	385	382
6	2100	7.4	1272	144	53	230	11.3	165	380	371
7	2120	7.5	1308	138	43	255	11.7	170	390	385
8	2170	nd	1301	145	51	235	11.8	181	380	388
9	2140	7.3	1273	110	53	258	12.9	178	330	420
11	2130	7.05	1265	140	55	220	10.5	201	325	411
12	2130	7.75	1244	145	85	165	10.1	203	340	397
13	2130	8.32	1319	144	53	230	10.6	92	450	385
23	2120	6.9	1218	135	50	220	12.4	196	325	378
26	2140	7.2	1264	149	52	220	18.3	256	310	387
27	2180	7.68	1320	131	51	250	12	132	430	380
28	2120	7.25	1288	141	53	235	10.8	163	390	377

29	2130	7.25	1284	147	55	220	11.8	190	360	395
30	2100	7.43	1285	145	52	225	12	172	375	390
31	2100	7.4	1272	146	55	210	13.6	185	370	385
32	2100	7.4	1262	146	55	210	13.6	185	360	385
33	2120	7.41	1262	146	52	215	12.5	188	370	373
34	2130	7.38	1266	143	54	220	13	188	355	387
35	2080	7.45	1250	144	50	220	11.9	193	355	373
36	2140	7.35	1311	151	54	220	12.5	164	430	362
37	2140	7.35	1295	141	48	240	12.1	189	390	369
38	2120	7.46	1275	134	48	240	11.2	193	390	355
39	2100	7.52	1254	139	51	230	10.8	179	355	379
40	2300	7.62	1429	142	50	280	12.1	166	500	362
41	2150	7.55	1306	144	51	230	9.7	171	420	366
42	2200	7.5	1346	138	51	255	11.5	174	430	374
43	2050	7.45	1230	142	50	215	12.6	168	330	396
44	1990	7.35	1195	155	52	185	14.3	160	310	399
45	2080	7.38	1238	143	53	210	11.6	164	350	388
47	2060	7.43	1242	148	51	210	12.9	171	340	391
48	2090	7.1	1242	74	54	290	11.1	170	340	395

49	2080	7.25	1251	149	55	210	11.7	148	350	401
50	2050	7.29	1231	148	55	200	11.2	165	340	394
51	2060	7.44	1238	145	55	200	11.04	156	365	384
52	2100	7.4	1267	142	57	210	14.3	161	370	393
53	2130	7.39	1287	143	52	230	12	185	390	368
54	2170	7.47	1308	147	56	225	20	183	370	399
55	2030	7.27	1208	147	54	200	11.4	174	310	399
56	2120	6.98	1269	143	53	225	10.9	156	360	399
57	2060	7.19	1233	129	55	220	11.02	157	350	390
58	2120	7.45	1272	139	52	230	11.3	173	340	413
60	2090	7.1	1243	140	53	220	10	169	350	386
61	2110	7.53	1267	142	54	225	11.1	201	350	384
62	2100	7.33	1263	142	50	225	12.2	151	370	388
63	2050	7.2	1245	140	46	225	11.2	159	350	393
64	2060	7.22	1241	142	43	230	11.3	164	340	393
65	2050	7.45	1223	143	53	210	11	159	310	417
66	2110	7.24	1266	148	54	220	7.69	160	350	406
67	2050	7.46	1212	147	52	200	11.8	174	300	414
68	2170	7.45	1325	132	41	265	18.2	171	390	393
70	2180	7.19	1279	142	42	255	17.9	165	340	400

nd: not detected

It is clear that the groundwater origin of Umm Alradhma limestone aquifer is meteoric, but the presence of marine salts in the groundwater is attributed to the effective leaching and dissolution processes through the flow path within the aquifer materials (limestone, dolomitic limestone and dolomite). Our results are also supported by Ghrefat et al. (2013) who determined the chemical characteristics of 72 groundwater samples collected from Midyan Basin in Riyadh area at Saudi Arabia.

Hydrochemical Coefficients:

Ion ratios are very important in determining the groundwater origin and the various hydrochemical processes contributing in water quality development. Generally, the results of the chosen ion ratios reflect meteoric water origin affected by the leaching and dissolution through the path of groundwater flow in Umm Alradhma limestone aquifer (Table 3).

Na+/Cl- ratio is less than one in the majority of groundwater samples and comprise MgCl2 salt reflecting that the chloride is higher than sodium. This mainly occurs through the addition of chloride salts of marine origin to water through leaching processes. On the other hand, Na+/Cl- ratio in groundwater samples number 7, 27, 37, 38, 40, 41, 42, 48 and 68 is more than one. They comprise Na2SO4 salt type reflecting that the sodium is higher than chloride. This mainly occurs through the addition of sodium salts of terrestrial origin to water.

High Ca2+/ Mg2+ ratio indicates dissolution of gypsum .

Sulfate/chloride ration (SO42-/Cl-) may be taken as a guide for detecting an excess of sulfate in groundwater associated with sulfate minerals dissolution or sewage contamination. Sulfate/chloride ration has a values less than one indicates that groundwater samples contains high Cl-ions. These results agree with recent report (El Alfy 2013) who modeled hydrochemical and assessment of groundwater contamination in northwest Sinai, Egypt.

• Water types

Durov's diagram (1948) was used to classify water types in Umm Alradhma limestone aquifer. Accordingly, groundwater in this aquifer is classified into 4 water types, which sodium chloride and calcium sulfate are the most dominant facies. The areal extent and distribution of these facies are shown on Fig. 9. The distribution of water types is explained as follows:

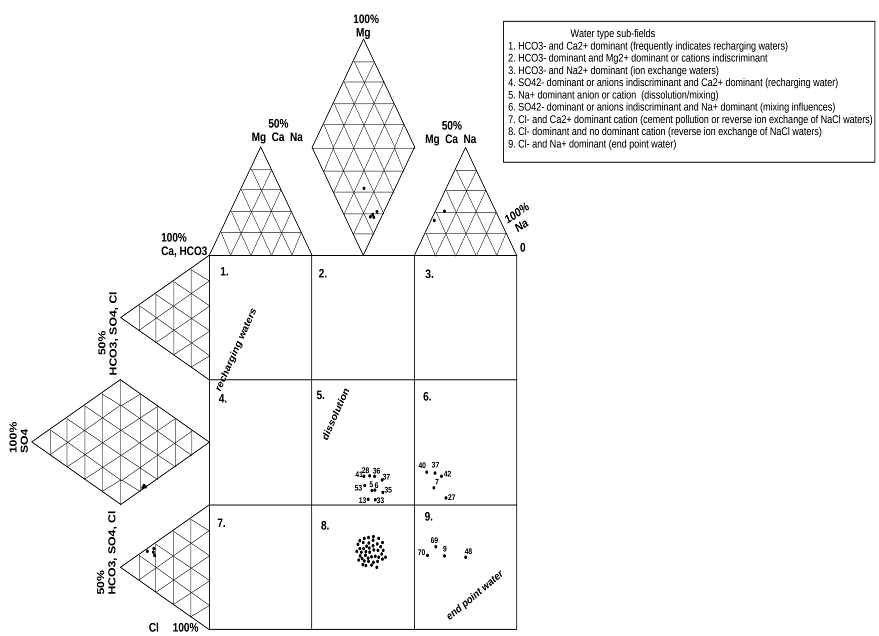

Fig. (9) : Expanded Durov diagram of groundwater samples

Table (4): Hydrochemical characteristics of groundwater,UMM ALRADHMA aquifer.

Well no.	Ion ratios			Hypothetical salts					
	Na/Cl	Ca/Mg	SO_4/Cl	NaCl	$MgCl_2$	Na_2SO_4	$MgSO_4$	$CaSO_4$	Ca $(HCO_3)_2$
1	0.83	1.71	0.6	44.71	9.32	_	11.06	21.57	13.34
5	0.93	1.69	0.74	46.67	3.26	_	16.57	20.56	12.94
6	0.98	1.95	0.75	47.14	2.51	_	17.46	20.08	12.81
7	1.05	1.95	0.75	49.88	_	2.32	16.22	18.76	12.82
8	0.96	1.72	0.72	47.95	2.19	_	16.91	19.34	13.61
9	0.97	1.26	0.58	53.98	0.76	_	19.61	12.15	13.5
11	0.85	1.55	0.58	46.07	7.48	_	13.72	17.55	15.2
12	0.66	1.03	0.63	34.32	17.48	_	14.81	17.97	15.42
13	0.95	1.65	0.86	47.09	2.86		17.13	25.97	6.95
23	0.93	1.64	0.63	47.66	3.99	_	15.84	16.96	15.55
26	0.92	1.73	0.59	46.19	4.44	_	15.23	14.7	19.44
27	1.05	1.56	0.83	49.11	_	1.92	19.12	19.96	9.89
28	0.99	1.61	0.76	47.54	2.09	_	17.65	19.66	12.46
29	0.88	1.62	0.67	45.42	5.82	_	15	19.45	14.31
30	0.92	1.69	0.71	46.72	4.13	_	15.68	20.43	13.04
31	0.87	1.61	0.71	44.55	5.76	_	15.48	20.18	14.03

32	0.87	1.61	0.69	44.55	6.25	_	14.99	20.04	14.17
33	0.92	1.7	0.73	45.55	3.84	_	16.32	19.83	14.46
34	0.91	1.6	0.68	46.09	4.94	_	15.75	18.81	14.41
35	0.94	1.75	0.7	46.62	3.31	_	16.12	18.95	15
36	0.97	1.69	0.87	45.22	1.51	_	18.81	22.15	12.31
37	1.03	1.78	0.78	48.1	_	1.34	18.19	18.03	14.34
38	1.07	1.69	0.81	47.02	_	3.17	18.49	16.48	14.84
39	0.96	1.65	0.69	48.02	2.87	_	16.7	18.47	13.94
40	1.22	1.72	1.02	43.74	_	8.99	17.36	18.26	11.65
41	0.99	1.71	0.85	47.21	_	0.2	19.38	20.4	12.81
42	1.07	1.64	0.85	47.21	_	3.46	18.65	17.93	12.75
43	0.86	1.72	0.61	46.35	7.38	_	12.4	20.84	13.23
44	0.74	1.81	0.57	41.04	14.32	_	6.69	25.06	12.89
45	0.86	1.63	0.66	44.97	7.32	_	13.56	21.29	12.86
47	0.85	1.76	0.64	44.88	7.87	_	12.09	21.77	13.39
48	1.15	0.83	0.63	53.02		8.25	21.15	4.3	13.28
49	0.83	1.64	0.64	44	9.81	_	11.37	21.31	11.51
50	0.8	1.63	0.64	42.93	10.26	_	11.42	22.47	12.92
51	0.83	1.6	0.7	43.32	8.27		13.53	22.68	12.2

52	0.86	1.51	0.7	44.64	7.09	_	14.97	20.98	12.32
53	0.99	1.66	0.78	47.47	0.75	_	18.95	18.76	14.07
54	0.91	1.59	0.68	46.3	4.95	_	15.75	19.33	13.67
55	0.8	1.65	0.57	43.5	11.24	_	10.15	21.44	13.87
56	0.89	1.63	0.66	46.58	6.24	_	14.03	21.13	12.02
57	0.89	1.42	0.66	47.24	5.49	_	16.27	18.68	12.32
58	0.88	1.62	0.61	47.86	6.17	_	13.69	19.15	13.13
60	0.9	1.6	0.67	46.29	5.67	_	14.96	19.85	13.23
61	0.93	1.59	0.67	46.55	4.03		16.57	17.48	15.37
62	0.92	1.72	0.7	47.32	4.51		14.84	21.63	11.7
63	0.9	1.85	0.66	48.22	4.59	_	13.58	21.17	12.44
64	0.92	2	0.64	49.12	4.02		12.94	21.02	12.09
65	0.8	1.63	0.55	44.95	11.53	_	9.36	21.62	12.54
66	0.85	1.66	0.64	45.23	8.38		12.19	21.94	12.26
67	0.77	1.72	0.53	43.69	12.5		8.23	21.86	13.72
68	1.08	1.95	0.73	50.36	_	4.24	15.36	17.31	12.73
70	1.02	2.05	0.62	52.32	1.24	_	14.38	19.24	12.82

- Type 8: the majority of groundwater samples lies in the concerned type. It is dominated by Cl- and sodium with Ca2+ becoming increasingly important. It is believed to be old recharge water that recharged during periods of high precipitation. The near absence water that recharge recently is the reason for not flushing the water through the system.
- Type 5: groundwater samples nos. 5,6,13,28,33,35,36,41 and 53 represent this type. It has no dominant anion or cation. It indicates that groundwater exhibits simple dissolution.

- Type 6: this type is found in groundwater samples nos. 7,27,37,40 and 42. This type has sulfate and sodium ions as dominant. It may have been derived by precipitation of calcium carbonate or dolomite or by Ca2+ exchange as the formation becomes dominated by argillaceous limestone.
- Type 9: the groundwater samples 9,48,69 and 70 represent type 9. It is dominated by Na+ and Cl- and represents the end point water.

Groundwater Quality

Umm Alradhma aquifer is considered the most promising aquifer for water supply. This is attributed to the fact that this aquifer provides Riyadh City about 300000 m3/day from Alhuni Wellfield. An attempt is carried out to evaluate the groundwater for different purposes and this evaluation reveals the following:

1- Drinking and domestic purposes*:*

Depending on the standards for drinking (WHO, 1972 and 1996), the groundwater of Umm Alradhma aquifer is acceptable.

2- Livestock and poultry:

According to the standards of livestock and poultry (NASNAE, 1972), the groundwater of the concerned aquifer is satisfactory.

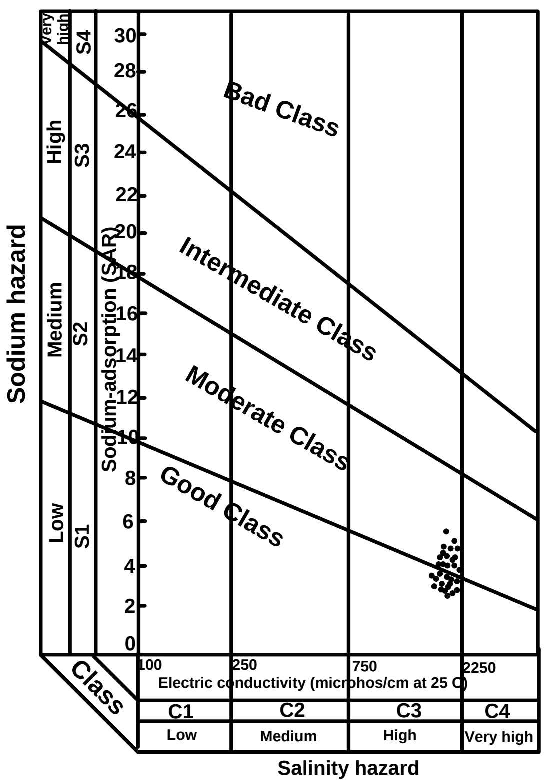

Fig. (10): Classification of groundwater for irrigation using U.S. Salinity Lab. Staff (1954).

3- Irrigation:

The suitability of the investigated groundwater for agricultural purposes was evaluated according to the U.S. Salinity Laboratory Staff (1954). All the samples of the Umm Alradhma aquifer occupy the good class (C3-S1) and moderate class (C3-S2) shown in Figure 10. The groundwater of the first class can be used for the irrigation of most plants and suits all soil texture, while the groundwater of the other class should be used only in coarse textured soils for salt tolerant plants.

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