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GROUNDWATER POTENTIAL IN THE CENTRAL PART OF AL JABAL AL AKHDAR AREA, NE LIBYA

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Abstract: Al Jabal Al Akhdar located in the North-Eastern part of Libya represents a region with promising ecological underpinning for grazing and other agricultural developments. In its central part, groundwater in the karstified Eocene and Upper Cretaceous limestone aquifer is the main source of water for drinking, agriculture, and grazing. The groundwater potential was studied based on the available literature and inquiries to water institutions in Libya, with responsibility to identify and classify the main water resources and preview their status to highlight the major issues regarding water resources management and their sustainability. Furthermore, a complete database for about 112 water wells drilled in the period 2003 - 2009 was used for the evaluation of the two aquifers. In this research, the hydrogeological and the Geographic Information System (GIS) were used to investigate the spatial characteristics of the groundwater system. The results indicate that the depth to water for the Upper Cretaceous aquifer ranges from 150 to 458 m, and the piezometric surface decreases from over 500 m (m.s.l) in the northern parts of the study area to -20 m (m.s.l) in southeastern part. Salinity ranges between 303 and 1329 mg/l indicating that groundwater belongs to the fresh - slightly fresh water class.

In the Eocene aquifer, the depth to groundwater ranges from 120 to 290.5 m and the potentiometric level decreases gradually southwards from 220 m (m.s.l) to -51 m (m.s.l) and characterized by steep slope in the southeastern part of the study area, where the aquifer characterized by relatively high productivity (specific capacity ranges between 10.08 and 332.3 m^2/day). The groundwater salinity within this aquifer ranges between 198 and 2800 mg/l (fresh to brackish water class). The annual average rainfall (from 280 to 500 mm) plays a significant role in the recharge of the two aquifers. The priority of groundwater quality and potentiality increases towards the central and northern portions of the concerned area.

Keywords: Eocene and Upper Cretaceous aquifers; Rainfall; potentiality; Geographic Information System (GIS); Recharge.

1. INTRODUCTION

Libyan economy depends primarily upon revenues from the oil sector. Agriculture contributes about 9 percent of GDP and employs 5 percent of the active part of the population; hence about 2 million ha of rangeland are rain-fed, mainly along the coast where annual rainfall is around 50 and 300 mm (FAO, 2009). More intensive irrigated farming has developed rapidly since the 1960s. The FAO AQUASTAT database reports that, in 2000, about 470,000 ha were equipped for irrigation using both fossil and shallow groundwater. Some of this area may now have been abandoned because of water shortages and poor quality water in the coastal aquifers; around 316, 000 ha was actually irrigated. Total agricultural consumption was 3,580 MCM/yr. Shallow groundwater and fossil water transferred from the south is used for irrigation along the coast where the most of the population lives. Total abstraction along the coast is around 1,500 MCM where natural recharge is only about 700 MCM. Following the discovery of fresh, fossil groundwater in the deserts of southern Libya, the local authority implemented “The Great Manmade River Project” to sustain its economy (Wheida & Verhoeven, 2005). The inspiration and credit of “The Great Manmade River Project” goes to the Libyan Revolution in 1969 that changed the planning and development policies of the country by creating certain notions of self-reliance, and self-sufficiency in food. Around 3,000 MCM of fossil groundwater is transported to the coast. However, overall, water consumption is still below the World Bank water poverty limit of 1,000 CM/capita/yr (FAO, 2009).

The Al Jabal Al Akhdar area is not supplied from the Great Manmade River Project, as there is some water resource available. Earlier researchers into the resources include FAO (1969) and Bukechiem (1987). In the first five year plan (1976-1980), 40 % of the total funds allocated for agricultural development in the eastern region of the country was directed to the Al Jabal Al Akhdar Authority (JAA), which replaced the pre 1969 National Agricultural Settlement (NAS) scheme. Since the early 1970s, the JAA focused on developing new lands and introducing nomadic people to sedentary agricultural systems by including the effects of tribal ownership.

The Al Jabal Al Akhdar projects included infrastructure development and implement of new farming systems in the region. The development of both underground and surface water resource was enhanced to meet the demands of increased irrigation (Benkhial & Bukechiem, 1980). The Al Jabal Al Akhdar project for irrigated farms was established in 1978 following two phases of water resource development. Between 1977 and 1981, Al Jabal Al Akhdar project drilled production water wells in six fields in two areas. After drilling and completion of the wells, the project was put on hold due to the political situation in Libya. In 2004, the work on the irrigation networks and farms was resumed. In the period 2001-2007, a number of production water wells were drilled for grazing, irrigation in different areas and for other purposes (Hamad, 2008).

The hydrogeological information from the new water wells in the central part of Al Jabal Al Akhdar has not previously been integrated with earlier studies to achieve a comprehensive knowledge and understanding of the groundwater resources. This is necessary for better strategic water management in these huge projects which underlie the quest for self-sufficiency and national economic prosperity. This research covers some principal parts of the groundwater resources; namely groundwater levels and water quality. The hydrogeological methods will be integrated with the Geographic Information System (GIS) that played a main role in understanding of the spatial characteristics of the groundwater system. The most useful tools among GIS in the field of groundwater resource investigations are the quantitative and qualitative methods of spatial analysis (Hiwot et al., 2004; Foglini, 2004). The power of these tools and applications are enhanced when they are combined with statistical methods for analysis.

2. DESCRIPTION OF THE STUDY AREA

The study area is about 22,000 km^2 comprises the central part of Al Jabal Al Akhdar area in NE Libya (Fig. 1). It lies between Latitudes 32º and 33º N and Longitudes 21º and 23º E and is bounded to the north by the Mediterranean sea. It includes many famous Libyan cities and villages and is regarded by the government as a key area for sustainable development based on the groundwater resources of the underlying Eocene and Upper Cretaceous limestone aquifers.

3. CLIMATE AND WATER BALENCE

The climate of the concerned area is arid and semi-arid with temperatures ranging between 13 ºC in January and 25 ºC in August and relatively high humidity (between 73.3 % in winter and 61.6 % in summer) due to the proximity of the sea. Data for three rainfall stations in the eastern half of the study area (at Shahat, Dernah near the coast and Jaghboub beyond the area to the SE) have been analyzed in this study. The time series data (Fig. 2) show that there is significantly less rainfall inland at Jaghboub than at the coastal stations; the mean annual values increase from only 15 mm at Jaghboub to 280 mm at Dernah and 550 mm at Shahat. There is insufficient data to define the distribution of rainfall within the eastern half of the study area, let alone in the western half where there are no stations with reliable, long term data. Water balance for the study area which made by the Libyan General Water Authority in year 2005, are summarized in Table 1. Groundwater recharge is 15 % of rainfall. Current groundwater abstraction is less than 0.01 % of this, indicating that the majority of the recharge goes into aquifer storage and / or emerges as spring flow.

4. TOPOOGRAPHY AND DRAINAGE

The topography of the Al Jabal Al Akhdar region comprises a series of mountain ranges trending approximately parallel to the Mediterranean coast (Fig. 1). The northern range is an escarpment that forms a persistent linear feature across the region at elevations of between 250 and 300 m asl. The second range is also an escarpment; elevation values are ranging between 450 and 600 m asl and the escarpment trends NE-SW in the west, curving round to east - west in the east.

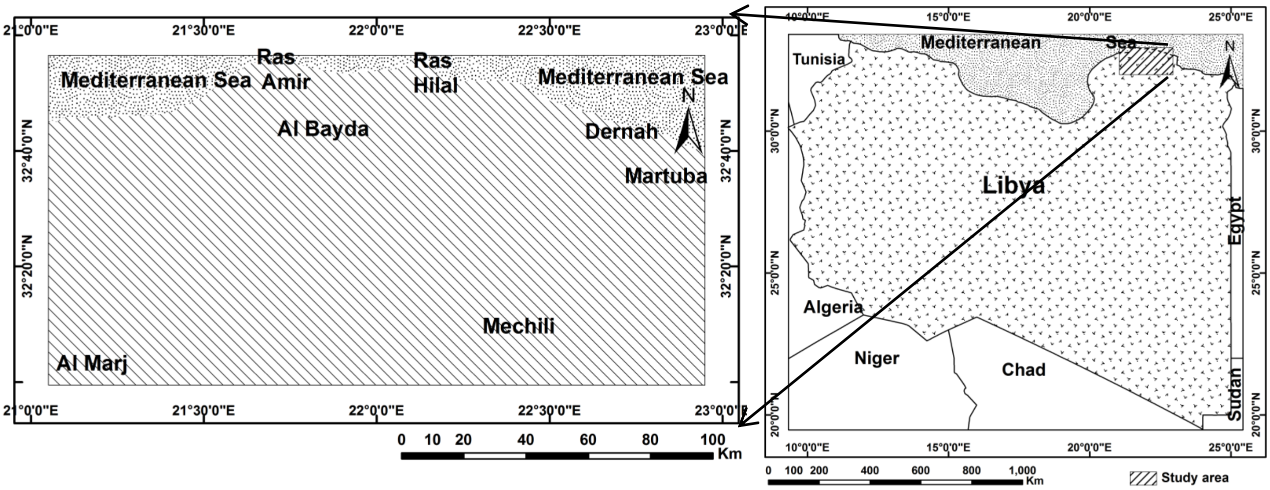

Figure 1. Location map of the central part of Al Jabal Al Akhdar area.

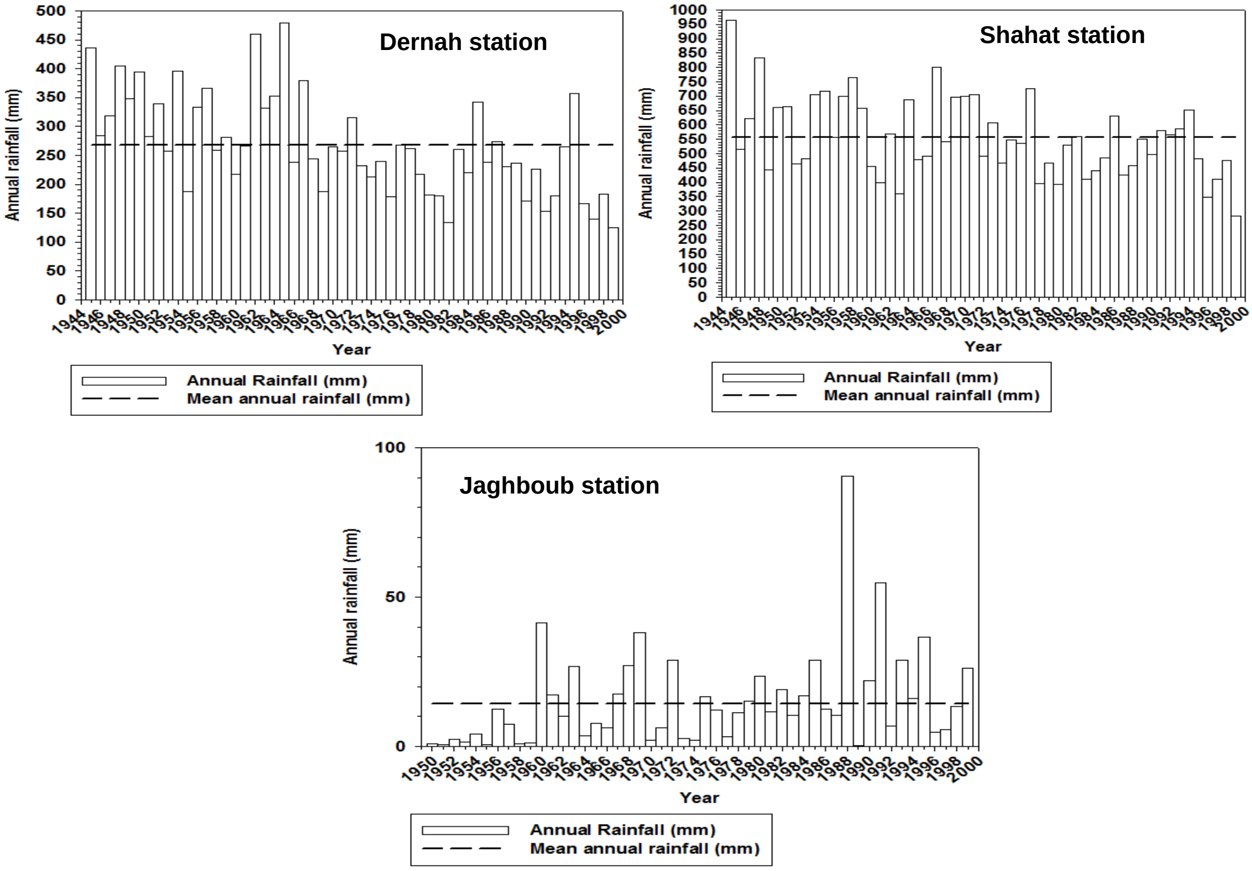

Figure 2. Time series of annual rainfall for the three stations in the study area.

Table 1. Water balance of the study area (based on GWA, 2005).

Precipitation (Mm³/yr)	1,500
Evapotranspiration (Mm³/yr)	1,125
Rain fall surplus (Mm³/yr)	375
Surface runoff (Mm³/r)	150
Recharge to groundwater (Mm³/yr)	225
Groundwater extraction (Mm³/yr)	2
Water Balance (Mm³/yr)	223

1

The southern range is the highest, at about 880 m asl in height. It forms a NE-SW trending undulating dome (Abd El-Wahed & Kamh, 2013).

Networks of ephemeral streams drain northwards to the Mediterranean sea from the northern escarpment and southwards into the desert from the southern escarpment charcterises the area. The latter being considerably longer than the former. These temporary surface water sources provide an additional renewable resource (El Osta & Masoud, 2015).

5. GEOLOGICAL SETTING

Structurally, Al Jabal Al Akhdar was formed through three major compressional events that occurred in the period between the late Cretaceous and early late Eocene. These events created folds and strike slip faults (Abd El-Wahed & Kamh, 2013 and Hamad, 1999). Al Jabal Al Akdar is an anticlinorium that plunges gently to the NE and SW and whose principal axis trends approximately N 50º E (Guiraud and Bosworth,1997. The main structural elements in the study area are: east – west to NE – SW trending en echelon folds, ENE – WSW trending strike slip faults, and subordinate, shorter orthogonal faults. The mountain ranges described above are associated with the ENE – WSW trending faults (Abd El-Wahed & Kamh, 2013). Lithologically, the strata that crop out in the study area consist mainly of marine carbonate rocks ranging in age from the Upper Cretaceous to Quaternary. The geology of the study area is shown in figure 3 (the eastern and southern margins are not shown on the figure) and the stratigraphic succession is detailed in figure 4. Limestones and dolomitic limestones belonging to the Al Baniyah, Al Majahir and Wadi Dukham Formations are of Upper Cretaceous age and crop out in the southern mountain range as the fault bounded Qsr Al Majahir fold belt (Fig. 3). The Paleocene is represented only by the chalky Al Uwayliah Formation in a small area in the centre. The overlying Apollonia and Dernah Formations are of Eocene age and comprise hard siliceous and chalky limestones and nummulitic and reefal limestones (Abd El-Wahed & Kamh, 2013). The former crops out near the coast, for example in the hills south of Susah. The latter is more widespread, outcropping across the north and at the Qsr Al Majahir fold belt where it rests directly on the Al Baniyah Formation due to faulting (Fig. 3). The Al Bayda Formation comprises beds of shelly limestone with marl underlying thick bedded reefal and skeletal limestone full of calcareous algae. The Al Abraq Formation consists of microcrystalline limestone, grading up to calcarenite limestone with intercalations of marls and marly limestone. Both these formations are of Oligocene age. They are present as a wide band across the study area from east to west with the younger formation cropping out on higher ground. Alternating layers of marl and limestone of Eocene age crop out across the eastern part of the study area. The strata consist of a transgressive carbonate sequence which progressively overlies the El Abraq and Dernah Formations. Thin, variable sediments of Quaternary age occur locally across the area, they include aeolian, littoral marine, lagoonal (sabkha) and alluvial deposits.

6. HYDROGEOLOGICAL SETTING

In general, the aquifer system in the study area comprises a sequence of carbonate rocks in which groundwater flows through a variable network of fractures, fissures and enlarged pores, alternating with less permeable layers of marl rich beds. Thus, the productivity of the principal aquifers depends upon the amount, size and connectivity of the openings within the carbonate rocks. Additionally, the more arenaceous Quaternary deposits form small aquifers with limited thickness and lateral extent. The direct infiltration of rainfall and to the infiltration of runoff water along wadi beds form the main sourceof the aquifer's recharge. The natural outlets of the aquifers are either springs, or in the case of the northern flank, directly into the sea. The hydrogeology of the study area is discussed in more detail below.

7. PRESENT STUDY: DATA, METHODS AND ANALYSIS

Different types of data have been collected for this present study:

1. Previous hydrological studies obtained from the document center of the General Water Authority Libya.
2. Reports of wells drilled between 2003 and 2009 obtained from the GWA, including the following hydro-geological data: water well coordinates, static and dynamic water levels, well yield, lithological logs and TDS values.
3. Remote-sensing data for generating a base map which includes: Landsat 7 ETM+ data with 30 m spatial resolution, SRTM data with 90 m spatial resolution and geological and topographical maps with the working scale of 1: 250,000.

Field investigations included the definition of lithological units, an inventory of existing water wells, and the measurement of groundwater depths in 112 wells, their specific capacities and TDS.

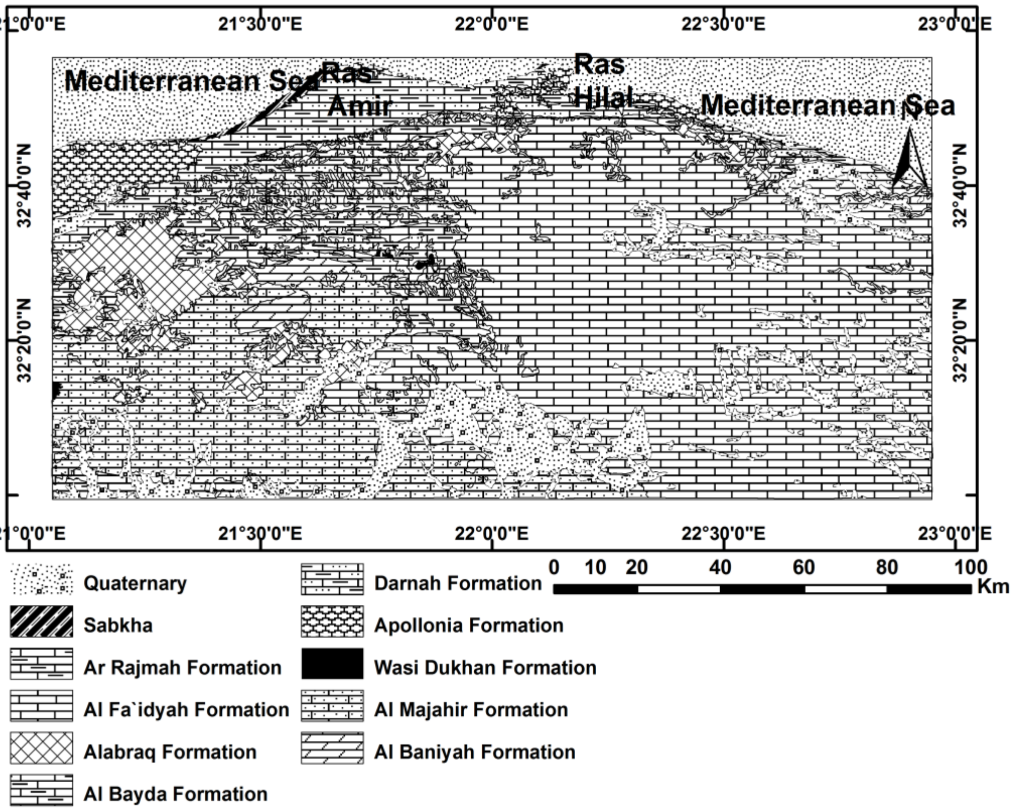

Figure 3.
Geological map of the central part of Al Jabal Al Akhdar area (after El Osta & Masoud, 2015).

Age		Formation	Lithology	Thickness (m)
Quaternary		fine to medium grained silt, sand, limestone etc: aeolian, littorial marine, lagoonal (sabkha), alluvium		
Miocene	Upper	Ar Rajmah	limestone	
	Middle			
	Lower	Al Faydiyah	alternating layers of marl and limestone	
Oligocene	Upper	Al Abraq	microcrystalline limestone, grading up to calcarenite with intercalations of marl and marly limestone, some dolomite and dolomitic limestone	
	Middle			
	Lower	Al Bayda	Algal Limestone member: thick bedded reefal and skeletal limestone full of *Archaeolithothanmion* algae	20 at Al Bayda
			Shahhat member: yellowish marl and chalky limestone with pelecypod shells	20 at Al Bayda
Eocene	Priabonian	Dernah	nummulitic and reefal limestone	100 at Dernah
	Lutetian	Apollonia	hard, siliceous and chalky limestone with chert nodules and fauna of nummulites and echinoids	75 at Susah hills
	Ypresian			
Paleocene		Al Uwayliah	chalky limestone	thin
Upper Cretaceous	Maastrichtian	Wadi Dukan	hard grey brown dolomite, often porous with dolomitic limestone intercalations in upper part	50 - 150
	Campanian	Al Majahir	marly limestone, microcrystalline limestone and dolomitic limestone with calcareous clay and marl layers	80 - 200
	Santonian	Al Baniyah	fractured, well bedded limestone and dolomitic limestone with intercalations of marl and marly limestone becoming frequent in upper part	>500
	Coniacian			
	Turonian			
	Cenomanian			

Figure 4. Stratigraphic columnar section in the study area.

The location of the water wells is shown in figure 5 and the measurements are presented in table 2. It is noted that specific capacity values have been calculated directly from field data for those wells in the Eocene aquifer. Specific capacity is a relatively simple parameter that indicates the productivity of a well (Jacob, 1950). It is defined as the ratio of the pumping rate to the resulting drawdown in water level. For steady-state conditions, specific capacity is a function of well radius, degree of aquifer penetration, well loss and transmissivity. For transient conditions, it is also a function of the duration of pumping and storativity (El Osta, 2012). For this study, the duration of pumping was often uncertain. Data from the water wells was entered into a GIS (ArcGIS 10.1) database. The primary objective of assessing the groundwater potential in the study area was achieved through the following methods:

- Integrating the hydrogeological information gathered from the newly drilled water wells (2009) with old data (2003) in the GIS database. This information includes specific capacity data calculated for 56 wells.
- Analyzing the pattern and the spatial distribution of groundwater levels using statistics and the GIS to determine depth to piezometric surface, piezometric levels and groundwater flow directions.
- Use of the GIS database to determine the spatial distribution of TDS values to evaluate groundwater quality.

8. RESULTS AND DISCUSSION

In the study area, the Eocene and Upper Cretaceous aquifers as sources for groundwater in term of quality and quantity were described as follows:

8.1. Upper cretaceous aquifer

The Upper Cretaceous aquifer mainly comprises the Al Baniyah Formation with thickness between 50 to 250 m as found in wells in the central and western parts of the study area (Fig. 4). The Al Baniyah Formation outcrops in the Qsr Al Majahir area in the central part of the concerned area due to the wrench pattern present (Fig. 3).

Springs associated with faults and folds form natural outlets of the aquifer and allow use of this groundwater in downstream areas. This aquifer is overlain by Paleocene chalky limestone strata, especially in the central and southern parts of the study area (Fig. 6).

The depth to the piezometric surface measured in 8 wells ranges from 150 m (well No. 107) to 458 m (well No. 109) with the maximum in the east (Fig. 7). The data shows that the Upper Cretaceous aquifer exists under fully confined conditions. The piezometric surface contour map (Fig. 8) shows relatively high elevations in the central and northern parts of the study area with decreasing to the south, while reaching -20 m (m.s.l) in the southeastern part.

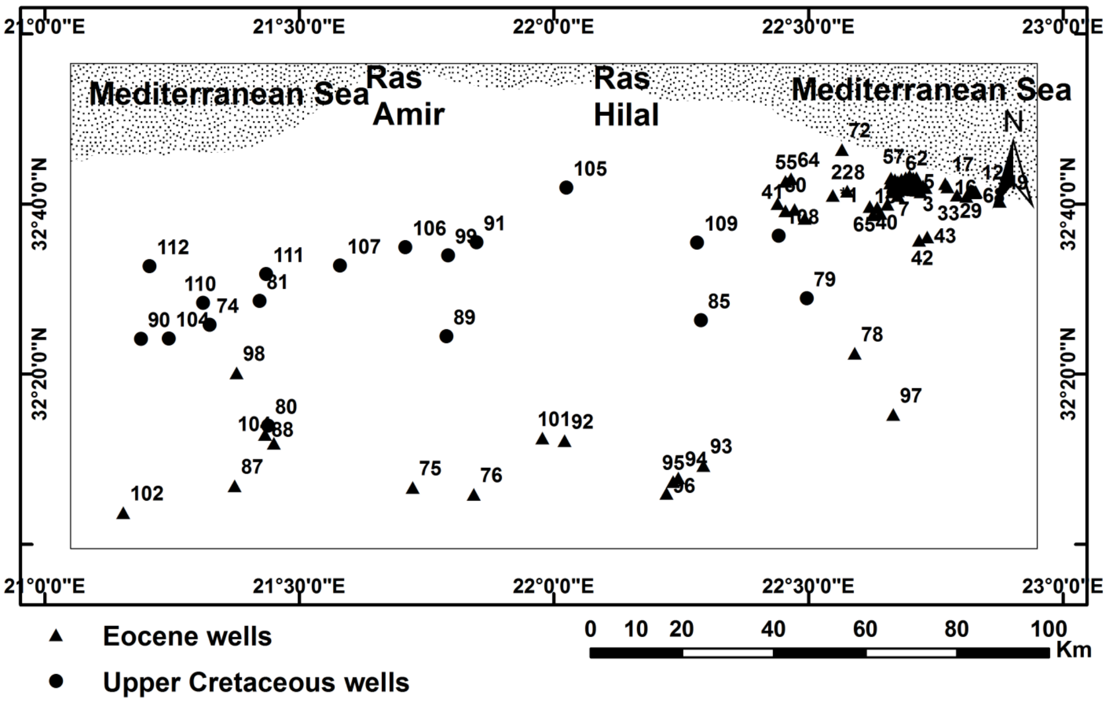

Figure 5. Wells distribution map in the central part of Al Jabal Al Akhdar area.

Table 2. Hydrogeological data in the central part of Al Jabal Al Akhdar area(Data source: Libyan General Water Authority eastern zone branch).

Well No.	Aquifer type	Total Depth (m)	Depth to water (m)	Piezometric surface (m) (m.s.l.)	Discharge Q (m^3/day)	Draw-down (m)	Specific capacity Sc (m^2/day)	TDS mg/l
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	Eocene Aquifer	360	176	141	604.8	4.5	134.4	600
2		275	168	83	129.6	10.2	12.7	1600
3		261	172	77	345.6	15	23.04	900
4		279	171	43	432	6.4	67.5	1900
5		300	172	79	-	-	-	900
6		255	169	77	259.2	10	25.92	199
7		255	148.5	111.5	302.4	20	15.12	198
8		283	179.5	117.5	432	30	14.4	640
9		258	166	90	432	23.6	18.3	900
10		250	164	95	302.4	30	10.08	1000
11		265	171	80	432	34.3	12,59	1500
12		270	168	37	475.2	16	29.7	1300
13		330	185	64	-	-	-	2800
14		262	179.5	65.5	345.6	30	11.52	1200
15		312.5	185	69	-	-	-	1230
16		264.5	176	50	432	14	30.85	1520
17		273	188	37	432	8	54	1200
18		300	181	68	-	-	-	970
19		260	165	97	432	2.7	160	1200
20		267	179.5	67.5	345.6	30.4	11.36	1350
21		268	176	74	-	-	-	1000
22		283	179.5	117.5	432	22.6	19.11	640
23		225	169	79	432	24.3	17.77	1200
24		330	179	68	-	-	-	1500
25		271	176	77	345.6	20.3	17.02	1200
26		290	177	85	-	-	-	1100
27		260	150	49	864	31	27.87	1200
28		272	162	83	-	-	-	2290
29		280	163	36	432	19	22.73	1350
30		257	170	76	604.8	25.8	23.44	1100
31		250	161	87	-	-	-	1200
32		274	162	97	604.8	2	302.4	1200
33		275	166	46	432	1.3	332.3	1200
34		326	187	209	432	10.2	43.35	550
35		326	171	87	475.2	2.5	190.08	1500
36		250	166	132	604.8	34	17.78	1200
37		265	171	75	432	20	22.6	1400
38		250	154	109	432	25	17.28	1400
39		258	169	90	345.6	25	13.82	1350
40		250	151.5	108.5	345.6	10	34.56	1200
41		272	181.5	211.5	-	-	-	600
42		270	163.5	129.5	518.4	3.3	157.09	1500
43		282	160	118	475.2	28.3	16.15	1580
44		265	174	78	432	20	21.6	1500
45		263	163.5	98.5	345.6	20	17.28	1300
46		296	189	202	-	-	-	385

Table 2. Continued.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
47		263	162	94	432	25	17.28	1220
48		252	131.5	155.5	-	-	-	1300
49		257	174	-28	518.4	20	25.92	1300
50		290	189	220	561.6	20	28.08	425
51		267	181	66	432	19	22.73	1300
52		265	173	81	-	-	-	1230
53		256	170.5	33	-	-	-	1350
54		252	169	79	604.8	36	17.28	1200
55		256	169	177	432	25	17.28	1200
56		253	168	87	-	-	-	1180
57		333	191	59	-	-	-	-
58		252	170	87	777.6	40.4	19.24	1300
59		257	165	93	432	23	18.78	-
60		272	185	61	432	13	33.23	1970
61		260	171	78	-	-	-	1110
62		262	175.5	66.5	345.6	15	23.04	1230
63		260	158	137	604.8	31	19.5	1000
64		268	175	186	-	-	-	1200
65		275	139	160	-	-	-	1700
66		257	179.5	69.5	345.6	12	28.8	-
67		250	169	80	-	-	-	-
68		262	170	33	604.8	25	24.19	1150
69		257	158.9	94.1	432	25	17.28	-
70		267	183.7	58.3	345.6	8	43.2	-
71		252	167.6	84.4	432	20	21.6	1300
72		329	213.8	-40.8	-	-	-	-
73		258	170	29	604.8	24	25.2	950
75		350	205.5	2.5	-	-	-	3237
76		350	194.8	2.2	-	-	-	7186
77		350	288.6	4.4	345.6	4	86.4	990
78		350	163.7	99.3	604.8	31	19.5	4233
82		300	120	-18	-	-	-	9578
83		350	213.6	15.4	-	-	-	1320
84		500	395	-51	432	15	28.8	1271
86		400	147.9	-1.9	-	-	-	7400
87		450	254.1	-2.1	-	-	-	1063
88		370	290.5	5.5	345.6	4.5	76.8	1033
92		270	230	0	-	-	-	1341
93		250	200	-12	-	-	-	2710
94		205	160	6	-	-	-	4624
95		200	166	-9	-	-	-	5436
96		200	154	2	129.6	4.3	30.13	4054
97		220	155	1	-	-	-	1092
98		0	370	8	-	-	-	1001
100		400	220.5	4.5	-	-	-	3266
101		300	273.2	-14.2	-	-	-	1631
102		370	213	12	-	-	-	1162
103		400	271	11	-	-	-	973

Table 2. Continued.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
74	Upper Cretaceous Aquifer	600	253.7	154.3	-	-	-	1030
79		480	391.95	7.05	-	-	-	907
80		400	303.2	-0.2	-	-	-	966
81		535	292.5	185.5	-	-	-	453
85		480	378	12	-	-	-	993
89		450	250	283	-	-	-	1094
90		350	260	179	-	-	-	1048
91		-	250	513	-	-	-	291
99		350	250	529	-	-	-	441
104		418	230	177	-	-	-	1329
105		340	214	522	-	-	-	334
106		-	210	544	-	-	-	303
107		-	150	478	-	-	-	378
108		570	223	155	-	-	-	480
109		547	458	6	-	-	-	500
110		600	261.4	170.6	-	-	-	1470
111		600	266.5	234.5	-	-	-	489
112		536	342.7	7.3	-	-	-	495

(-): indicates that the values not detected.

Salinity ranges between 303 (well No. 106) and 1329 mg/l (well No. 104), indicating that groundwater of the Upper Cretaceous aquifer belongs to the fresh - slightly fresh water class according to the Chebotarev classification (1955). This relatively wide range of salinity may be attributed to the effective of recharge from the seasonal rainfall. The TDS distribution map (Fig. 9) shows increases along the main flow direction from north to the south. Consequently, overlaying the piezometric contour map for the Upper Cretaceous aquifer (Fig. 8) and TDS distribution (Fig. 9) shows that the areas where low values of the Total Dissolved Solids (TDS) have been detected correspond with higher rainfall, especially in the northwestern portion of the concerned area, and with high values of groundwater elevation.

8.2. The Eocene aquifer

In this study, the Eocene aquifer has been investigated in two areas; one is covering the southern flank of the mountains and the other one covers in the northeastern part of the area. This aquifer comprises the Darnah Formation, where about 150 m of nummulitic and reefal limestones overlie the microcrystalline limestones of the Apollonia Formation. It forms the main aquifer in the study area where 93 wells with depths ranging between 200 (well no 84) and 500 m (well No. 95) with an average of 285 mbgl , are tapping this aquifer. The Eocene aquifer is overlain by Oligocene and Miocene strata in the south and by the Miocene strata only in the north, so the recharge area is large in the northern part rather than the southern part (Fig. 6 and Table 3). Further south, groundwater within this aquifer exists under confined conditions and the depth to groundwater has a wide range from 120 (Well No.82) to 290.5 mbgl (well No.88).

In the southern section of this aquifer, the depth to piezometric surface increases from south to north. There is a more concentric pattern in the north east section (Fig. 10). In contrast, the piezometric surface contour map (Fig. 11) shows that, in the south, the piezometric surface decreases gradually southwards and eastwards. In the northeastern part of the study area the surface is characterized by steep slopes from a high of over 200 m (m.s.l) to values below sea level near the coast.

Table 3. Main aquifer characteristics of Al Jabal Al Akhdar area (GWAE).

Aquifer type	Average Depth below the ground level (m)	Main geological constitutes
Quaternary	From 10 – 50	Fluvial deposits
Miocene	From 100 – 150	Marly limestone
Oligocene	From 200 – 250	Calcarenitic limestone
Eocene	From 250 – 350	Nummlitic limestone
Upper Cretaceous	From 250 – 350	Dolomitic limestone

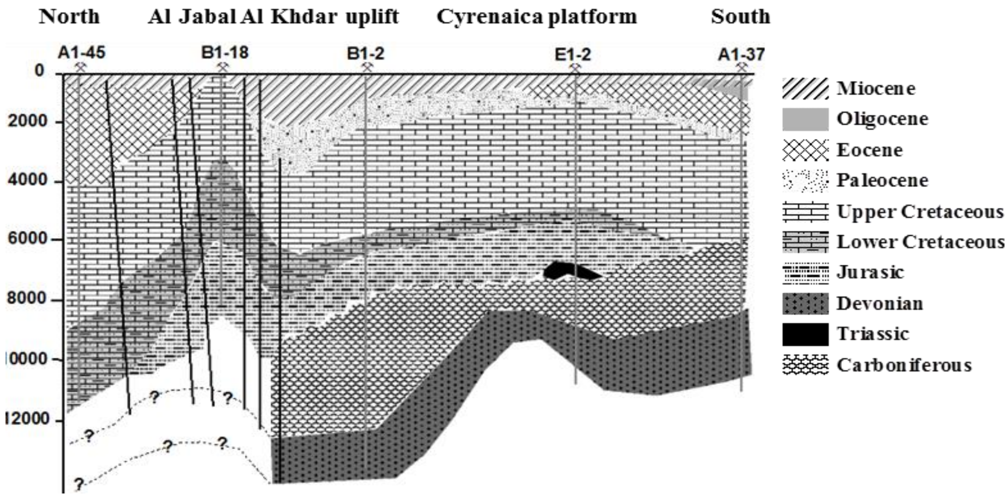

Figure 6. North – South subsurface cross section along Al Jabal Al Akhdar area (Hassan S., 2010)

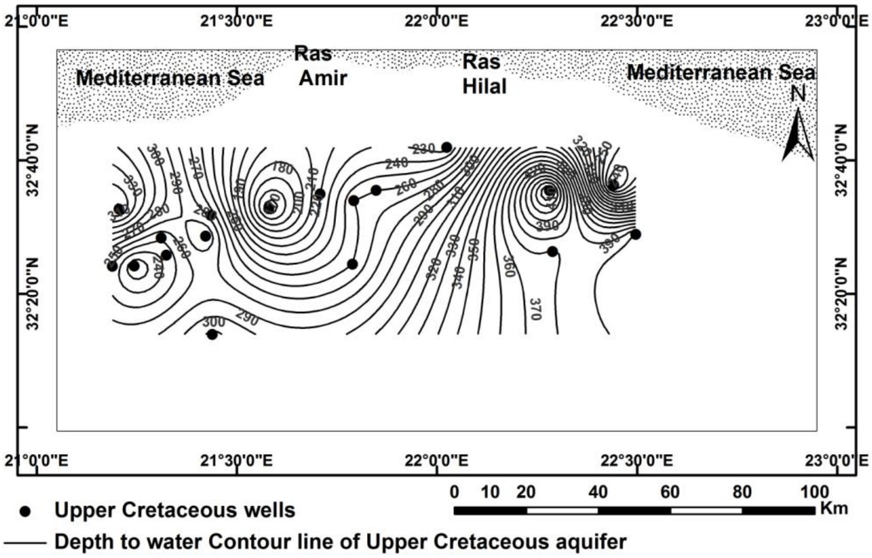

Figure 7. Depth to water contour map of the Upper Cretaceous aquifer in the study area (year 2014).

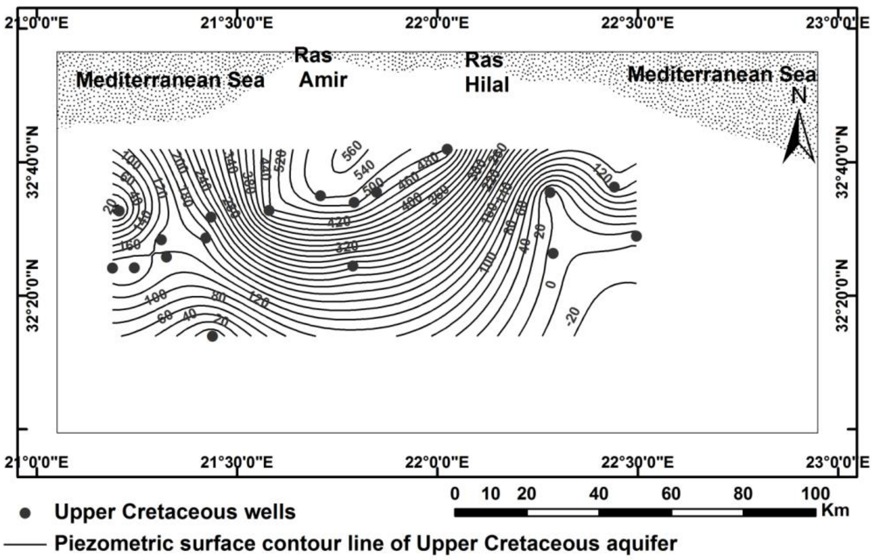

Figure 8. Piezometric surface contour map of the Upper Cretaceous aquifer in the study area (year 2014).

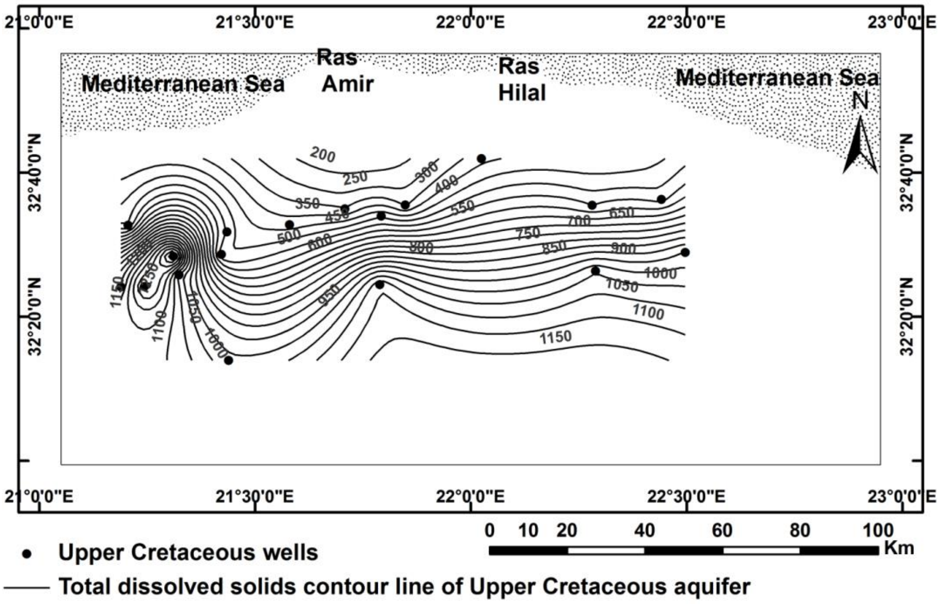

Figure 9. TDS disribution contour map of the Upper Cretaceous aquifer in the study area (year 2014).

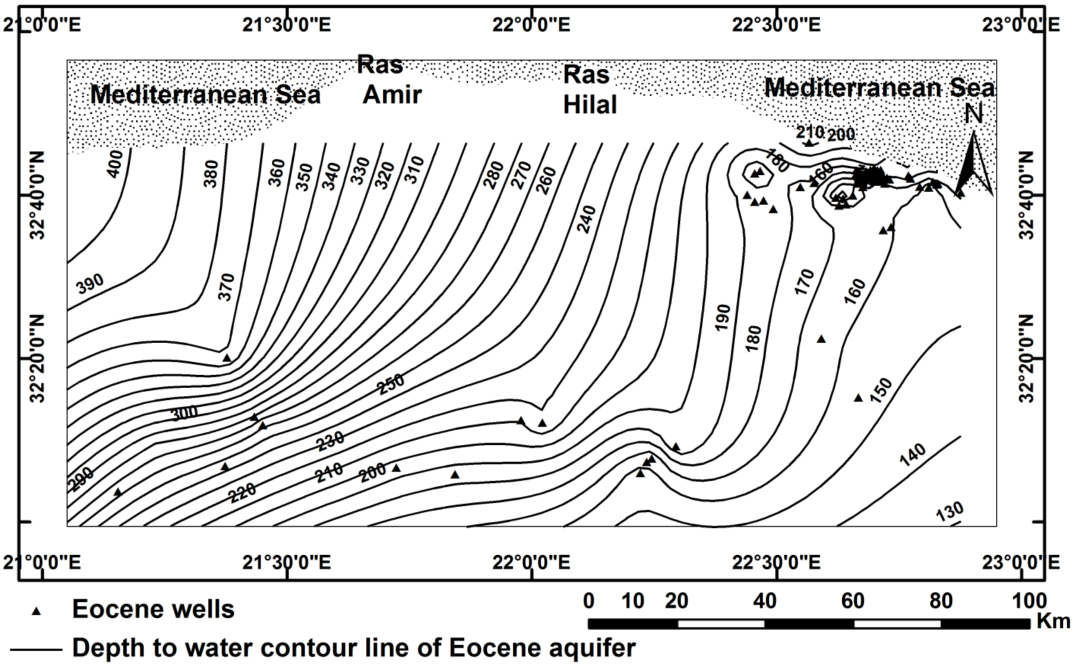

Figure 10. Depth to water contour map of the Eocene aquifer in the study area (year 2014).

In the natural condition the direction of ground water flow and location of water divides is generally controlled by geological formations and structures. However, in the north east of the study area it is likely that groundwater discharge by pumping has an overriding impact.

The specific capacity values vary between 10.08 m^2/day in well No. 10 (low productivity) and 332.3 m^2/day in well No. 33 (relatively high productivity). The frequency distribution for specific capacity values (Fig. 12) shows that more than 80% are lower than 37 m^2/day. This wide variation is not related to well depth (Fig.13) but it is probably due to the karstic nature of the aquifer.

The groundwater salinity within this aquifer ranges between 198 and 2800 mg/l (fresh to brackish water class according to Chebotarev, 1955). The TDS contour map (Fig. 14) shows high salinity contents (1400 to 2800 mg/l) in the south and eastern parts of the study area and low salinity contents (200 to 1400 mg/l) in the northeastern part. The high salinity in the southern central part may be attributed to over pumping and low amount of recharge from the rainfall. An anomalous area of high TDS values is located in the southern central part of the study area. This high salinity values can be attributed to the effect of the geological formations in the southern parts of the study area, those characterized by marine carbonate rocks intercalated with shallow marine deposits of lagoons and sabkha like gypsum, and anhydrite. Therefore the Eocene aquifer's water is affected by recharge through these formations. The low salinity values recorded in the northeast near the Mediterranean Sea suggest good recharge source from the seasonal rainfall.

8.3. Groundwater recharge and use

As mentioned before, the Upper Cretaceous aquifer contains water of less salinity than the Eocene aquifer. The groundwater salinity within the Eocene aquifer is relatively high where it is confined except for the area in the northeastern corner, where there is a high recharge from seasonal rainfall. This suggests that some of the total recharge is not able to penetrate into the Eocene aquifer. We also note that the discharges from springs is a significant part of the natural water balance and is likely to be a major component of existing groundwater use in downstream areas.

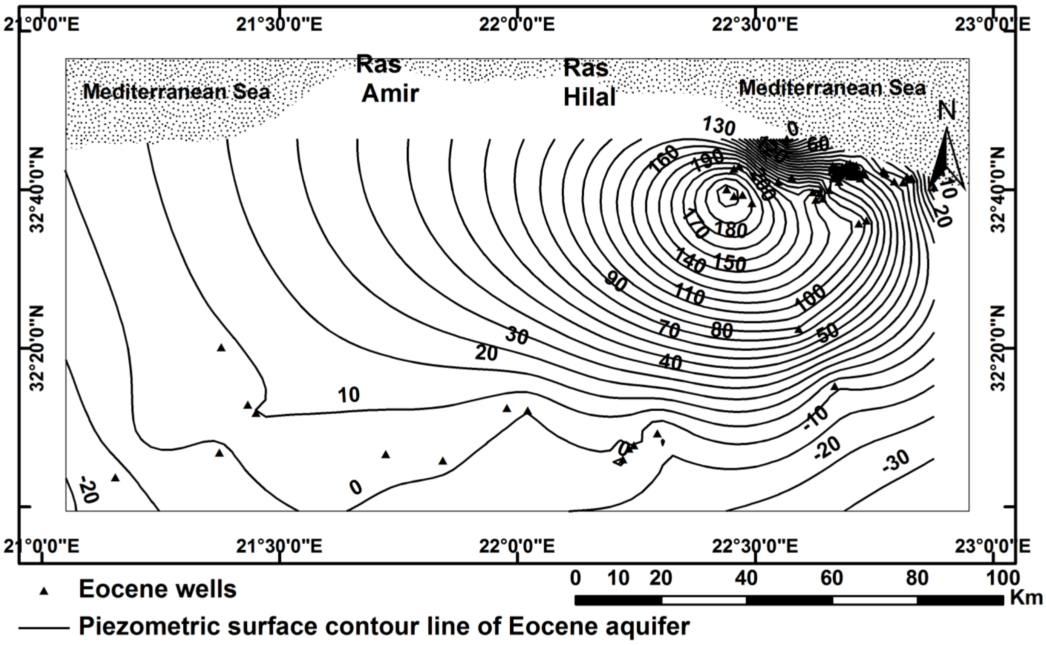

Figure 11. Piezometric surface contour map of the Eocen aquifer in the study area (year 2014).

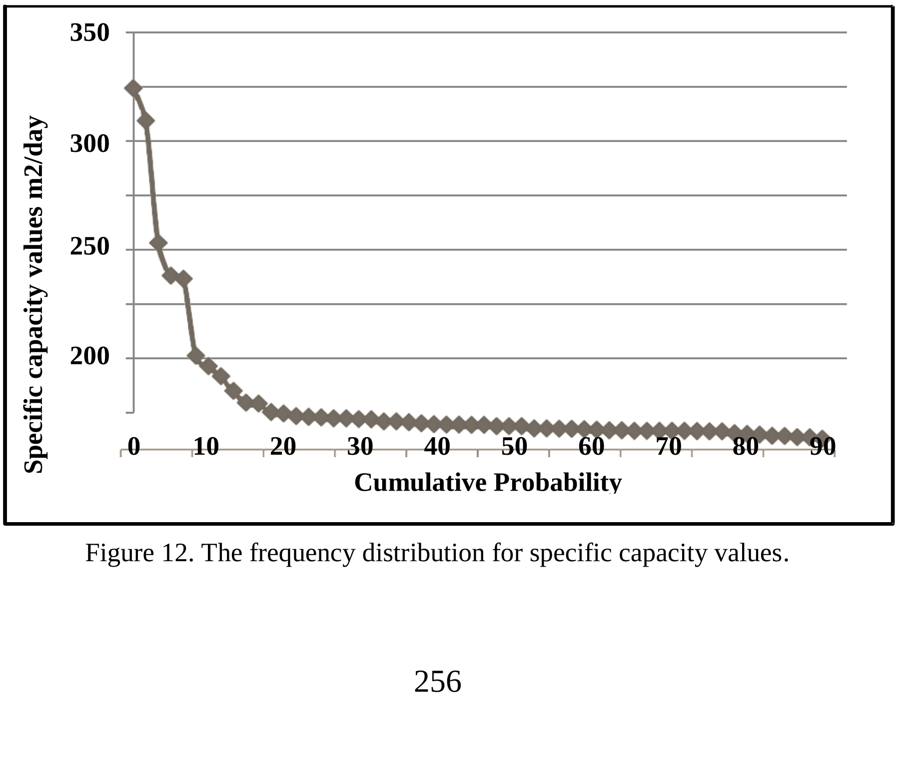

Figure 12. The frequency distribution for specific capacity values.

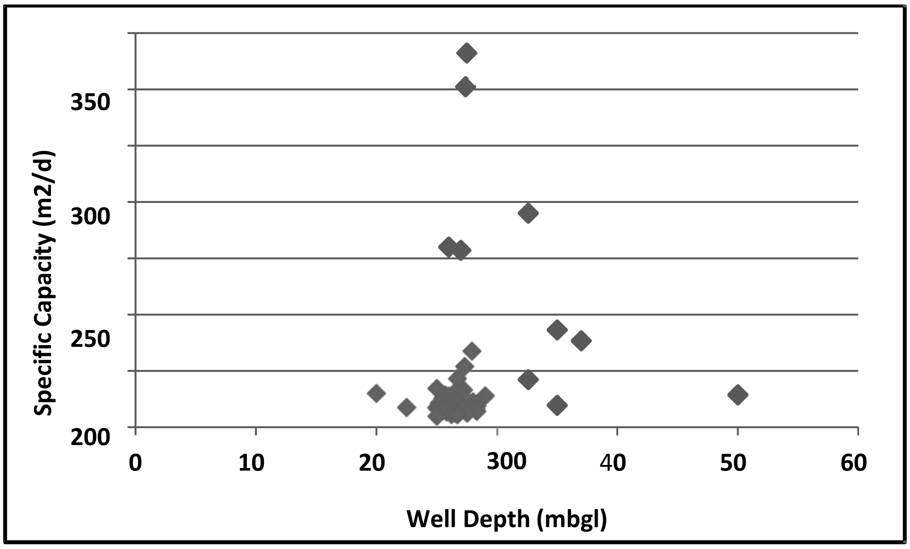

Figure 13. specific capacity - well depth relationship.

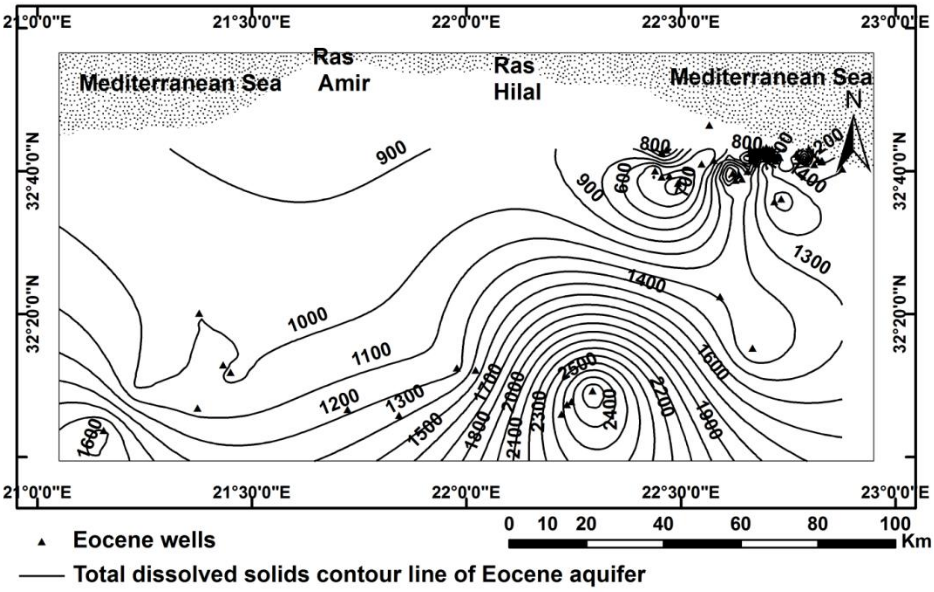

Figure 14. TDS disribution contour map of the Eocene aquifer in the study area (year 2014).

It is therefore possible that the value of net water balance shown as 223 x 10^6 m3/year in Table 1 overestimates the groundwater potential of the two main aquifers at many locations. In the study area, there is a strong relation between the seasonal rainfall and aquifer recharge, where the annual average rainfall (from 280 to 500 mm) plays a significant role in the recharge of the two aquifers (El Osta and Masoud, 2015). The central and northern portions of the concerned area appear promising for agriculture expansion by drilling new water wells; hence the priority of groundwater quality and potential for development increases towards these areas. This suggests a Decision Support System (DSS) could be developed in which different factors, e.g., aquifer types, irrigation type, crop unit, rainfall, water consumption and existing downstream water use are collected together to create a more comprehensive tool in order to define suitable land use and groundwater extraction.

9. CONCLUSIONS

The central part of Al Jabal Al Akhdar area represents a region with promising environmental conditions for agricultural developments. Groundwater in the karstified Eocene and Upper Cretaceous limestone aquifers is the main source of water for drinking, agriculture, and grazing, even there is now considerable groundwater extraction, where it exists under confined conditions.

In this study, there is a strong link between the seasonal rainfall and the recharge to the groundwater of the two aquifers, wherever the annual average rainfall (from 280 to 500 mm) plays a significant role in the recharge of the two aquifers, especially that near to the ground surface. Accordingly, the Eocene and Upper Cretaceous aquifers had the medium potential as groundwater resources in terms of quality and quantity, and their spatial extension is mainly around the central part of Al Jabal Al Akhdar region. The depth to the water for the Upper Cretaceous aquifer ranges from 150 to 458 m and increases eastwards. The Piezometric surface contour map shows high values in the northern parts of the study area, and decreases to the southern direction until reaches -20 m (m.s.l) in southeastern part.

On the other hand, The Eocene aquifer represents the main aquifer in the study area, with depth to groundwater ranges from 120 to 290.5 m, while the potentiometric level decreases gradually southwards and characterized by steep slope in the southeastern part of the study area. The specific capacity of the Eocene aquifer varies between 10.08 m^2/day (low productivity) and 332.3m^2/day (relatively high productivity). The Upper Cretaceous aquifer contains water of less salinity (303 - 1329 mg/l) than the Eocene aquifer (200 – 2800 mg/l). In conclusion, the central and northern portions of the concerned area are promising for agriculture expansion by drilling new water wells, hence the priority of groundwater quality and potentiality increase in these areas.

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