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ORIGINAL ARTICLE

Hydrogeological setting of a karstic aquifer in a semi-arid region: a case from Cheria plain, Eastern Algeria

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Abstract The Cheria basin is formed primarily by succession of three aquifers; from the more important one to the less important. The first one is the Maestrichtian permeable limestone aquifer which exists on the border. The second is Eocene fissured karstic limestone aquifer that constitutes a great potential of water in the study area. Its thickness is varied from 10 to 200 m. The third is mio-plio-quaternary alluvial aquifer which has no hydraulic interest due to the drought of the latest decade, The basin is affected by several tectonic phases and neotectonic movements. Compared with subsurface karstic phenomena (karstified fractures), these data allow us to propose a diagram of the preferential directions evolution of the karstifications (orientations N40 and N140 principally). There are four significant groups obtained from the rose diagram, these groups have been classified according to their order of importance: the first group is 130°–140°E; the second group is 100°–110°E; the third group is 40°–50°E; and the fourth group is 0°E.

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Introduction

Cheria plain which covers an area of 720 km^2 is located about 45 km south west of Tebessa city and in the north east of Algiers between 7°30′–8°E, and 35°–35°30′N (Fig. 1). It is a wide triangular plateau. The altitudes vary from 985 to 1700 m. The development of the urban population and the agriculture provokes an increasing strain of the quantity and the quality of water resources. Cheria basin constitutes an individualized hydrogeological basin and is formed by different geological formations. It is limited by synclines folds initiated during Eocene and Miocene compressive phases. It can be subdivided into three hydrogeological units, namely porous and two fissured formations. The porous formations consist of mio-plio-quaternary, whereas the fissured formations are constituted by karstic limestone, and they are subdivided into two different units. They form the most interesting reservoir, while the Eocene limestone aquifer forms the permanent water available in the study area.

Geological and climatological context

The studied area is located in a semi-arid region. The annual precipitation and temperature average successively are 280 mm/year 15 °C (Chamekh 2014). The remarkable precipitation, the presence of fractures and fissures and cold–dry climate facilitate the appropriate conditions for karstification. The great part of annual precipitation comes

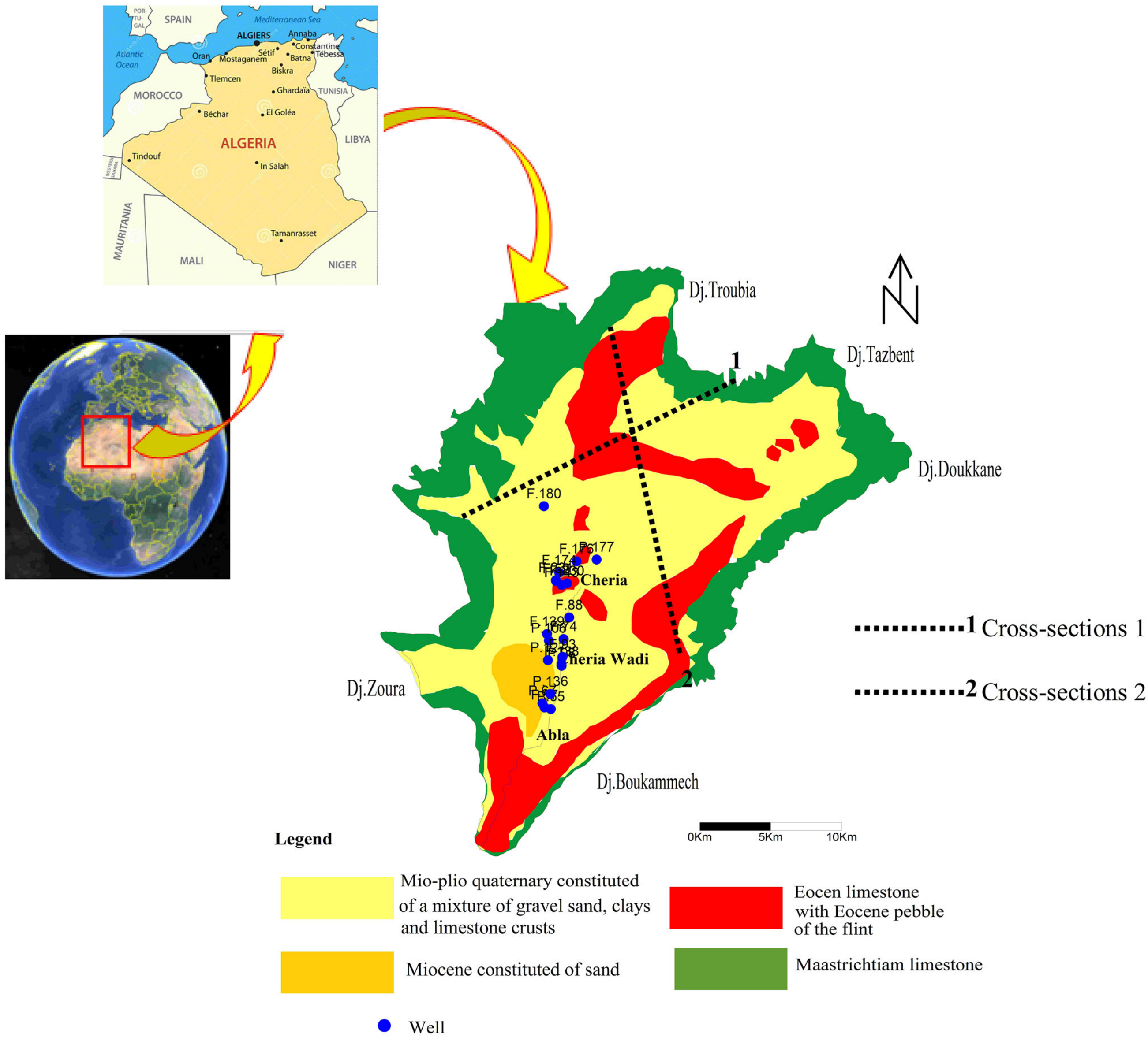


Fig. 1 Geological and geographical map of the studied region (Chamekh 2016)

from snow, which falls in winter and melts with increasing temperature in early spring.

The Eocene limestone aquifer is intensively fractured and karstified. The major sub surface karst cavities is located in the northern and the centre part of Cheria syncline. They are widespread in the Eocene forming the upper formation under the Quaternary cover in the Cheria syncline.

On the geological plan, the basin is synclinal structures with a stratigraphic succession (Fig. 2) ranging from Cretaceous to Eocene constitute the main formations. The later constitute the upper formations which occupy more than 80% and it is under the quaternary cover, the 20% are composed from the mio-plio quaternary filling deposits in the Cheria syncline. Evidently enough, geological climate factors will have an influence on the groundwater flow field. Eocene limestone formations are overlain by mio-plio-quaternary alluvial (Chaffai et al. 2006; Baali 2007; Fehdi et al. 2010; Chamekh 2014). Eocene limestone is intensively fractured and covered by varying thickness layer constituted by gravel, sand, silt and clay (Fehdi et al. 2010).

The basin is affected by many different tectonic phases and neotectonic movements (Hammimad 2005). Fractures orientations are dominantly found in NE–SW and NW–SE, and they are sliced by a sub-orthogonal third set of N–S. Generally, fractures are underlain by zones of localized weathering and increased permeability and porosity.

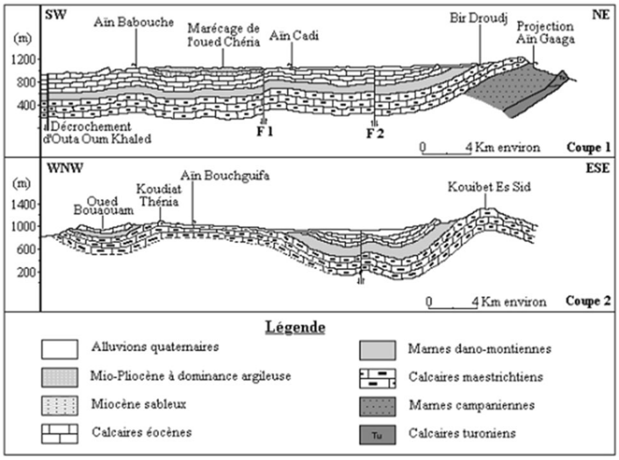


Fig. 2 Geological cross section of the studied region (Gaud 1977)

Hydrogeological setting

Eocene limestone constitutes thick, densely fractured carbonate succession, and it is characterized by a high permeability (Chamekh et al. 2015), and the presence of many karst landforms (Gaud 1977; Chaffai et al. 2006). It constitutes the most extensive aquifer in Cheria plain which covers an area about 100 km^2 at the centre of the basin. The depth of the aquifer roof ranges from 100 to 250 m. The perennial water availability is related to the great potential of Eocene limestone aquifer. The alluvial aquifer is not appreciably used for drinking water as it used to be. From a hydrochemical point, both the amount of dissolved limestone and the enlargement of fractures depend obviously on the chemical composition of the rock and the water (Kiraly 1971). The chemical analysis results of this study are listed in Tables 1 and 2.

Karst is a unique hydrogeologic terrain in which the surface and ground water regimes are highly interconnected and often constitute a single and dynamic flow system (White 1993). In the Cheria plain, the karst is a landscape which is formed from the dissolution of soluble rocks including Eocene limestone. It is characterized by sinkholes, caves and underground drainage system. Nearly all the surface karst features are formed by internal drainage and the collapse which trigged by the development of underlying caves. This process of dissolution leads to the development of the caves, sinkholes, springs and streams that are typical of a karst landscape. In Cheria syncline, the karst sinkholes are simulated out using Flac 2 D software (Aziz et al. 2014). The diameters of the underground cavities vary from 1 m to more than 40 m.

The karst aquifer can be conceptualized as an open hydrologic system having a variety of surface and subsurface input, throughput, output flows and boundaries. They are defined by the catchment limits and geometry of conduits (Ford and Williams 1989).

Table 1 Chemical composition (in mg/l) of groundwater (September 2013)

Well	Water samples	Ca	Na	K	Cl	Mg	Hco_3	SO_4	NO_3	EC (µS/cm^2)
F.57	1	142	85	8	94	55	82	492	98	2324
P.67	2	156	88	8	303	49	99	388	110	3667
P.65	3	145	96	7	89	145	94	495	84	3749
F.88	4	119	71	11	92	52	72	258	75	2005
F.138	5	111	83	10	89	43	71	197	82	1556
P.136	6	143	87	17	97	56	79	450	104	3476
F.139	7	126	75	11	185	39	77	215	117	1953
F.176	8	102	33	7	57	25	107	113	42	958
F.174	9	122	31	10	76	95	109	129	38	1154
F.143	10	108	32	7	76	21	109	116	34	1060
P.177	11	111	30	9	57	26	112	128	45	1113
F.230	12	94	28	10	151	17	108	148	41	1114
F.180	13	90	31	7	56	27	113	106	37	1115
F.231	14	102	30	7	120	22	102	147	65	1025
F.52	15	106	31	6	121	16	109	987	48	1149
P.98	16	134	128	7	311	57	48	184	123	2577
P.106	17	132	115	14	127	188	55	205	73	1606
P.127	18	138	118	11	120	65	51	400	88	1792
F.74	19	119	106	6	122	51	41	168	103	1301
F.93	20	106	105	7	125	69	43	181	104	1052

Table 2 Chemical composition (in mg/l) of groundwater (April 2014)

Well	Water samples	Ca	Na	K	Cl	Mg	Hco_3	SO_4	NO_3	EC ($\mu S/cm^2$)
F.57	1	152	42	21	189	9	120	532	100	9532
P.67	2	90	65	14	186	5	100	325	48	8214
P.65	3	152	45	21	290	9	142	256	23	2450
F.88	4	143	23	21	320	5	65	142	56	2206
F.138	5	136	25	2	199	4	53	95	50	1950
P.136	6	140	63	11	780	16	131	286	85	3950
F.139	7	121	35	9	256	34	52	125	92	2230
F.176	8	123	15	5	251	25	61	84	43	1320
F.174	9	162	23	4	120	31	43	142	35	1420
F.143	10	153	14	6	98	42	53	92	38	1321
P.177	11	142	12	8	195	29	48	67	39	6825
F.230	12	148	30	2	142	31	65	65	43	6847
F.180	13	156	14	4	142	12	91	120	53	2250
F.231	14	168	23	6	100	32	58	103	75	4350
F.52	15	149	34	9	98	27	67	104	61	2320
P.98	16	195	68	15	420	34	251	256	135	3214
P.106	17	185	56	9	415	60	295	295	120	3521
P.127	18	214	65	12	365	24	245	421	182	1952
F.74	19	184	48	9	493	25	351	289	235	1842
F.93	20	142	92	8	423	42	254	301	156	1753

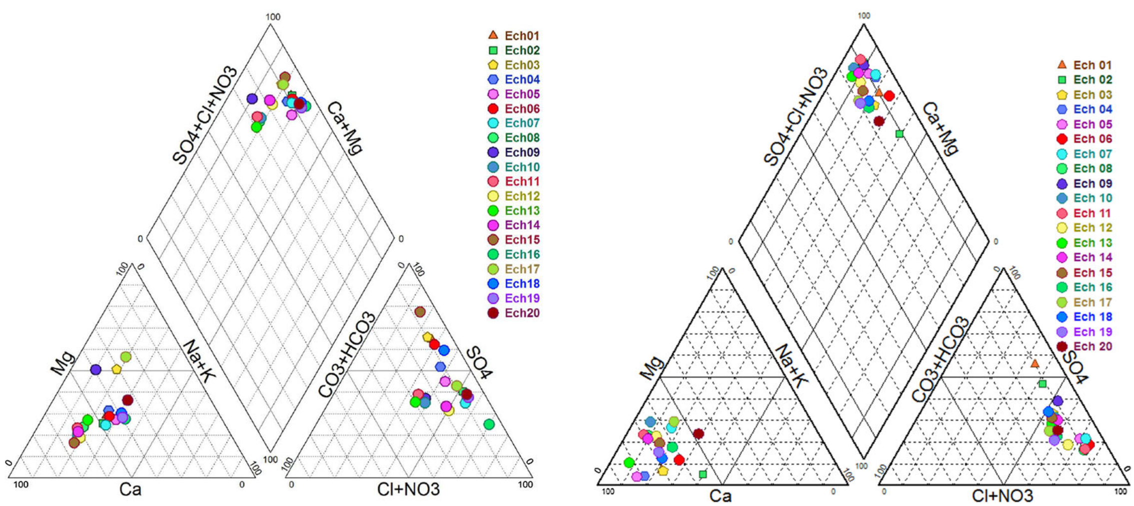


Fig. 3 Piper diagrams of September 2013 and April 2014 (Chamekh 2016)

According to the Piper and Schoeller–Berkaloff diagram (Figs. 3, 4), two types of water facies are found depending on the traversed formations lithology, where wells, springs and streams are located in. From one hand, wells and rivers in karstified rocks have low salinity water with conductivity values between 300 and 700 µS/m, Calcium Ca > 170 mg/l and bicarbonate Hco_3 > 130 mg/l.

On the other hand, the conductivity values vary between 1000 and 2000 µS/m, Calcium Ca > 60 mg/l and bicarbonate Hco_3 > 90 mg/l in springs and wells on the alluvial aquifer.

Methods of field investigation

In the karstified Eocene limestone, lineaments tend to be less detected in discharge areas (lowland, wide and flat valleys) in contrast to the high density in recharge areas (highland narrow-mountainous ravines). In addition, the presence of a stream network in the former can be considered as a recharge source to the underlain karstic groundwater system.

Aerial photographs (1:2000), topographic maps, geological maps and satellite images are part of the remote

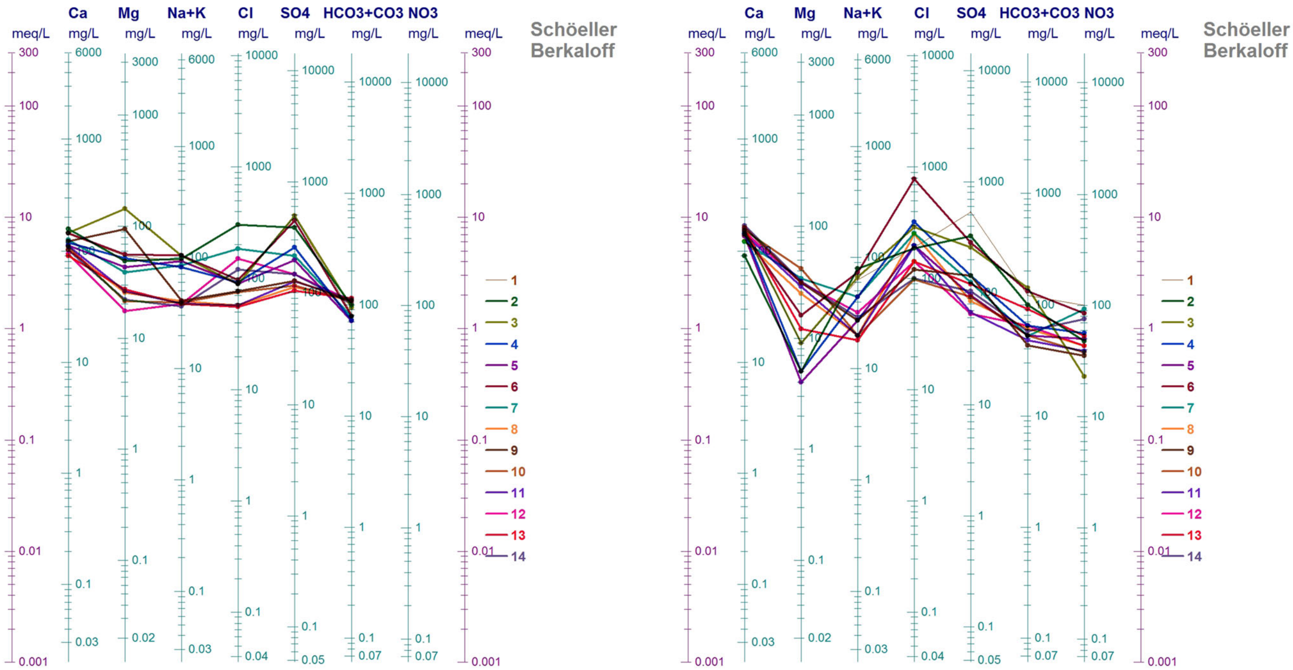


Fig. 4 Schoeller–Barkaloff diagrams of September 2013 and April 2014 (Chamekh 2016)

sensing analysis. The lineament frequency and the lineament intersection maps are based on the aerial photographs. The grid files were located and contoured in Surfer software, which also produces the lineament frequency and the lineament intersection maps. These maps identify areas of high fracture frequency and of highest fracture intersections.

The piezometric survey was undertaken in six parts. From May 2010 to April 2014, sixty points of piezometric measurements were performed (wells and drilling). The initial phase of the survey starts from site visits to all properties within the respective field areas. Then, landowners were contacted regarding the location of bores, wells and springs on their property. Next, relevant details were recorded and permission were sought to revisit the sites to survey the wellhead elevation and groundwater level during the main survey.

During the sites visits, details of bores, wells, springs and water hole were recorded using a standard field sheet. The spatial location of relevant features was fixed using a handheld GPS unit.

Results and discussion

The piezometric map (Fig. 5) of different periods showed a flow converges to the center. In the northern part of the basin, the flow direction is north–south while in the southern part the flow converging towards a drainage axis, which coincides clearly with the Wadi Cheria that has west direction (close to the mountain of Allouchat). Two zones were identified according to hydrodynamic and hydrochemical properties. The map indicates the existence of a depression cone in Cheria village where the flow converges; the latter is apparently due to an overexploitation of groundwater; this zone is characterized by the presence of a great number of wells. All karstic areas are prone to subsidence because of natural or induced fluctuations in the local groundwater levels. Both local groundwater recharge and abstraction can lead to this subsidence.

The hydrochemical study is based on the water sampling from May 2010 to April 2014. This performance showed a remarkable dominance of magnesium chloride facies or calcium chloride facies (Chamekh et al. 2015), which hides the bicarbonate facies due to the circulation of ground water in the carbonate rock existing in the studied areas (Baali et al. 2014).

The presence of high nitrate concentrations in the groundwater samples which are collected from shallow aquifer is resulted from the contamination of Cheria Wadi not from the massive usage of artificial fertilizers.

Broadly speaking, the water shows a very high salinity with conductivity 9000 µS/m in the south basin, and 800 µS/m in north basin and with pH values around 6–8 (Chamekh 2014).

The effective management of karstic aquifers should include controls on the rate and range of the fluctuations in the piezometric surface and the distribution of infiltration.

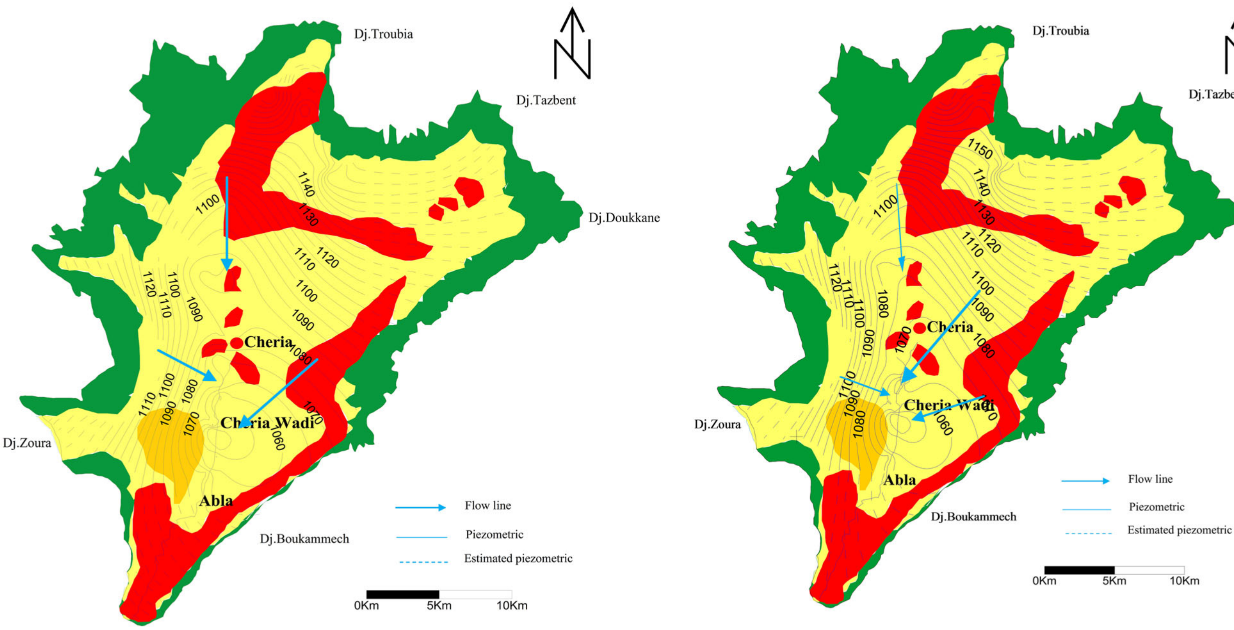
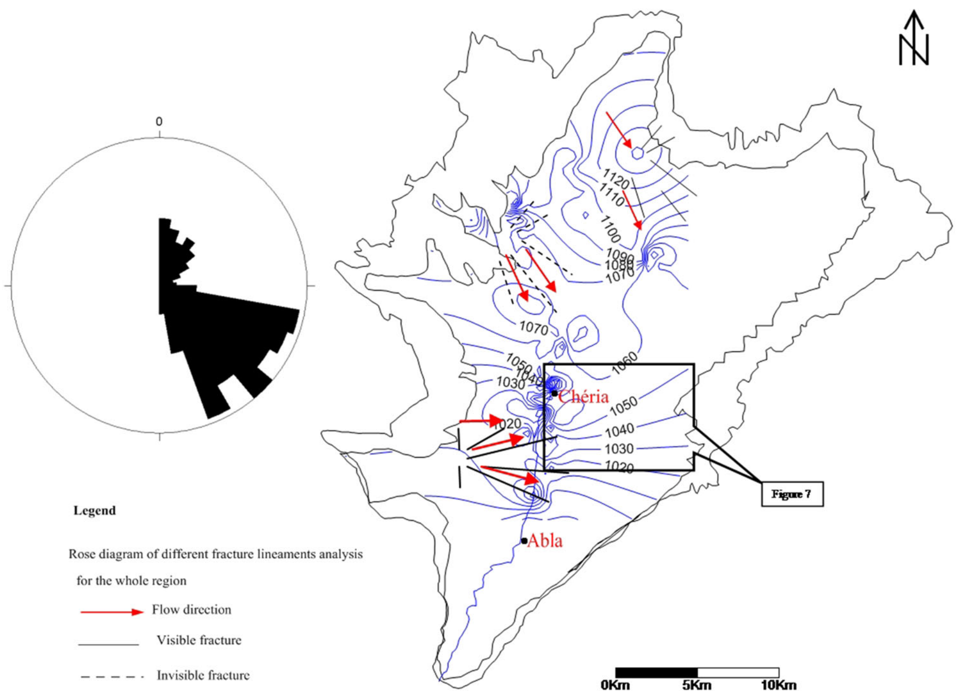


Fig. 5 Piezometric map of September 2013 (left) and April 2014 (right) (Chamekh 2016)

Fig. 6 Relationships of fractures mapped from the area (Chamekh 2011)



Large-scale abstraction for industry or irrigation can cause subsidence. Irrigation of fields is confirmed as cause in the increase of the subsidence features in geologically susceptible areas (Gutiérrez et al. 2008). The effect of underground water fluctuation has also a paramount importance (Sowers 1975), which describes the occurrence of two large sinkholes after 3 days of pumping. Catastrophic collapses can be happened, as an example the problems that appeared by abstraction and irrigation in Cheria. The general direction of principle stress can be obtained from the rose diagram trends according to the classical interpretation (Chamekh 2011). A relation is proposed between tectonic episodes of faulting style and preferential directions of karstification and flow direction (Fig. 6).

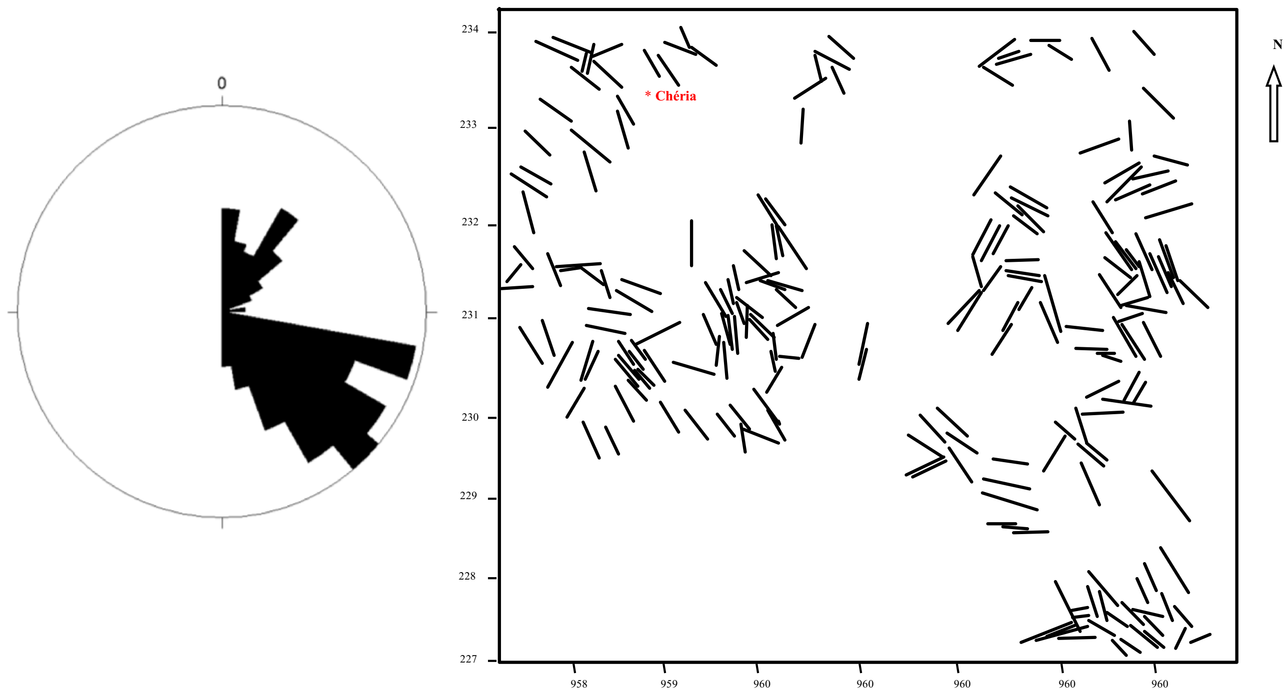


Fig. 7 Lineament mapping and cross diagram of fracture distribution

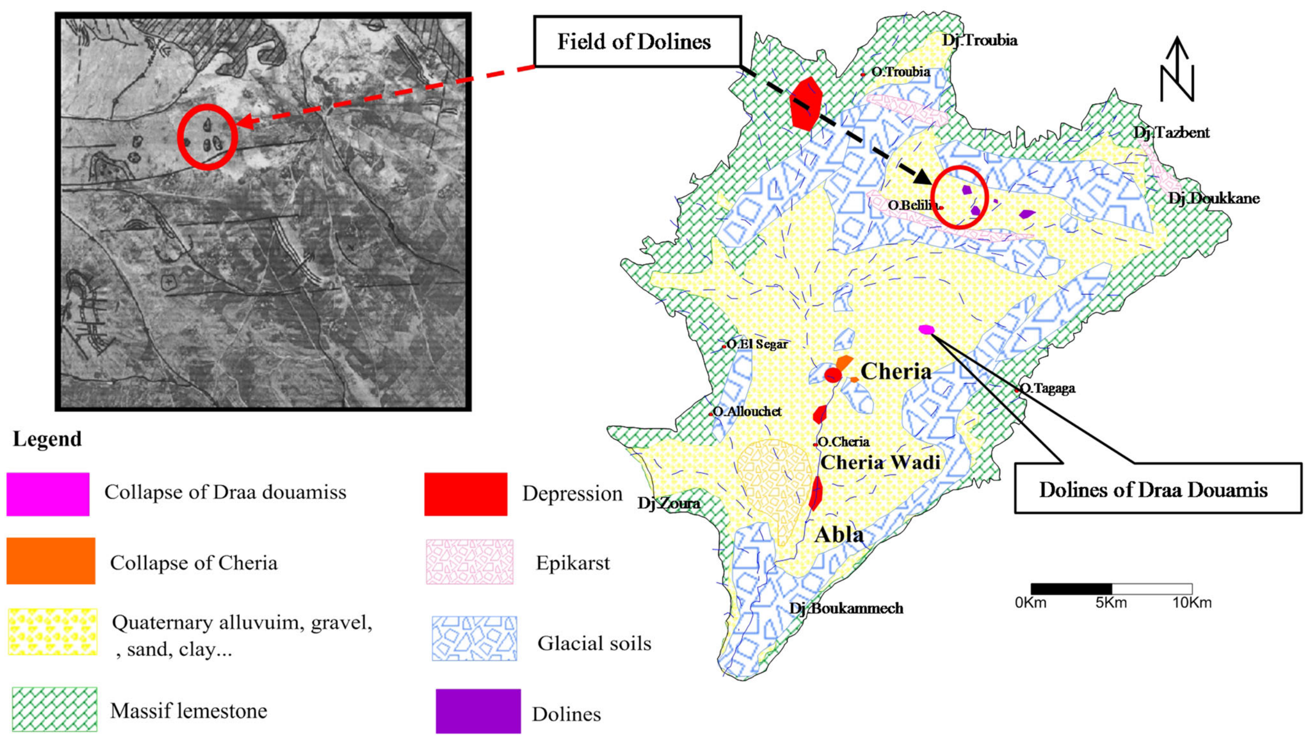


Fig. 8 Geomorphological map of the area surrounding the Cheria karst system (Chamekh 2016)

There are four groups obtained from the results gathered from the rose diagram (Fig. 7); they are classified according to their order of importance: the 1st group is 130°–140°E; the 2nd groups is 100°–110°E; the 3rd group is 40°–50°E and the 4th group is 0°E. They are caused by the tangential movements compression (Baali 2007). The direction N40–50 is the result of post-Miocene fault which creates the rift of El Hamammet (Hammimad 2005). In this case, the movement of the karst groundwater is closely controlled by the regional tectonic structure. Many cavern conduits have been found in the basin and their development coincides with the direction of geological fault and fractured zone (November 1999). A lot of sinkhole and dolines are covered with a layer of Quaternary alluvium consisting of clay, sand and gravel debris of Eocene limestone rocks, like dolines of Draa Douamis in north of the basin (Fig. 8).

Conclusion

Based on the results of the previous maps, the predominate flow converges from the periphery to the centre. The most important directions of flows are NW, NNE–SSW and they move into the centre. The recharge zones can be identified with the subsurface aquifers. The natural discharge zones are reproduced in the subsurface; the pattern of the major drainage axis is created by the watercourse along the piezometric surface of the subsurface aquifers. The southern part of the basin is often converging towards a drainage axis which coincides clearly with the Wadi Cheria (EW direction). The application of remote sensing technique and the aerial photographs leads to identify and understand the fracture system which is the result of structural deformation. Flow pattern of the Eocene limestone aquifer system reveals that the groundwater direction flows are toward the south and south eastern parts and is guided by the fractures and the preferential directions of the karst cavities.

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