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The Effects of Water Table Decline on the Groundwater Quality in Aquifer of Torbat Jam Plain, Northeast Iran

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Abstract. The prime objective of this research is to study and examine the groundwater decline and its effect on the quality of groundwater in aquifer of Torbat Jam plain for a period of 19 years. Torbat Jam plain stretching over an area of about 3500 km2, in northeastern part of Iran. The plain is considered as a semi-arid to arid zone. It has gained substantial importance because of agricultural prosperity. Almost all water consumption needs are met from groundwater resources. In the last decades, rapid population growth coupled with agricultural expansion has significantly increased demand on groundwater resources. Large increases in water demand with little recharge have strained groundwater resources resulting in declines in water levels and deterioration of groundwater quality in the major parts of the plain. It's worth mentioning th00at the paramount cause of sharp drop in the groundwater table in recent years is conclusively attributed to pumping out of well water which confirmedly exceeds the level of the natural recharge. As a result, the average water level, for instance, has dropped from 1036.47 m to 1002.75 m during the years from 1987 to 2006 with an annual rate of declining about 1.77 m.

Keywords: Aquifer, Unit Hydrogragh, Water Level Decline, Water Quality, Water Type

1 INTRODUCTION

Groundwater is a vital natural resource. It is estimated that approximately one third of the world's population use groundwater for drinking [9]. In some parts of the worlds such as large areas of the Middle East, groundwater is the unique source of water. In general, the Middle East is characterized by scarcity of water and rapid growth in population. Water is therefore the most important constraint for future development in this region [3], [6], [7]. However, it is anticipated that the process of development will continue, resulting in greater demands for fresh water and declining groundwater level. Iran as a country in the Middle East is confronted by multiple water-related problems, such as drought and environmental degradation from overexploitation of aquifers in the central and eastern parts of the country.

Understanding the groundwater quality is important as it is the main factor determining its suitability for drinking, domestic, agricultural and industrial purposes [13]. In the study area, the extensive agricultural activities and urbanization resulted in the contamination of the aquifer in recent years. The Torbat Jam aquifer is an alluvial unconfined aquifer. The aquifer lies in the Torbat Jam plain, southeast of Mashhad city in the province of Khorasan Razavi northeast Iran (Figure 1). The plain with an area of about 3500 km2 is located in a watershed with the same name which lies between longitudes 59° 33′ and 61° 07′ east, and latitudes 34° 45′ and 35° 58′ north.

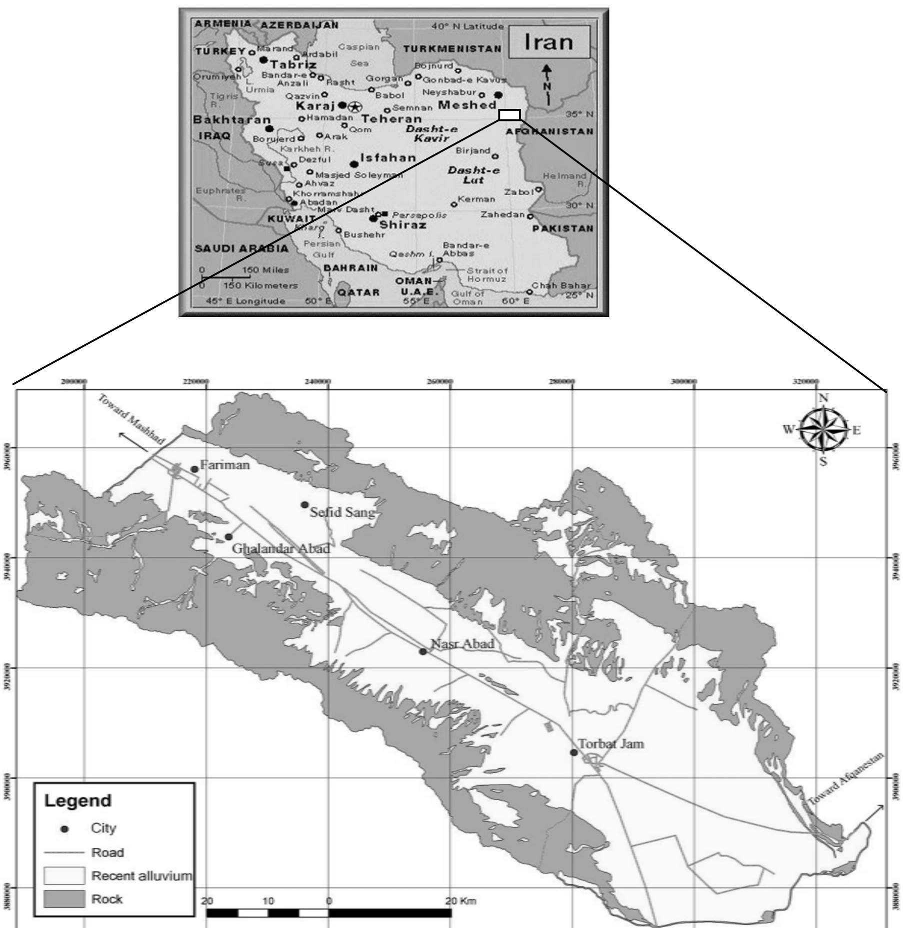


Figure 1. Location map of the study area

2. PHYSIOGRAPHIC OF THE PLAIN

The plain slopes mainly towards the east and is surrounded by mountains to the north and south and is a sub-watershed of Harerrod watershed. The total area of the Torbat Jam watershed is about 6355 km^2. The biggest city of the region is Torbat Jam in the southeast of the plain. The population of county Torbat Jam has increased from 36108 in 1976 to 239395 in 2006 [8]. During recent years, high demand for water during the growing season and low renewal rate of groundwater resources have resulted in the depletion of the Totbat Jam aquifer.

The climate in the plain is semi-arid to arid and strongly continental. The data covering a period from 1983 to 2006 reveal major fluctuations in the level of precipitation and temperature. The average annual precipitation during this period was 208.9 mm in the plain and 261.1 mm in mountain, with maximum rainfall in January to April, while the maximum absolute temperature was 50.5°C in summer and minimum absolute temperature was -19.5°C in winter. The average potential evaporation was 1789 mm per annum. The humidity in Torbat Jam station in southeast of the plain ranges from a minimum of 22% to a maximum of 78%. Figure 2 shows monthly average precipitation and temperature in the Torbat Jam station during period of 1977 to 2000. There is a significant variation in mean annual precipitation across the plain. The average yearly rainfall gradually decreases from western mountains towards the east [8].

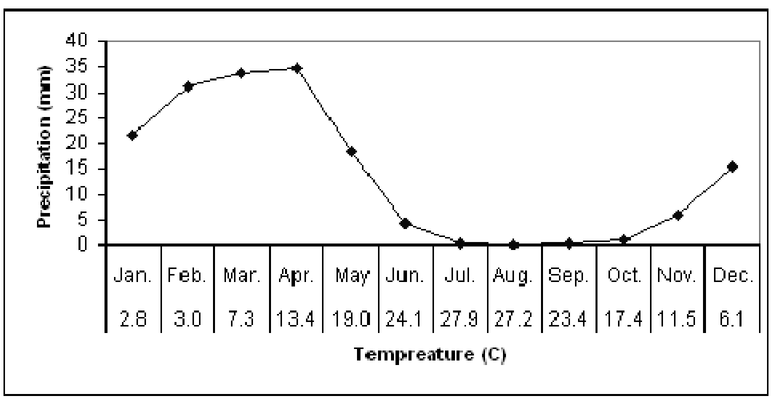


Figure 2. Monthly average precipitation and temperature in the Torbat Jam station

3. HYDROGEOLOGICAL CONDITION OF THE AQUIFER

The primary source of fresh water for agricultural, domestic and industrial uses in the area is groundwater from Torbat Jam aquifer, which is the major aquifer in the plain. It is an alluvial unconfined aquifer comprising mainly gravel and sand. The main source of recharge is infiltration from rainfall. Discharge occurs artificially through water galleries know locally as "quanat" and naturally by a number of springs. The major portions of abstractions are via dug wells which supply water for drinking as well as agricultural purposes. Because abstraction and discharge exceed recharge, groundwater levels have declined over the past 20 years. Deterioration in water quality has also occurred in major parts of the plain, with increasing salinity of groundwater.

A number of studies carried out since 1970, define the hydrogeological conditions of the region. Geophysical investigations were carried out using electrical resistivity methods in 1974 (57 vertical electrical sounding in 9 profiles) and 1978 (65 VES in 10 profiles). Through these investigations, the locations, number and category of underground layers, as well as the depth and the extent of the aquifer, were identified.

The study area has a wide variety of rock units of different origins surrounding the plain. These rock units have an effect on the quality of groundwater. Igneous rocks of low permeability predominate at outcrop. A number of springs, of low discharge flow from the mountains into the plain. Other types of rock units outcrop in the region are very important from the hydrogeological perspective including Miocene evaporates are grouped into two parts, namely low permeability and impermeable rock. These evaporates contain gypsum and salt and have a large negative effect on the quality of both ground and surface waters in the region. These evaporated sediments generally extended in the southeast of the aquifer where the groundwater quality is recorded to be in the worst condition.

The alluvial sediments and the alluvial fans rainfall water enters the aquifer have a considerable spread. The sediments are mainly of large grain particles having a high rate of permeability and high electrical conductivity. These sediments are main sources of recharge of the aquifer. Moreover, there are a number of rivers which, flowing just for a few days in winter and spring, enter the plain and recharge the sediments.

Other factors such as length of groundwater flow paths also affect the quality of the groundwater. In flat eastern part of the plain at the downstream end of the aquifer where the flow path is longer, groundwater is of chloride type and it indicates the low quality and brackish nature of this part of the aquifer. In this portion, the aquifer consists of finer materials where the depth to groundwater is as little as 10 m. The maximum depth of the bedrock has been estimated at 400 m in the western part of the plain beneath city of Fariman. The maximum depth of the groundwater is also reportedly 217 m in the western part of the region.

Mirshahi [8] reported the storage coefficient of the aquifer about 0.05. The pumping tests in the aquifer show that transmissivity is in the range 200 to 5000 m^2/d. The study of water level fluctuations indicate that direct infiltration from rainfall, recharge from agricultural irrigation, and underground flows from mountain into the plain result in water level increase. As mentioned before, the aquifer discharges naturally by a number of springs, and discharges artificially through a number of dug wells and quanats that result in water level decrease.

4. OVEREXPLOITATION OF THE AQUIFER

Overexploitation of the groundwater resource leads to lowering of groundwater levels in the study area. The inhabitants of the plain depend entirely on the groundwater resources for all domestic, agricultural and industrial purposes. In order to determine groundwater level decline, water level measurements were collected from 44 observation wells over the period 1987 to 2006. The unit hydrograph is drawn on the basis information acquired from 44 wells (Figure 3). Minimum average groundwater levels occur in March (due to high rainfall and low abstraction of groundwater) and maximum average in August (due to low rainfall and high abstraction of groundwater).

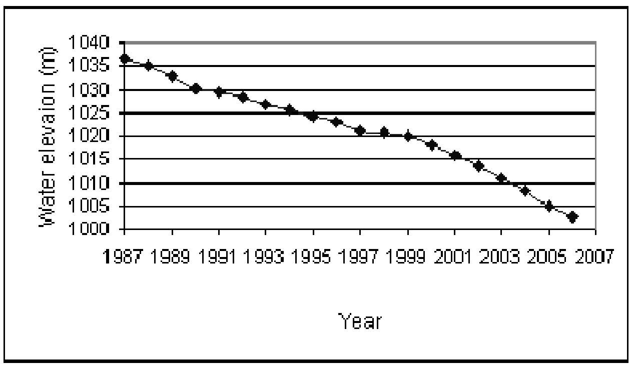


Figure 3. Unit hydrograph of groundwater in the plain

From the decline in groundwater levels and the storage coefficient of the alluvial aquifer (5 percent), the total volume of depletion in groundwater is estimated at about 266 million m^3 from 1987 to 2006 or 14 million m^3/year of storage has been lost. The unit hydrograph of the region reveals that average water level declined over the period 1988 to 2006 (Figure 3), from 1036.47 m to 1002.75 m, a total fall of 33.72 m, an average decline of 1.77 myr^{-1}.

5. DECLINING GROUNDWATER LEVELS AND CHANGING QUALITY

The quality of groundwater is the resultant of all the processes and reaction that act on the water from the moment it condenses in the atmosphere to the time it is discharged by a well [1]. Water level decline is often associated with increasing groundwater salinity e.g. [11]. The intense decline in water level and the increase in groundwater salinity will be different, with regard to the amount of aquifer recharge, as well as the thickness of fresh water layer [3]. Over-exploitation and pollution of groundwater in the semi–arid areas are reported by many researchers e.g. [2], [12].

This study shows that excessive exploitation of groundwater results in a fall in water levels. This, in turn, results in low quality of groundwater. Suitability of groundwater for domestic and irrigation purposes is determined by its groundwater geochemistry. In order to study groundwater conditions and to determine an average electrical conductivity, available data for 8 wells have been collected for years 1998 and 2005. The groundwater locations were selected to cover the entire study area. Chemical results of the collected data across the plain for 1998 and 2005 are shown in tables 1 and 2 respectively. The collected water samples have been analysed for electrical conductivity (EC), pH, total dissolved solids (TDS), major cations like calcium, magnesium, sodium, potassium and anions like bicarbonate, carbonate, chloride, nitrate and sulphate, using the standard methods. The results indicate that groundwater is characterised by high concentration of almost major cations and anions from 1998 (Table 1) to 2005 (Table 2). For example, average total anions increased from 17.02 meq/l to 19.02 meq/l, cations from 17.01 meq/l to 19.84 meq/l, EC from 1738 µs/cm to 1809 µs/cm and TDS from 1072.3 mg/l to 1144.7 mg/l. Figure 4 shows a comparison between EC for years 1998 and 2005.

Table 1. Chemical data of 8 groundwater samples across the plain in 1998

UTM		EC (µs/cm)	TDS (mg/l)	Anions (meq/l)					Cations (meq/l)				
UTMX	UTMY			CO3	Hco3	Cl	SO4	Total	Ca	Mg	Na	K	Total
229444	3946837	559	357.2	0.60	2.90	1.00	1.50	5.80	0.40	2.20	3.20	0.00	6.00
239902	3941806	770	851.8	0.60	4.00	4.10	5.00	13.60	1.30	3.10	9.20	0.00	13.70
258161	3924480	1081	420.2	0.40	2.70	1.20	2.70	6.90	1.50	2.40	3.00	0.00	7.00
266234	3919328	1515	677.9	0.40	3.00	3.60	4.00	10.90	1.20	2.20	7.50	0.00	11.00
285767	3913449	2490	1568.7	0.40	3.00	11.80	9.60	24.80	3.20	5.90	15.70	0.00	24.80
286289	3898076	2530	1593.9	0.40	2.70	8.90	13.00	25.20	2.80	6.00	16.40	0.00	25.00
299238	3906625	2920	1839.6	0.20	1.80	16.80	9.80	28.80	3.40	7.00	18.40	0.00	28.60
303707	3901608	2040	1285.2	0.40	2.10	8.70	8.80	20.20	3.10	3.50	13.60	0.00	20.00
Average		1738	1072.3	0.43	2.78	7.01	6.80	17.02	2.11	4.02	10.88	0.00	17.01

Table 2. Chemical data of 8 groundwater samples across the plain in 2005

UTM		EC (µs/cm)	TDS (mg/l)	Anions (meq/l)					Cations (meq/l)				
UTMX	UTMY			CO3	Hco3	Cl	SO4	Total	Ca	Mg	Na	K	Total
229444	3946837	561	353.4	0.50	3.30	0.90	1.20	5.90	1.20	2.00	2.60	0.00	5.80
239902	3941806	776	488.9	0.60	3.00	2.10	2.20	7.90	0.60	1.70	5.50	0.00	7.80
258161	3924480	1179	744.0	0.40	3.30	4.00	4.70	12.40	2.50	4.20	5.50	0.00	12.20
266234	3919328	1521	958.2	0.20	4.50	3.40	7.80	15.90	3.80	5.70	6.20	0.00	15.70
285767	3913449	2320	1461.6	0.20	3.30	11.0	9.50	24.00	2.70	5.40	15.70	0.00	23.80
286289	3898076	3330	2097.9	0.00	2.70	14.0	17.0	33.70	5.00	5.90	22.60	0.00	33.50
299238	3906625	3100	1953.0	0.00	2.30	17.0	13.5	32.80	4.10	6.30	22.20	0.00	32.60
303707	3901608	2210	1392.3	0.00	2.30	10.4	9.40	22.10	2.80	4.30	15.00	0.00	22.10
Average		1809	1144.7	0.24	3.09	7.53	8.16	19.02	2.84	4.44	12.56	0.00	19.84

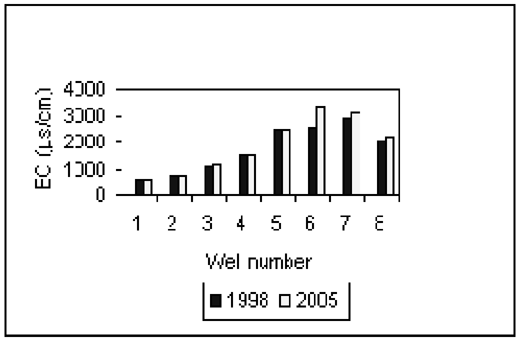
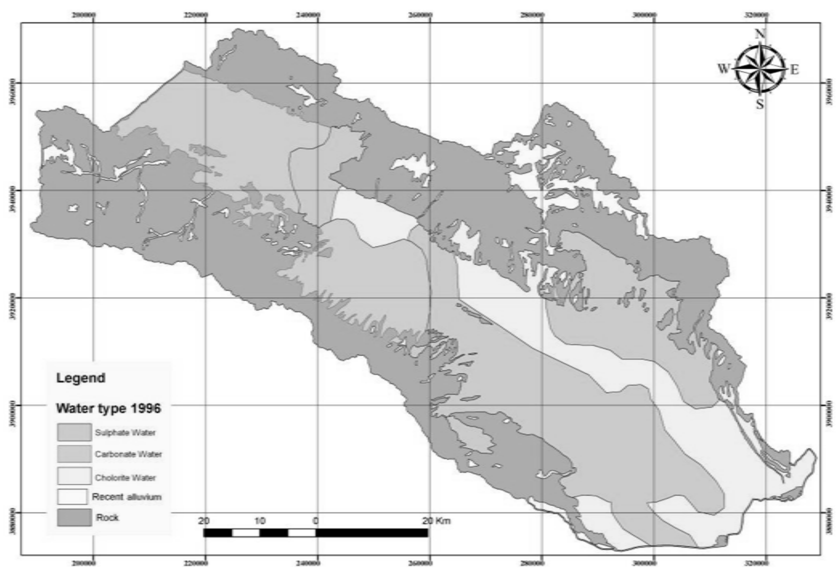


Figure 4: A comparison between EC for years 1998 and 2005

In recent years groundwater type has changed in the whole region. For example, the chloride type has extended from years 1996 to 2006 in the eastern part of the plain. At the same period the carbonate type has decreased in the western part (Figure 5).



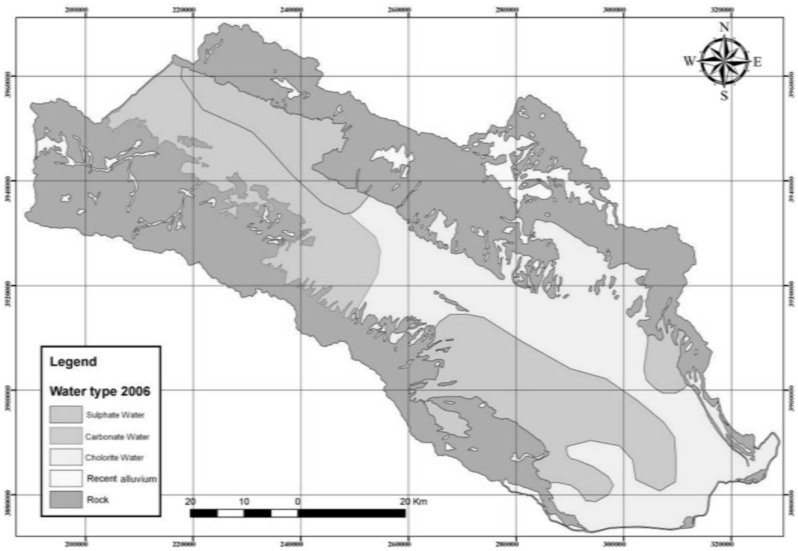
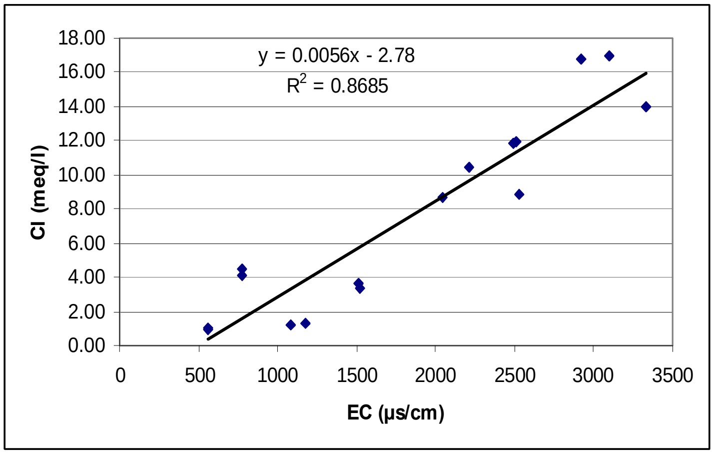


Figure 5. Changing of groundwater type during years 1996 and 2006

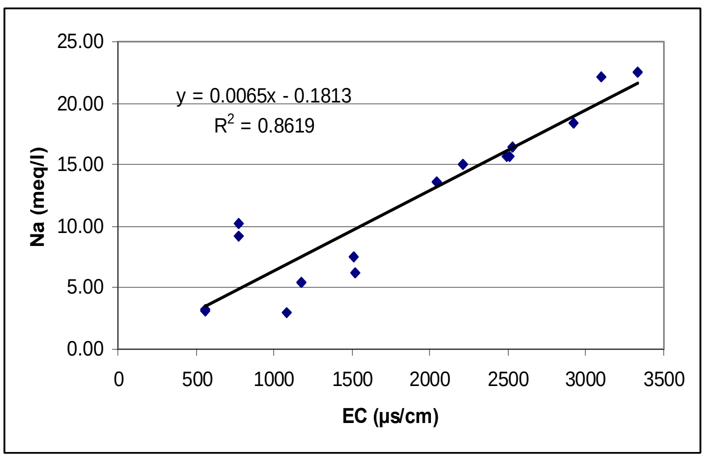
6. RELATIONSHIP BETWEEN WATER SALINITY AND WATER CONDUCTIVITY

Hydrologists have widely accepted the correlation of ion concentration of the water with the electrical conductivity that measured in µs cm^{-1} [4], [5]. Correlation between salinity and the electrical conductivity in the study area indicates rise in the electrical conductivity caused by declining groundwater level. However, the main processes influencing the groundwater chemistry are mineral precipitation and dissolution, cation exchange related to the type of sediment or rock adjacent to the groundwater resources.

The reason for increasing salinity and electrical conductivity appears to be decline in groundwater level due to extensive exploitation of groundwater in the region. This has caused discharge to exceed recharge. In comparison between the amount of ions and electrical conductivity, most of ions are increasing with increased electrical conductivity, while at the same time a strong linear correlation with $r^2>0.86$ exists between Cl, Na and electrical conductivity (Figure 6).



(a)



(b)

Figure 6. (a) Correlation between EC and Cl, (b) correlation between EC and Na.

7. CONCLUSIONS

Groundwater is the unique source of water for all purposes in the Torbat Jam plain. Due to population and agricultural growth, the demand for water has increased significantly. Therefore, groundwater sources can not meet the demand. The aquifer of the plain is already being over-exploited, resulting a fall in groundwater level. The unit hydrograph from 1987 to 02006 confirms that water levels have declined by 33.72 m from average 1036.47 m to average 1002.75 m, and still continue to fall by 1.77 m yr^{-1}.

The results show that groundwater in the major portions of the study area are characterised by high concentrations of major cations and anions due to the continuous decline of groundwater level. Deteriorating quality and declining groundwater levels threaten to affect more of the resource in future.

Assessment of the groundwater type and the unit hydrograph of the aquifer show an increase in the chloride type and decrease in carbonate type with a drop of groundwater levels for the whole region during the study period from 1996 to 2006.

Fine grained materials containing salt rich deposits in southeast of the aquifer, are likely to be a major factor in increasing salinity in groundwater in this part of the aquifer. However, the over-exploitation of groundwater is an environmental hazard which causes the salinity of groundwater and makes it unsuitable for the irrigation of fertile lands as well as for the drinking purposes in the region.

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