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The Effects of Water Table Decline on the Groundwater Quality in Marand Plain, Northwest Iran

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Abstract

Marand plain, a part of the Caspian Sea catchment, stretching over an area of about 820 km^2, in northwestern part of Iran is considered as a semi-arid zone. It has gained substantial importance because of agricultural prosperity and population density. 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 Marand groundwater resources resulting in declines in water levels and deterioration of groundwater quality in the major parts of the plain. It's worth mentioning that the paramount cause of sharp drop in the groundwater table in the 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 1179.9 m to 1168.2 m during the years from 1982 to 2000. The prime objective of this research is to study and examine the groundwater decline and its effect on the quality of groundwater in the Marand aquifer for the said period.

Keywords: *aquifer, decline, groundwater, Iran, quality.*

Introduction

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 (Haddad and Mizyed, 1996, El-Fadel *et al.*, 2001, Haddad and Lindner, 2001). An adequate knowledge of the groundwater resource is imperative for successful groundwater management. However, it is anticipated that the process of development will continue, resulting in greater demands for fresh water.

The Marand aquifer lies in a semi-arid area in the northwestern part of Iran (Figure 1). The aquifer lies beneath the Marand plain, an area of about 826 km^2, situated to the northwest of Tabriz city in the province of East Azarbayejan. The area lies between longitudes 45° 15′ and 46° 05′ east, and latitudes 38° 18′ and 38° 46′ north, as a part of the Caspian Sea basin.

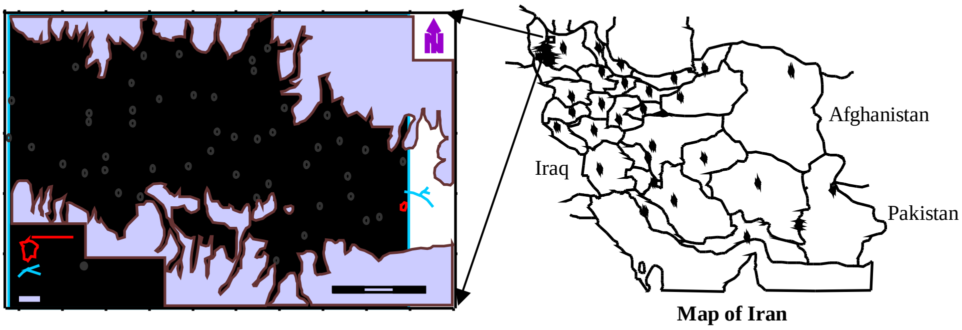


Figure 1: Location map

The region has a semi-arid climate, with maximum absolute temperature about 40.6°C in summer and minimum absolute temperature -22.5°C in winter. The average potential evaporation is 1789 mm per annum. The humidity in the Marand station ranges from a minimum of 29% to a maximum of 85%. The average annual precipitation is 236 mm, with maximum rainfall in April and May. Figure 2 shows monthly average precipitation and temperature in Marand station in the southeast of the plain during the period of study from 1977 to 2000. There is a significant variation in mean annual precipitation across the plain. The average yearly rainfall gradually decreases from 450mm in the eastern mountains to 150mm towards the west (Allaf-Najib, 2002). Table 1 shows the annual precipitation on the Marand station from 1977 to 2000.

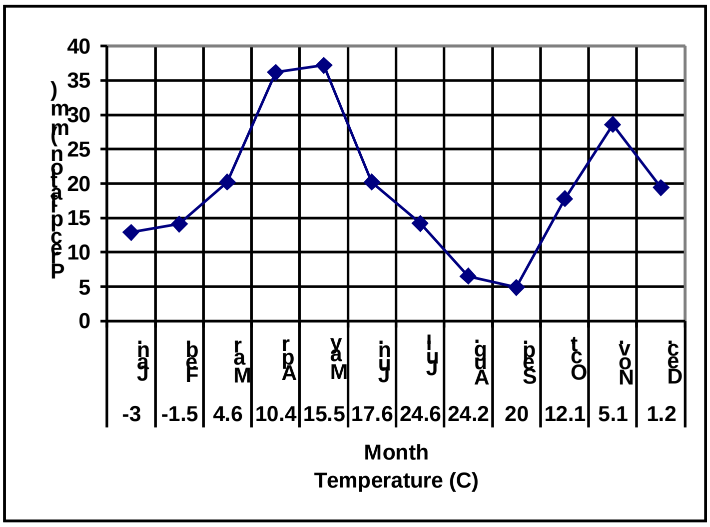


Figure 2: Average temperature and precipitation on the Marand station over a period of 24 years

The Marand plain slopes mainly towards the west. The plain is surrounded by mountains to the north, east and south. The plain is a sub-basin of the Caspian Sea basin. The total area of the Marand basin is about 2084 km^2. The biggest city of the region is Marand in the southeast of the plain. The city population has increased from 36,108 in 1976 to 120,776 in 2001.

During the recent years, high demand for water during the growing season and low renewal rate of groundwater resources have resulted in the depletion of the aquifer. Water level decline is often associated with increasing groundwater salinity (e.g. Sarah, 1997). 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 (Reilly and Gibs, 1993). Over-exploitation and pollution of groundwater in the semi–arid areas are reported by many researchers (e.g. Ballukraya, 2001, Subba Rao, 2003).

Table 1- Annual precipitation at the Marand station over a period of 24 years.

Year	**Rainfall (mm)**	**Year**	**Rainfall (mm)**
1977	362.9	1989	165.8
1978	247.7	1990	221.5
1979	284.5	1991	161.6
1980	224.6	1992	189.4
1981	266.0	1993	295.0
1982	276.7	1994	350.2
1983	205.4	1995	266.7
1984	146.9	1996	215.2
1985	199.3	1997	240.8
1986	223.9	1998	207.6
1987	197.2	1999	276.3
1988	263.4	2000	175.3

Average = 236

A number of studies carried out since 1974, 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. In 1982, the hydrogeology of the region was studied by Mohab Ghods Engineering Company (Mohab Ghods Engineering Company, 1983). Groundwater has been sampled every year in June and October since 1981, and analyzed for major ions, EC and pH.

Marand aquifer

The primary source of fresh water for agricultural, domestic and industrial uses in the area is groundwater from the Marand aquifer, which is the major aquifer in the plain. It is an alluvial aquifer comprising mainly gravel and sand. The main source of recharge is infiltration from rainfall, and discharge is via baseflow to the Zilberchay river. Discharge also occurs artificially through water galleries know locally as “qanat”. 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 (Figure 3).

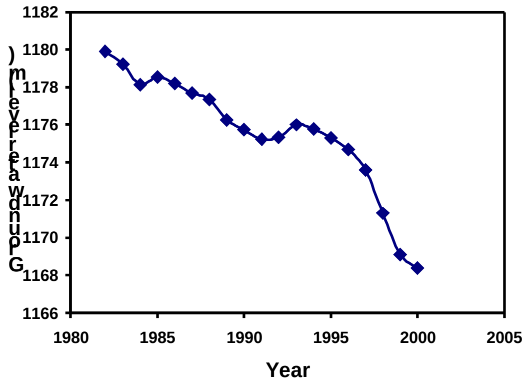


Figure 3- Unit hydrograph of groundwater in the Marand plain.

Deterioration in water quality has also occurred in major parts of the region, with increasing salinization of groundwater. The 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 southwest of the aquifer where the groundwater-of-quality is recorded to be in the worst condition.

Another rock unit greatly influences the hydrogeological conditions. It is the Pliocene conglomerate which covers part of the region. These coarse grain size and high porosity of the Pliocene conglomerate have culminated in its high permeability. This conglomerate with high transmissivity constitutes most of the bedrock in the Marand aquifer.

The occurrence of the conglomerate on the east and to some extent on the south of the plain controls a part of the recharge of the aquifer.

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 Marand 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 western 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 3 m.

Discussion

Over-exploitation of the aquifer

Over-exploitation of the groundwater resource leads to lowering of groundwater levels in the study area. The inhabitants of Marand 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 58 observation wells over the period 1980 to 2000. The unit hydrograph is drawn on the basis information acquired from 40 wells (Figure 3). Minimum average groundwater levels occur in March (due to snow melt and low abstraction of groundwater) and maximum average in August (due to low rainfall and high abstraction of groundwater).

The average depth of the bedrock has been estimated at 300 m and the average saturated thickness of the aquifer is about 264 m. The maximum depth of the groundwater is reportedly 128 m; the minimum about 3 m and the average depth of groundwater is 36m (Allaf-Najib, 2002). From the decline in groundwater levels and the storage coefficient of the alluvial aquifer, the total volume of depletion in groundwater is estimated at about 350 million m^3. Since he 1982, 19.44 million m^3/year of storage has been lost.

Average groundwater contour lines and flow lines in the plain are shown in Figure 4. As a result of groundwater curves, it can be concluded discharge occurs in the western part of the aquifer. Based on the minimum depth of the groundwater (3 m), the evaporation from the aquifer is considered to be negligible. The groundwater contour lines indicate that groundwater flows from higher ground in the NE and S to lower ground in the W. The average gradient is 21 in a thousand, but varies from 50 per thousand at the upstream end and 4-6 of the downstream.

Allaf-Najib (2002) reported hydraulic properties of the aquifer: transmissivity is 154.18 m^2/d, and the storage coefficient 0.0625. The pumping and recovery tests in 22 locations of the aquifer show that transmissivity is in the range 25 to 945 m^2/d (Table 2).

The aquifer is mainly recharged by infiltration of rainfall. 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. The aquifer discharges naturally by baseflow to the Zilberchay river and to a number of springs, and discharges artificially through a number of dug wells and qanats that result in water level decrease. The unit hydrograph of the region reveals that, except for the water years 1993-1994 in which the aquifer recharge exceeded abstraction, average water level declined over the period 1982 to 2000 (Figure 3), from 1179.9 m to 1168.2 m, a total fall of 11.7 m, an average decline of 0.65 myr^{-1}.

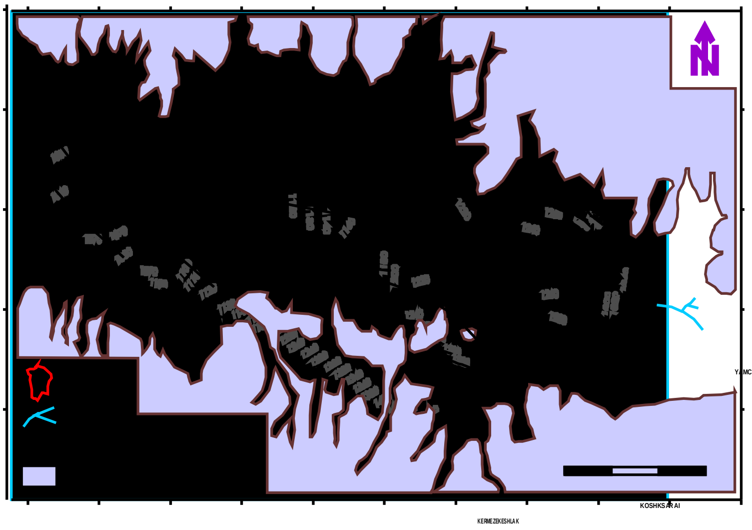


Figure 4 - Groundwater contour lines and flow lines of the aquifer.

Declining groundwater levels and changing quality

This study shows that excessive exploitation of groundwater results in a fall in water levels. This, in turn, results in low quality of ground water. In order to study groundwater conditions and to determine an average electrical conductivity, 18 wells, 1 spring and 3 qanats were chosen from the aquifer for investigation purposes. Groundwater samples were collected during the months of June and October in 1986, 1991, 1996 and 2001. Average yearly electrical conductivity for all collected data for the period of study is shown in Table 3. An increase in electrical conductivity (EC) of the groundwater is indicated across the plain for the period of study.

Table 2. Transmissivity test results.

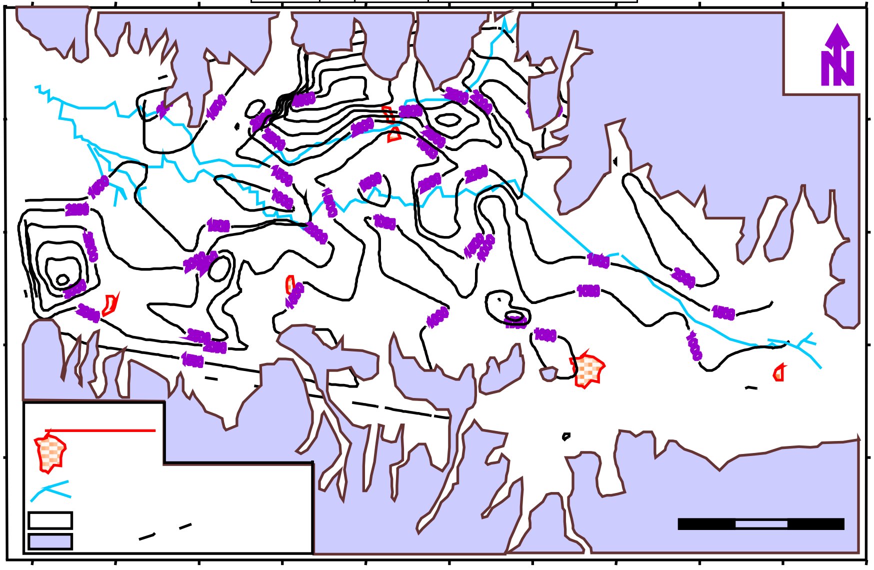
No.	Well Number	UTMY	UTMX	Transmissivity (m^2/day)
1	5G-6D	4266350	541150	25.73
2	8F-1D	4266700	558250	120.8
3	3G-6D	4262800	532950	92.55
4	8F-27D	4264300	555610	119.9
5	9G-27D	4262250	560500	102.22
6	4H-3D	4257900	536750	98.24
7	5H-9D	4256950	542900	40.0
8	7H-24D	4256250	550250	27.21
9	6H-42D	4256350	546950	73.0
10	8H-20D	4257250	556200	98.0
11	7H-28D	4256050	554600	67.0

12	9H-40D	4259400	563550	954.09
13	10H-48D	4257650	567000	71.47
14	11H-18D	4256200	572650	56.9
15	11H-25D	4255450	571400	45.09
16	11I-32D	4253280	572800	134.3
17	12I-5D	4254000	578300	785.0
18	12H-6D	4257200	578200	207.0
19	9H-41D	4256600	562730	25.0
20	11I-5D	4253950	570550	34.1
21	11I-20D	4252350	571350	79.34
22	9H-10D	4258500	564550	135.0

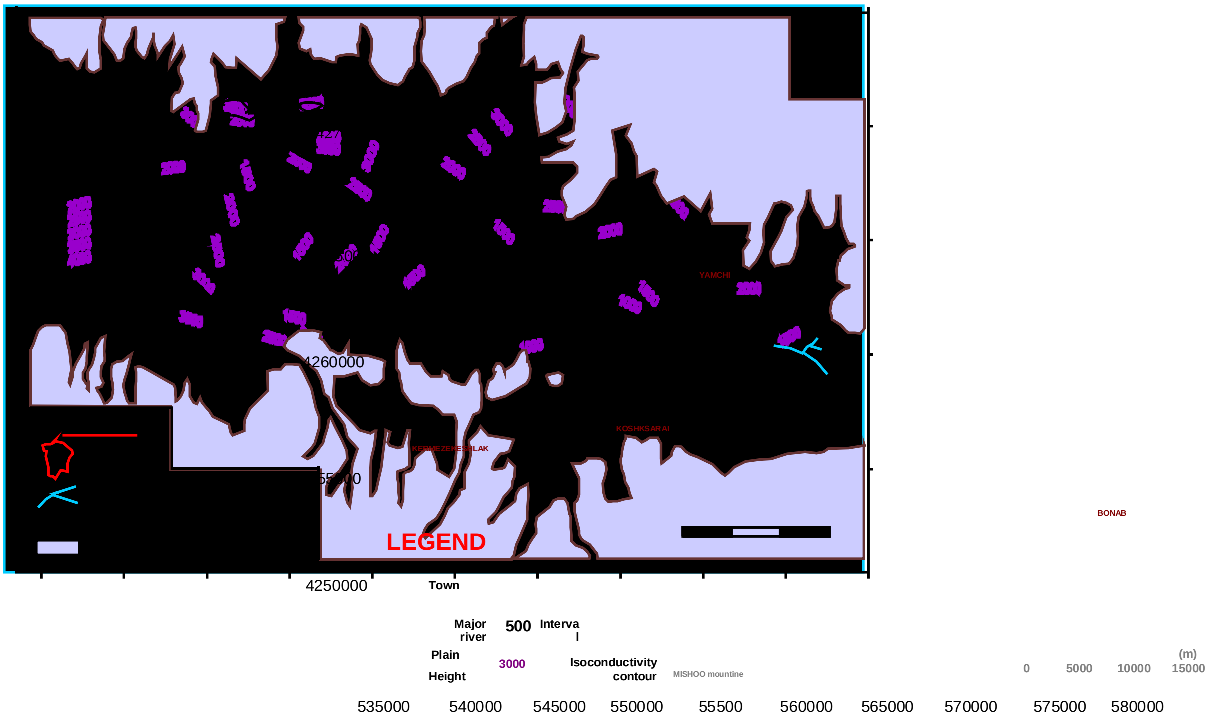
Average: 154 (m^2/d)
The idea

Table 3. Yearly measurements of electrical conductivity over a period of 15 years for all collected samples across the plain.

Year	**Month**	**Electrical conductivity** (?s cm^{-1})
1986	June	1534
	September	1638
1991	June	1475
	September	1631
1996	June	1925
	September	1933
2001	June	2016
	September	2067



(a)



(b)

Figure 5- Isoelectrical conductivity maps, (a) June 1991, (b) June 2001.

Groundwater electrical conductivity of the aquifer varies from about 500 to 1000 ?s cm^{-1} in the southern and southeastern parts of the aquifer to 4000 - 4500 ?s cm^{-1} in the southwest. Figure 5 shows the isoelectrical conductivity map for June 1991 (Figure 5a) and June 2001 (Figure 5b) respectively. The difference in electrical conductivity in recharge, discharge and evaporating areas is very high and variable. Low electrical conductivity and the good quality of groundwater in the southeastern belt of the aquifer are due to the negligible distance between the recharge zone and the existing Pliocene conglomerate. The electrical conductivity in this part of the aquifer ranges between 500 to 1000 ?s cm^{-1}. Similarly in the northern part, the electrical conductivity falls within the range of 3000 to 3500 ?s cm^{-1} because of the recharging process from the marl sediments. But in the southwestern part, the electrical conductivity of the groundwater is high between 4000 and 4500 ?s cm^{-1}, because of the existence of Miocene evaporate sediments which consist of salt, gypsum and marl.

The comparison of the isoelectrical conductivity maps in June 1991 and June 2001 indicates that the electrical conductivity had increased during the period of study, and a higher increase was discovered in the southwestern and northern parts. The conductivity had gone up from 3500 ?~~s-c~~m^{-1} in 1991 to 4500 ?~~s-c~~m^{-1} in 2001 in the southwest.

The average electrical conductivity was calculated by using Teissen polygon method and Equation 1.

$$\overline{EC_n} = \frac{A_1 \times EC_1 + A_2 \times EC_2 + \ldots A_n EC_n}{A_1 + A_2 + \ldots\ldots A_n} \tag{1}$$

where,

any feedback mean,-in

A_n= area related to any polygon

Chemical analysis of 10 groundwater samples across the plain is shown in Table 4. The samples analyzed for, EC, TDS, pH, Anions (CO3, HCO3, Cl, SO4) and cations (Ca, Mg, Na, K). This results indicate that groundwater is characterised by high concentration of almost major cations and anions from 1991 (Table 4a) to 2001 (Table 4b). For example, average total anions increased from 15.47 meq/l to 20.11 meq/l, cations from 15.35 meq/l to 20.10 meq/l and TDS from 1010.5 mg/l to 1309.6 mg/l.

Table 4(a). Chemical data of 10 groundwater samples across the plain in 1991.

UTM		**EC** ?$/cm	**TDS** mg/l	**PH**	**Anions** (meq/l)					**Cations** (meq/l)				
UTM X	**UTM Y**				**CO3**	**Hco3**	**Cl**	**SO4**	**Total**	**Ca**	**Mg**	**Na**	**K**	**Total**
533529	4262200	1152	763	7.7		2.7	4.3	4.4	11.4	2	5.6	3.8		11.4
532750	4259350	708	447	8.2	0.1	4	1	1.95	7.05	1.8	3.7	1.5		7
543010	4262762	1062	692	7.9		3.3	5.2	2.04	10.54	1.4	2.1	7		10.5
576674	4253159	458	294	7.7		3	1.5	0.1	4.6	0.7	0.9	2.9		4.5
563967	4261453	2012	1314	7.7		8	9	3.35	20.35	2.6	5.4	12		20
550700	4266350	1400	891	7.7		7.2	5.5	1.17	13.87	3.4	3.2	7.2		13.8
562500	4270270	1685	1110	6.7		3.6	5.5	7.77	16.77	5	5.6	6.1		16.7
550330	4260857	816	519	7.2		4.2	2.7	1.22	8.12	1.8	3.2	3.1		8.1
557113	4257974	2085	1349	6.6		6.2	6.1	8.5	20.8	7	4.5	9.2		20.7
536491	4257749	4220	2726	7.5		5	27	9.1	41.1	2.5	8.3	30		40.8
Average		1559	1010.5						15.47					15.35

Table 4(b). Chemical data of 10 groundwater samples across the plain in 2001.

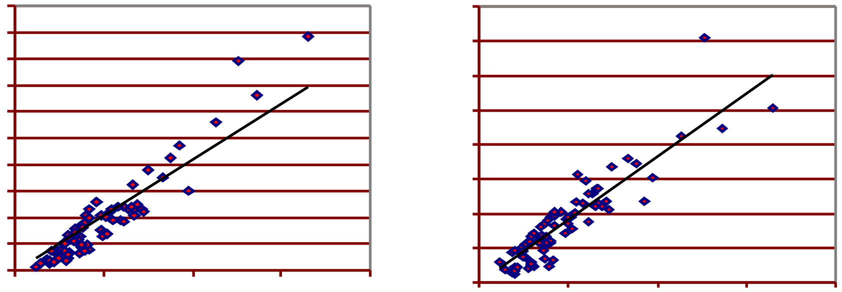
UTM		**EC** s/cm	**TDS** (mg/l)	**PH**	**Anions** (meq/l)					**Cations** (meq/l)				
UTM X	**UTM Y**				**CO3**	**Hco3**	**Cl**	**SO4**	**Total**	**Ca**	**Mg**	**Na**	**K**	**Total**
533529	4262200	1485	961	7.73		3.3	8.5	3	14.8	4	5.4	5.25	0.14	14.79
532750	4259350	785	503	7.26		3.7	1.5	2.6	7.8	3.9	2.1	1.68	0.09	7.77
543010	4262762	1950	1253	7.04		5.7	10.5	3.2	19.4	6	4	9.2	0.16	19.36
576674	4253159	725	441	8.23	0.3	4.2	2	0.71	7.21	2.1	0.7	4.3	0.1	7.2
563967	4261453	2440	1582	7.45		8	12	4.27	24.27	8.2	3	12.8	0.2	24.2
550700	4266350	1420	909	7.21		8.2	5.8	0.12	14.12	3.9	3.3	6.8	0.11	14.11
562500	4270250	2610	1719	7.43		4.7	12	9.3	26	10.2	4.8	11	0.23	26.03
550330	4260857	905	568	8.29	0.5	3.5	3.2	1.8	9	2.3	2.3	4.3	0.09	8.99
560600	4266600	2850	1882	7.64		5	11.5	11.9	28.4	10	6.4	11.8	0.21	28.41
536491	4257749	5050	3278	8.53	0.8	4.2	39.5	5.6	50.1	6	8	35.5	0.61	50.11
Average		2022	1309.6						20.11					20.10

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 ?s cm^{-1} (Freeze and Cherry, 1979, Frohlich and Urish, 2002).

Correlation between unit hydrograph and the average electrical conductivity indicates rise in the electrical conductivity caused by declining groundwater level. However, the main processes influencing the groundwater chemistry are Stalinization, mineral precipitation and dissolution, cation exchange related to the type of sediment or rock adjacent to the groundwater resources and also the fall of water levels.

The reason for increasing 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 exists between Cl, Na and electrical conductivity (r^2>0.8) (Figure 6).



(a) **(b)**

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

Conclusions

Groundwater is the unique source of water for all purposes in the Marand plain. Due to population and agricultural growth, the demand for water has increased significantly and groundwater sources can not meet the demand. The aquifer of the Marand plain is already being over-exploited, resulting a fall in the aquifer level. The unit hydrograph from 1982 to 2000 confirms that water levels have declined by 11.7 m from average 1179.9 m to average 1168.2 m, and still continue to fall by 0.65 m yr^{-1}.

Assessment of the electrical conductivity and the unit hydrograph of the aquifer show an increase in the electrical conductivity with a drop of groundwater levels for the whole region.

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.

Groundwater flow lines, in the western and southwestern parts of the aquifer reach to the impermeable sediments hence giving a rise to the water level to near ground surface (about 3 m). Based on the minimum depth of the groundwater, the evaporation from the aquifer is considered to be negligible.

Fine grained materials containing salt rich deposits in southwest of the aquifer, are likely to be a major factor in increasing salinity in the 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 Marand plain.

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