Sustainable development analyses to evaluate groundwater quality and quantity management

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Abstract In this study, a qualitative and quantitative change of groundwater resources of Damghan Basin was analyzed. Fifty-four active piezometric wells was used in the region which mostly suffer from shortage of drinkable water standard. Physical properties of 59 quality wells have been evaluated in order to determine the quality of groundwater by measuring factors such as pH, hardness, chloride content, electrical conductivity and total dissolved solid (TDS). By physical/chemical analyses, it was concluded that results for selected resources of Damghan Basin have been more comprehensive during 2008–2009 in comparison with other periods because scattered data cover all areas of the basin. By comparing the results with drinking water quality standards (WHO), assessment of water resources were conducted as acceptable to unsuitable. Hydrochemical perspective drawn using Piper diagram indicates that most of the selected water resources in the area contain chloride constituents. However, Na% values indicate that just 83 % of samples are permissible for using in irrigation purposes.

Keywords Groundwater quality · Damghan Basin · Piper diagram · Assessment

Introduction

Many studies have been conducted to evaluate the groundwater quality in different parts of the world (Ehteshami et al. 2014; Ehteshami and Sharifi 2015; Robins 2002; Mishra et al. 2005; Edmunds et al. 2003; Edet 1993; Bohlke 2002; Celik and Yildirim 2006; Gallardo et al. 2005; Gallardo and Tase 2005; Seka et al. 2012; Muellegger et al. 2013; Devic et al. 2014; Han et al. 2014; Baghvand et al. 2010; Aranda et al. 2006). Previous studies focused on the management of groundwater and also on the connection between surface water and groundwater (Jang et al. 2012; Lijzen et al. 2014; Banks et al. 2011; Park et al. 2014; Kornelson and Coulibaly 2014; Han et al. 2014; Basu and Mater 2014; Purwaningsih and Notosiswoyo 2013; Isa et al. 2012). Some researchers studied Kashan Basin in Central Iran (Jamshidzadeh and Mirbagheri 2011). According to their study, most water samples were not potable. In addition, according to the Piper diagram, the chemical characteristics of water are dominated by NaCl. %Na values indicate that just 53 % of samples are permissible for irrigation. In 2010, Baghvand et al. analyzed the hydro chemical quality of groundwater in an aquifer in Central Iran (Baghvand et al. 2010). They found that illegal groundwater pumping, mainly for regional agricultural uses during recent years, has caused groundwater degradation. In 2008, Shah et al. compared the quality of groundwater in Gandhinagar Taluka (India) with the standard values of WHO (Shah et al. 2008). They finally came up with a correlation ratio between electrical conductivity (EC) and dissolved solid (TDS) for natural waters such as

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Fig. 1 Location of Damghan Basin with its chart showing different uses of groundwater

fresh water, sea water and tender coconut (Thirumalini and Kurian 2009). Based on their study, a linear correlation exists between the aforesaid two parameters for freshwater while this correlation is logarithmic for saltwater. Lions

Fig. 3 Water table changes in Damghan Basin

et al. (2014) reviewed studies that address the potential impacts of CO₂ geological storage leakage on fresh groundwater quality (Lions et al. 2014). Geophysical and geochemical surveys were conducted by Anderson et al. (2014) to understand groundwater discharge into Great Salt Lake (GSL) and assess the potential significance of groundwater discharge as a source of selenium (Anderson et al. 2014). Tomaszewicz et al. (2014) studied seawater

Fig. 2 Location of sampling wells in Damghan Basin

Fig. 4 Piper diagrams for selected water resources of Damghan

intrusion as a result of increased urbanization as well as groundwater exploitation and global sea level rise (Tomaszkiewicz et al. 2014).

Population growth is leading to excessive water demand for industrial, domestic and agricultural usage. Damghan is located in a semi-arid zone, has been suffering from the lack of adequate precipitation, especially in recent years. Excessive groundwater withdrawal can lead to problems such as water shortage due to water table decline, increase in water bills as pumping cost increases and the decline in water quality due to saltwater intrusion (Jamshidzadeh and Mirbagheri 2011). The main objective of this study is to provide a comprehensive data on groundwater quality in Damghan Basin. Additionally, we aimed to study the quality and quantity of groundwater in the basin in order to evaluate the suitability of groundwater for drinking and other uses.

Materials and methods

Damghan Basin, with an area of about 5863 km², is located between 53°22' and 54°42' longitude and 35°43' and 36°31' latitude. The basin is bound by Sari-Nekah and Bastam cities on the north, the city of Shahroud on the East, as well as Haj Aligholi Desert, Semnan Desert and the cities of Ghaem-Shahr and Jouybar on the West. The area studied in Damghan is located geographically in the north of Semnan Province and southeast of Mazandaran Province. Twenty-year average temperature of Damghan plain and its highlands has been recorded at 15.3 and 11.6 °C, respectively, with the long-term average temperature in the studied area standing on 13.3 °C. The 20-years average precipitation figures recorded for both the plain and the highlands stand at 130.3 and 216.6 mm, respectively. The average precipitation in the study area has been recorded at about

Fig. 5 Change of EC in Damghan Basin

Table 1 Hydro-chemical parameters for selected water samples in Damghan Basin

Parameter	EC	TDS	pH	Ca	Mg	Na + K	HCO ₃	CO ₃	Cl	SO ₄
Number of samples	59	59	59	59	59	59	59	59	59	59
Arithmetic mean	2884.37	1920.24	8.17	8.33	6.35	14.08	3.55	0.15	17.36	7.69
Maximum	10,490	6990	8.5	58.6	20.5	47.1	7.7	0.5	68.7	31.3
Minimum	1234	820	7.5	2.6	2	2.8	1.4	0	7.2	1.4
Variation range	9256	6170	1	56	18.5	44.3	6.3	0.5	61.5	29.9
Mode	None	None	8.2	4.5	None	None	None	0	None	None
Median	2220	1481	8.2	5.6	4.6	11.8	3.4	0	13.8	5.1
Variance	2,215,364	983,637	0.06	55.48	15.42	48.9	1.74	0.3	101.3	34.86
Standard deviation	1488.41	991.78	0.23	7.45	3.93	6.99	1.32	0.18	10.07	5.9
Variation coefficient (%)	51.6	51.65	2.87	89.42	61.84	49.67	37.15	117.2	57.98	76.78
Coefficient of skewness	0.05	0.05	-0.02	0.1	0.04	0.04	0.02	0.01	0.06	0.04

177.6 mm. Highlands of Damghan are a part of Alborz mountain range, which its height reduces toward south and finally reaches Haj Aligholi Desert. The maximum and minimum height of the studied area stood at 3684 and 1042 m, respectively in northeast and southeast of that area. Figure 1 represents the study area in Damghan. It should be noted that about 91 % of groundwater withdrawal is carried out for agricultural uses, 7 % for drinking and sanitation, and 2 % for industrial uses. The corresponding pie chart of groundwater uses is also shown in Fig. 1.

In this research, 54 observation wells and 59 quality wells were used to evaluate groundwater quality and

quantity. Figure 2 shows the location of sampling wells in Damghan Basin. All samples were analyzed for their physicochemical parameters such as pH, EC, TDS, Cl and hardness.

Results and discussion

Groundwater depletion

In order to determine water table changes in this basin, data obtained from 54 observation wells from 1995 to 2010 were monitored, controlled and released by the Ministry of

Table 2 Quality standards for drinking water, World Health Organization

Parameter	Desirable limit (DL)	Maximum permissible limit (PL)	Health implications
pH	9.2	7–8.5	Taste
EC $\mu\text{mohs cm}^{-1}$	1400	500	Gastro-intestinal irritation
TH (mg/L)	500	100	Scale formation
Na (mg/L)	200		Scale formation
Ca (mg/L)	200	75	Scale formation
Mg (mg/L)	150	50	Encrustations in water supply structure
Cl(mg/L)	600	200	Salty taste
SO ₄ (mg/L)	400	200	Laxative effect
NO ₃ (mg/L)	45	–	Methamoglobinemia
F (mg/L)	1.5	–	Fluorosis
Zn (mg/L)	5	–	Cause astringent taste uses and apolescence in water
Cu (mg/L)	1	–	Discoloration and corrosion of pipes fitting and utensils
Fe (mg/L)	0.3	–	Permutates bacterial growth
Mn (mg/L)	0.1	–	Adverse effect on domestic uses and water supply structure

Energy (Damghan Water Organization) (Fig. 2). Figure 3 represents the mean water table changes and shows mean annual water table changes. According to data obtained from 54 observation wells, the mean water table had declined from 1995 to 2010. Figure 4 and 5 show the increasing trend of drilling wells and groundwater withdrawal for six statistical years. The number of deep and semi-deep wells has increased from 1221 to 1245.

Groundwater quality degradation

Typically, one of the reasons for groundwater depletion is deterioration in quality due to increased salinity. Determination of groundwater quality depends on several physicochemical parameters and their concentrations, which can be measured by conducting laboratory tests. In order to evaluate the suitability of groundwater for different uses such as agriculture as well as industrial and domestic use, data obtained from 59 sampling wells monitored and published by the Ministry of Energy in 2010 were analyzed in this study to determine their physicochemical properties such as pH, TDS, EC and Cl as it shows in Table 1.

Standards set for drinking water in different countries depend on financial, geographical, nutrition and climate conditions, as we cannot define an accurate standard for all people across the world. Drinking water standards suggested by the World Health Organization (WHO) have been shown in Table 2, while Table 3 shows a comparison between standards set by the US Environmental Protection Agency (EPA) and Iran's Ministry of Energy (WHO 2011). These values have been determined on the basis of the maximum amount of elements in water and values above them signify contamination of water. Quality criteria for

Table 3 Comparison of quality standards of water in Iran and the USA

Water quality parameter	USEPA	Iran Ministry of Energy
Nitrate	10	46
Nitrite	1	0.1
Phosphate	0	0.2
Fluoride	600	6
Sulfate	260	400
Chloride	–	600
Calcium	–	200
Magnesium	–	260
Sodium	0.3	–
Iron	–	1
Total solid	–	2000
Total hardness	–	600
Total coliform	0	0
pH	–	–

drinking water are usually based on per capita consumption of 2 L of water per day.

Hydrochemical diagrams

In order to evaluate the type of groundwater, Piper diagram related to groundwater in the area were studied. In this diagram, studied water samples do not show any differentiation in anionic and cationic triangles. In other words, the origins of minerals in groundwater are mostly similar in terms of cations and anions. Determination of the type of groundwater in the study domain shows that in this area three types of chloride, bicarbonate and sulfated types are not actually common, as we see that the dominant type of

Fig. 6 Change of TDS in Damghan Basin

water resource samples are chloride in the plain area. Figure 4 shows the Piper diagram for June 2008.

EC

This parameter represents the status of ions in water samples. Therefore, as the value of ions increases in water, electrical conductivity (EC) improves relatively. Spatial distribution of EC has been drawn for the study domain (Fig. 5). This graph, with the highest value of EC, is related to northeast sections of the aquifer (in the vicinity of Hossein Abad village), which is about $1100 \mu\text{mohs cm}^{-1}$. The increase in salinity in northeast area of the aquifer could be related to the impact of Chah Jam Desert, which is located southeast of the aquifer, because this phenomenon has already occurred as a result of the excessive water withdrawal and the transmission of salinity from the desert to the aquifer. The noticeable point about curves with similar electrical conductivity is their high congestion in northeast areas in comparison with west and southwest, which represents an increase in salinity toward eastern zones.

Table 4 Range of TDS related to water quality

TDS (ppm)	Typical
0–1000	Fresh water
1000–10,000	Brackish water
10,000–100,000	Saline water
>100,000	Brine water

TDS

Curves of 1000 and 7500 mg/L represent the minimum and maximum values of TDS, respectively. Curves representing low values of remaining dry minerals are related to western areas of the aquifer, while the maximum values of curves are related to the southeastern part of Damghan around Chah Jam Desert (Fig. 6). Table 4 shows the range of TDS related to water quality.

In order to gain more knowledge about the relation between TDS and EC values in this region, a regression model was introduced. Hence, we can formulate both values and have more accurate estimation for the area. The population regression model is: $y = B_1 + B_2x_2 + u$; It is

Table 5 Error analyses of measured values

Regression statistics		Explanation
Multiple R	0.989582341	$R = \text{square root of } R^2$
R square	0.97927321	R^2
Adjusted R square	0.978972822	Adjusted R^2 used if more than one x variable
Standard error	159.9969466	This is the sample estimate of the standard deviation of the error u
Observations	71	Number of observations used in the regression (n)

Fig. 7 Changes of chloride concentration in Damghan Basin (2005)

assumed that the error u is independent with constant variance. We wish to estimate the regression line: $Y = b_1 + b_2x_2$. We did this using the Data Analysis Add-in and Regression. In the following, the standard error here refers to the estimated standard deviation of the error term shown in Table 5. It is sometimes called the standard error of the regression.

$$\text{TDS} = 19.575 + 0.666\text{EC}. \quad (1)$$

As it is common to remove intercept value for the relation between TDS and EC; therefore, the final equation could be as follows:

$$\text{TDS} = 0.666\text{EC}. \quad (2)$$

The analyses shows the correlation coefficient of $R^2 = 0.98$. Therefore, the predicted values and real values were acceptably compatible.

Chloride concentration

The concentration of chloride is an index of water salinity and has the highest impact on increasing the value of EC. Additionally, its high concentration in water is not desirable due to the saline taste spreading through the water. According to the diagram prepared for chloride during the sampling period (2009), it was found that there is a correlation between chloride and EC curves of the aquifer (Fig. 7). Table 6 also shows the classification of groundwater based on Cl ion concentration and its environmental impact. The chloride diagram of 2009 shows that there has been a remarkable change in the value of the chloride. We can only point out the extension of minimum salinity curve toward eastern zones of the aquifer followed by a reduction in the value of maximum curve from 70 mg/L to 68 mg/L. Additionally, the general pattern of the curves has changed

Table 6 Classification of groundwater based on chloride concentration

Class	Deviation	Chloride (mg/L)	Concentration
1	Insignificant	<20	Low
2	Moderate	20–60	Moderate
3	Significant	0–100	Fairly high
4	Large	100–300	High
5	Very large	>300	Very high

due to the feeding effect of current rivers in north and southeast areas and has been also studied slightly toward southeast.

Sodium concentration

The standard value of sodium concentration in drinking water is 200 mg/L. The mean value for concentration of this ion in the study area is equal to 320.26 mg/L, which exceeds the standard value. The higher-than-standard value may cause kidney and heart diseases as well as hypertension in humans.

Value of pH

The mean value of pH in groundwater is equal to 8.21, which is a little alkaline but still within the permissible range for drinking.

Conclusion

The main objective of this study was to determine quality and quantity of groundwater in Damghan Basin. According to the unit hydrograph of Damghan plain, the results of this study show that the mean reduction in water table has been 5.88 m with the mean annual loss put at about 0.58 m from 2000 to 2010. The maximum loss of groundwater in west of Damghan was 15 m, which is the result of excessive water withdrawal. Based on this research, the quality of groundwater was unsuitable for drinking in most regions around Damghan Basin and in some areas it could be harmful to human health. The quantity of groundwater in this basin is influenced by saline intrusion from the adjacent desert. By comparing the results with WHO's standards for drinking water, we can conclude that the most of the selected water resources have a water quality between acceptable and unsuitable phase. Hydrochemical diagrams determined using Piper diagram show that the dominant type of water resources in this basin is the chloride type. However, Na% indicates that just 83 % of samples are permissible for use in irrigation.

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