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Assessment of groundwater quantity and quality and saltwater intrusion in the Damghan basin, Iran

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ABSTRACT

This study describes the groundwater quantity and quality conditions in the Damghan aquifer in Iran. The quantitative analysis of data obtained from observation wells indicates overexploitation of groundwater during recent years, which has resulted in deterioration of water quality. The mean water level has declined about 7.4 m between years of 1966 and 2010. The hydrochemical facies of water collected from sampling wells were investigated though Piper and Chadha diagrams, and the general dominant type of water in the study area was determined as Na-Cl. The quality assessment examined the suitability of groundwater for drinking and irrigation purposes. Compared to the World Health Organization (WHO) guidelines for drinking water, all regions were found to have unpotable groundwater. Furthermore, unsuitability of groundwater for agricultural applications due to high salinity was observed through analysis of major quality indicators. The saltwater intrusion was investigated by ionic ratio analyses and was determined to be the main factor contributing to high salinity and deterioration of the groundwater quality in the Damghan basin.

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1. Introduction

The escalation of the global population has resulted in a tremendous increase in water demand during recent decades. This ever-growing water demand from both domestic and agricultural uses has led to overexploitation of groundwater, especially in regions with arid, hot climates and poor surface water resources.

Many researchers have assessed the groundwater quality in various basins around the world (Arumugam and Elangovan, 2009; Baghvand et al., 2010; Basavarajappa and Manjunatha, 2015; Gautam et al., 2015; Jamshidzadeh and Mirbagheri, 2011; Jang et al., 2012; Moujabber et al., 2006; Raju, 2007; Raju et al., 2015; Sherif et al., 2011; Srinivasamoorthy et al., 2014; Wanda et al., 2011). Moujabber et al. (2006) concluded that monitoring and early detection of salinity in groundwater are necessary for further water management and remediation. There have been numerous research efforts that have assessed the quality of groundwater reserves in Southern India through analysis of collected samples (Arumugam and Elangovan, 2009; Basavarajappa and Manjunatha, 2015; Raju, 2007; Srinivasamoorthy et al., 2014). Among those, Raju (2007) and Arumugam and Elangovan (2009) investigated the geochemical properties and suitability of groundwater for drinking and irrigation by analyzing its major ions and chemical indices. Jang et al. (2012) established an irrigation management plan of groundwater resources based on the spatial variability of water quality and quantity parameters in a plain prone to severe land subsidence and seawater intrusion in Taiwan. Wanda et al. (2011) assessed the dominant hydrogeochemical processes affecting the quality of groundwater in Northern Malawi. The modeling efforts by Cobaner et al. (2012) indicated that a projected increase in groundwater use would lead to further seawater intrusions into the Goksu Delta, Turkey, which could harm crops and productivity of farmlands. Gautam et al. (2015) performed a comprehensive evaluation of groundwater quality conditions for both drinking and irrigation purposes in a river basin in India. And finally, two separate studies of an aquifer in Central Iran used the groundwater facies and spatial distribution of major water quality indicators to examine groundwater quality degradations due to saltwater intrusion (Baghvand et al., 2010; Jamshidzadeh and Mirbagheri, 2011).

While all of the aforementioned studies have provided invaluable results from around the world, they have predominately focused on limited quality indicators, and many have neglected to assess both aspects of drinking and irrigation suitability of

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Table 1
The physicochemical parameters for samples collected within the Damghan basin.

Sampling Well ID	Geographical Coordinate		pH	EC (μs/cm)	TDS (mg/L)	Cations (meq/L)					Anions (meq/L)					Total Hardness (mg as $CaCO_3$)	$Cl/(HCO_3+CO_3)$
	X	Y				Ca	Na		Mg	Total Cations	CO_3	HCO_3	SO_4	Cl	Total Anions		
W1	233600	3983400	7.9	2180	1450	2.6	16.6	10.13	2.5	21.97	0	1.5	5	15.2	21.7	255	10.13
W2	240800	3989200	7.7	1540	1029	3.8	9.5	2.69	2	15.65	0	3.5	2.6	9.4	15.5	290	2.69
W3	244050	4002600	7.9	1810	1203	3.3	12.2	10.31	2.5	18.14	0	1.3	3.5	13.4	18.2	290	10.31
W4	246350	3987550	8.2	1580	1052	3.6	8.7	3.76	3.5	15.91	0	2.5	4	9.4	15.9	355	3.76
W5	249800	3999900	8.2	3490	2320	8.7	19.1	3.85	6.2	34.17	0	5.5	7.5	21.2	34.2	745	3.85
W6	252700	3982250	8.1	2550	1700	5.1	16.1	5.63	4.4	25.68	0	2.4	9.3	13.5	25.2	475	5.63
W7	254500	3976850	8.4	3800	2530	7.8	23.2	11.77	6.6	37.66	0.4	1.8	9.7	25.9	37.8	720	11.77
W8	257950	3980700	8.5	1888	1253	7	9.6	5.08	2.4	19.08	0.4	2	4.2	12.2	18.8	470	5.08
W9	260900	3985150	8.5	2810	1865	5.5	16.2	7.88	6.7	28.52	0.4	2.2	4.9	20.5	28	610	7.88
W10	263400	3992300	8.4	1845	1230	4.5	10.5	2.84	3.7	18.75	0.4	3.9	2	12.2	18.5	410	2.84
W11	265650	4008400	7.5	3550	2370	13.7	11.7	3.73	10	35.81	0	4.5	14.3	16.8	35.6	1185	3.73
W12	269250	3998400	8.5	4830	3220	15.1	21.8	6.27	11.1	48.02	0.4	4.7	10.7	32	47.8	1310	6.27
W13	272825	4011600	7.8	4450	2960	13.2	22.2	2.36	8.8	44.64	0	7.2	20.4	17	44.6	1100	2.36
W14	280800	4014150	7.7	3970	2640	15.5	11.8	4.06	12.4	39.97	0	4.8	16.2	19.5	40.5	1395	4.06
W15	251750	3997750	8	2130	1424	6.1	7.1	2.02	8.2	21.64	0	4.5	8	9.1	21.6	715	2.02

groundwater. Also, assessing both the quality and quantity conditions of groundwater reserves may lead to more effective future decision making and subsequent establishment of any necessary regulations. By assessing multiple characteristics of groundwater parameters, this study aims to provide a more robust interpretation of true groundwater conditions.

Located in a semi-arid region with limited annual precipitation, Iran is identified as a country with high likelihood of water shortage crises in the near future (Baghvand et al., 2010). Groundwater resources supply more than half of the country's total water demand, and massive withdrawals have led to quality depletion of several aquifers, particularly those located in the vicinity of deserts. Continuous groundwater level drawdowns and subsequent negative hydraulic gradients may contribute to the hazard of saltwater intrusion. Consequently, there is a consistent necessity for monitoring the groundwater quality to evaluate its suitability not only for drinking, but also for other purposes.

Due to recent intense domestic and agricultural activities in the Damghan region of Iran, the assessment of groundwater hydrogeochemistry in this region is essential. While there are studies assessing the groundwater quality deterioration in central Iran (Baghvand et al., 2010; Jamshidzadeh and Mirbagheri, 2011), currently there are no comprehensive studies assessing the groundwater quality in the Damghan basin. Therefore, the primary objective of this study is to ascertain the groundwater quality for drinking and irrigation purposes in this area. The high withdrawal rates from this basin, combined with arid climates, are suspected to have had an adverse effect on the quality of the aquifer. The salt lake and salt domes surrounding the study area may also accelerate the rate of any potential groundwater quality deterioration due to the saltwater intrusion. A secondary objective of this document is to provide guidance for similar future studies that intend to evaluate the suitability of groundwater resources for various uses in other regions throughout the world.

2. Description of the study area

The Damghan plain has an area of about 5865 km^2 and lies between northern latitude of 35° 43′ to 36° 31′ and eastern longitudes of 53° 22′ to 54° 42′. The Damghan basin, with an area of approximately 1400 km^2, is surrounded on the north by the Alborz Mountains and a range of salt domes and on the south by the Haj-Aligholi desert, part of which constitutes a salt lake. The maximum and minimum elevations of the study area are 3756 and 1,023 m, respectively. The groundwater in the Damghan basin flows from the northeast and southwest regions toward the east. The location of the study area within Iran is shown in Fig. 1. This area has an annual average precipitation depth of 127.3 millimeters, temperature of 16.3° Celsius, and relative humidity of 57%. Because of the arid, hot climate governing the study area, groundwater is the only water source for urban and agricultural purposes. Rapid urban development, as well as increase in agricultural activities, has resulted in overexploitation of the Damghan basin. Different uses of groundwater across the study area for 2008 indicated that agricultural applications include more than 95% of groundwater consumption. Approximately 3% of groundwater consumption was for drinking and sanitation purposes and the rest was used for other applications, including industry and livestock.

3. Materials and methods

Various physicochemical parameters of 15 sampling wells, as reported by the Ministry of Energy (the Semnan Water Organization) in 2010, were analyzed to assess the groundwater quality of the basin. The layout of the sampling wells within the study area is