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RESEARCH PAPER

Exploitation management of potable groundwater in a desert region of northeast Iran: GIS multi–influencing factors

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Abstract
The potable groundwater crisis has escalated in Davarzan crucial alluvial aquifer due to over–exploitation and poor management, though it acts as a reliable resource during the drought situations. Davarzan crucial aquifer is located near the salty playa and ophiolite complex in a desert area at northern Iran. The main aims of the paper were determining groundwater potential zoning and exploitation management of potable groundwater using the quality instruments associated with implementing multi–quantity–hydrogeology criteria. The trend of increasing EC values and groundwater flow direction are from the northern to the southern adjacent desert. Based on the GIS modeling, the two potable groundwater potential zone maps were produced using the qualitative (pollution and salinity) and quantitative layers. Both layers have made most of the groundwater unsuitable in the central and southern parts of the area. Although most of the north and northwest parts of the area falls under the good groundwater potential zone for potable usage, overexploitation of the groundwater has caused the groundwater level to decline and salinity increase towards the aquifer. Therefore, for exploitation management of potable groundwater without causing additional storage loss in this desert region, sustainable yield is advised and it could be turning potable water wells into agricultural wells. The results of this research have significant implications in exploitation management of potable groundwater in desert regions.

Keywords: Groundwater Budget, Overexploitation, Qualitative Layer, GIS, Davarzan, Iran

Introduction

Groundwater is an important resource for human wellbeing, economic development and sustainable agriculture (Fagbohun 2018). More than 60% of agricultural practices are based on groundwater as a source of water (Thakur, Bartarya, and Nainwal 2018). With extractive technology improvements, the use of this water resource for human consumption and agriculture has increased considerably over the last few years (Garrido et al. 2006). In addition, in many arid and semi–arid regions of the world, groundwater resources have declined sharply since the mid–twentieth century for a number of reasons, including industrial and agricultural development, urbanization, population growth, and declining rainfall (Ray et al. 2017). Dependence on underground water is expected to increase in the future and needs in 2050 are estimated about three times the current level as a result of population growth (Jasrotia et al. 2016). Therefore, there is an urgent need to map areas that may hold substantial groundwater resources for future uses (Thakur et al. 2018).

Aquifers with fresh water in the subsurface are very localized (Satpathy and Kanungo 1976). For this reason, researchers are very interested in mapping the different potential groundwater

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areas (Das and Pardeshi 2018). Groundwater mapping is defined as a very important tool for the systematic development and planning of water resources (Elbeih 2015). Spatial hydrogeological maps provide spatially distributed information about aquifers, including their geological, hydrogeological, and hydrochemical–pollution characteristics (Díaz–Alcaide and Martínez–Santos 2019). Groundwater maps allow planners to develop sustainable management strategies. In addition, they make it possible to identify suitable areas for locating productive wells. It also helps to understand the vulnerability of groundwater aquifers and associated ecosystems to pollution and over–exploitation, identifying areas for artificial recharge, and transmitting information to groundwater users (Díaz–Alcaide and Martínez–Santos 2019, Ahmed and Sajjad 2018). Groundwater availability is dependent on many factors such as geology, geomorphology, slope, soil texture, drainage density, linear concentration, rainfall, land use of an area. (Magesh et al. 2012, Ganapuram et al. 2009, Mukherjee et al. 2012). These factors can be interpreted in GIS using remote sensing data (Ganapuram et al. 2009).

GIS and RS are very important tools for groundwater studies, especially for complex systems (Howari et al. 2007). They are widely used to assess, monitor and manage visual representation in a variety of fields including the environment, disasters and hydrology (Jasrotia et al. 2016) (Kaur et al. 2020) (Patra, Mishra, and Mahapatra 2018). Studies performed by remote sensing and GIS to explore groundwater susceptible areas show that the factors involved in determining potential groundwater areas are different and hence the results vary accordingly (Magesh et al. 2012). Many studies in the field of GIS and remote sensing have yielded useful results in delineating groundwater potential zones (Murthy 2000, Sreedevi et al. 2005, Arulbalaji et al. 2019, Avtar et al. 2010, Shekhar and Pandey 2015, Sadeghfam et al. 2016, Al–Ruzouq et al. 2019).

Groundwater resources remain an important source of water for livelihood in most parts of Iran. Unfortunately, the lack of scientific management of groundwater resources has led to a decrease in groundwater levels throughout Iran as a result of high water abstraction (Chitsazan and Movahedian 2015). This situation has intensified in the eastern regions of Iran due to successive droughts and the lack of adequate rainfall, especially in recent years. Therefore, accurate study and knowledge of water resources is of particular importance. In this regard, determining areas with better potential for groundwater abstraction is necessary for the optimal management of these valuable resources. Davarzan aquifer is one of the important aquifers in Khorasan Razavi province, which supplies potable and agricultural water of Davarzan area. Due to recent droughts and uncontrolled exploitation of groundwater resources, this aquifer has experienced a significant decline.

The main objectives of this study are: (i) Preparation of maps of various factors affecting groundwater in GIS. (ii) Determining potential groundwater areas and verifying them. (iii) Determining the path of groundwater flow. (IV) Estimating the groundwater budget as a key step to achieve proper management and protection of this important resource. Therefore, the paper ends with a discussion of qualitative tools related to the implementation of multi–quantitative hydrogeology criteria for groundwater potential zoning in GIS and management of potable groundwater exploitation in the region.

Study area

Davarzan plain is the westernmost plain of Razavi Khorasan Province, located between 36°10° to 36°20° north latitude and 56°45° to 10°57° east longitude. This plain, with an area of 703.2 square kilometers, has a relatively elongated shape and has valuable groundwater resources called Davarzan aquifer (Figure 1). The city of Davarzan with a population of about 22 thousand people is the main city of this plain and uses the aquifer of this plain for drinking and agriculture purposes.

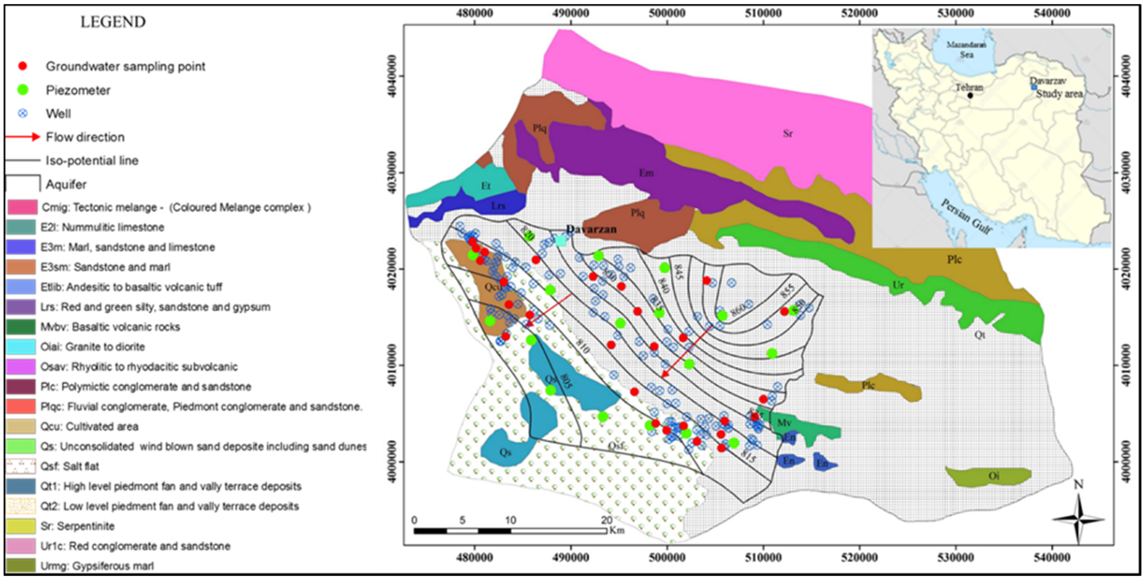

Figure 1. Geological map and iso–potential line of the study area

The oldest formation in the region belongs to the Cretaceous, which is observed in the northern heights of the plain as a series of ophiolite mélanges (Mazhari and Attar 2015). But in general, the largest area of the formations belongs to the third and fourth geological eras, and the largest extent is related to the Quaternary, Miocene and Paleogene. Sediments of the Tertiary period of geology are mostly in the form of Paleogene conglomerate, tuff, andesite and evaporite sediments of chalk and salt in the south and in the slopes of the northern highlands of the plain (Moghadam et al. 2015). Most of the recharge of the Davarzan aquifer occurs from the northern ophiolitic heights with a maximum height of 2920 meters above sea level. The general direction of groundwater flow is from northeast to southwest of the aquifer (Figure 1). Davarzan aquifer is of unconfined type and the water table in it is monitored by a 17 observation wells since 1991 until now. There is no surface water in the Davarzan aquifer area and only in the rainy season (winter to spring) runoff from the northern highlands occurs locally. Groundwater in the Davarzan aquifer is drained by 185 deep and semi–deep well for drinking and agriculture purposes. The annual average rainfall, temperature and evaporation are 142 mm, 18.2°C and 2824 mm, respectively.

Methodology

The method adopted for this study is summarized in Figure 2. In this study, each of the factors affecting the determination of groundwater potential zone (GPZ) in separate layers were entered into GIS software. These parameters are: Groundwater recharge rate, hydraulic conductivity, groundwater depth, groundwater drawdown rate, saturation zone thickness, groundwater salinity and pollution.

Groundwater recharge rate was estimated based on water level fluctuations using equation 2. This equation is based on the assumption that an increase in the water level in unconfined aquifers is due to the recharge water arriving at the water–table (Scanlon et al. 2002, Jafari et al. 2019).

$$R = S_y \Delta H / \Delta t \qquad (1)$$

Where Sy is the specific yield of the aquifer and ΔH represents the is change in water–table height over time interval Δt. To calculate the recharge, the annual increase of the water level was measured in 18 piezometers installed in the Davarzan aquifer in a statistical period of 10 years. Also, specific yield values were obtained based on the pumping test results in the area. The annual recharge rate was estimated by multiplying the specific yield value around each piezometer and the groundwater increase values according to equation 1.

The results of pumping tests and drilling logs in Davarzan aquifer were used to estimate the appropriate values of hydraulic conductivity. Also, the depth of the groundwater of Davarzan aquifer was measured by piezometers installed in the aquifer. To determine the annual groundwater drawdown rate in different parts of Davarzan aquifer, the total drawdown during the 10–year statistical period (September 2011 to August 2020) was calculated using the hydrograph of each piezometer. Then, by dividing the total drawdown by the number of years of the statistical period, the annual drawdown per piezometer was calculated. The thickness of saturated zone was also estimated based on the results of exploratory excavations and geophysical results in Davarzan aquifer.

In order to prepare qualitative layers (electrical conductivity and pollution), 26 samples of groundwater were taken in September 2021 from the pumping wells of Davarzan aquifer (Figure 1).

To prepare qualitative layers (electrical conductivity and pollution), 26 groundwater samples were taken in September 2021 from the pumping wells of Davarzan aquifer (Figure 1). Physical parameters, including pH, temperature and electrical conductivity (EC) were measured in situ. For the analysis of selected heavy metals, 1.5 liters of each sample was taken in black glass containers that were pre–cleaned using ultrapure water. All samples were immediately filtered through acid–treated Millipore filters (0.45 µm mesh, disposable not reusable) into pre–cleaned polyethylene–terephthalate (PET) bottles. The filtered samples were acidified to pH<2 with ultra–purified 6 mol/L HNO3 to prevent metal precipitation. The samples were preserved at about 4°C and immediately transferred to the Laboratory in Iran to determine the heavy metals concentration (Fe, Zn, Cu, Ni, etc) by ICP–MS method. Then the heavy metal pollution index (HPI) was calculated based on equation 3.

$$.HPI = \frac{\sum_{i=1}^{n} WiQi}{\sum_{i=1}^{n} Wi} \quad (2)$$

The Heavy Metal Pollution Index (HPI) shows the overall water quality with regard to heavy metals. where, W_i is denoted as the unit weight of the ith parameter metal (was computed as: $1/S_i$), (Prasad and Bose 2001, Hoaghia et al. 2019), Q_i is the sub–index of the ith parameter and n is the number of heavy metals measured. Q_i is expressed as follows

$$Qi = \sum_{i=1}^{n} \frac{|Mi-Ii|}{Si-Ii} * 100 \quad (3)$$

where M_i is the value measured for the ith heavy and Ii is the ideal permissible limit for the ith heavy metal, and S_i Standard permissible value. The S_i and I_i values are presented in Table 1.

Table 1. S_i and I_i values of heavy metals for calculating HPI (Sudegi et al. 2023)

Heavy metals	Standard permissible value (ug/l) (Si)	ideal permissible vaue (ug/l) (Ii)
As	50	10
Ba	700	–
Cr	50	–
Cu	1500	50
Fe	300	–
Ni	70	20
Pb	50	10
Zn	15000	5000

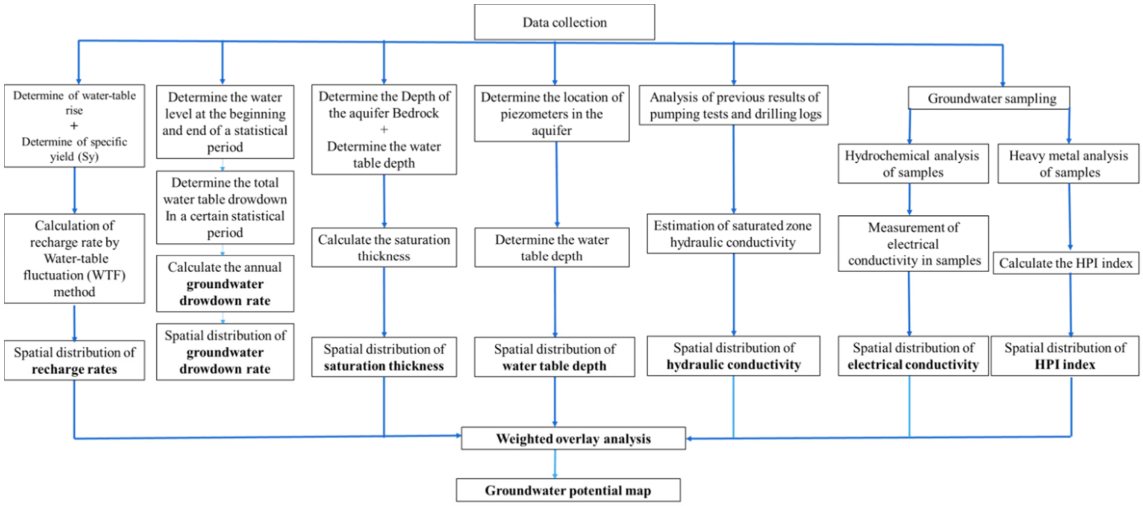

Figure 2. The research's flow chart, briefly explaining all the main activities that have been carried out throughout this study

The method used in the present study is called weight overlay analysis, in which the weight of multiple factors is calculated using the weighted linear composition (WLC) method (Malczewski 1999). Following equation provides a simplified equation of WLC:

$$\text{Groundwater potential zone} = \Sigma A_i X_i \quad (4)$$

where, A_i = weight of each factor, X_i= individual factor.

Weighted overlay and classify

The thematic layers of recharge rate, discharge rate, groundwater depth, groundwater drawdown rate, saturation zone thickness, groundwater salinity, and groundwater pollution were used for the delineation of groundwater potential zones (GPZ) in the study area. Each thematic layer has been given weightage according to their strength. The effect of each influencing factor may contribute to delineating the groundwater potential zones (Magesh et al. 2012). All of these thematic layers were integrated using Arc Info GIS software to delineate potential areas. The weight of different themes was determined based on their effect on groundwater potential on a scale of 0 to 100% (Table 2). The different characteristics of each subject assigned weights on a scale of 1 to 10 due to their relative impact on groundwater potential (Table 2 and Fig. 4). The total weight of the various polygons in the integrated layer was obtained from the following equation to obtain the groundwater potential index (Rao and Briz–Kishore 1991):

$$GPZI= ((Rr_w)(Rr_{wi}) + (Dr_w)(Dr_{wi}) + (Gd_w)(Gd_{wi}) + (Gdr_w)(Gdr_{wi}) + (ST_w)(ST_{wi}) + (Gs_w)(Gs_{wi}) + (Gp_w)(Gp_{wi})) \quad (5)$$

where GPZI is groundwater potential zone index, Rr is recharge rate, Dr is discharge rete, Gd is groundwater depth, Gdr is Groundwater drawdown rate, ST is saturation zone thickness, Gs is groundwater salinity and Gp is groundwater pollution. The 'w' and 'wi' refer to the normalized weight of a theme and the normalized weight of the individual features of a theme, respectively.

Results and discussion

The methodology combines GIS with the Analytic Hierarchy Process (AHP). Multiple seven thematic layers were generated. For the first time, the new parameters such as annual decline rate, annual exploitation rate, salinity, pollution effect are used to investigate the potential of the aquifer in this study in an arid region. After the AHP procedure and rank assignment, the thematic layers were integrated using the raster calculator to obtain the groundwater potential zones map. So, the paper concludes with a discussion of quality instruments associated with implementing multi–quantity–hydrogeology criteria for groundwater potential zoning and exploitation management of potable groundwater in the area.

Table 2. Ranks and weights for thematic layers and their subclasses

Thematic Layer	Thematic Layer Weight (%)		Classes	Ranks
	Considering the quality parameters	Regardless of quality parameters		
Recharge rate (mm/y)	15	25	9_15	2
			16 – 22	3
			23 – 30	5
			31 – 43	7
			44 – 58	9
Hydraulic conductivity (m/d)	15	25	<10	5
			10 _ 20	7
			21 –30	9
Water table drawdown (m/y)	15	20	0.065 – 0.162	9
			0.163 – 0.228	8
			0.229 – 0.278	7
			0.279 – 0.327	5
			0.328 – 0.425	3
Water table depht (m)	5	10	2 _ 24	7
			25 – 48	5
			49 – 79	4
			80 – 115	3
			116 – 150	2
Saturation zone thickness (m)	20	20	68 – 77	5
			78 – 86	6
			87 – 95	7
			96 – 105	8
			106 – 115	9
Electrical conductivity (µs/cm)	10	_	547 – 1164	9
			1165 – 1631	8
			1632 – 2134	7
			2135 – 2750	5
			2751 – 3457	3
HPI	20	_	<50	10
			50 – 100	8
			>100	2

Recharge rate

Groundwater recharge in Davarzan aquifer was estimated using water level data in each piezometer based on water table fluctuations (WTF). To estimate groundwater recharge based on the WTF method, groundwater increases related to recharge events during the rainy season were calculated based on the hydrographs of each piezometer and then combined to estimate the annual increase (ΔH). Specific yield values in the Davarzan aquifer were also determined based on previous pumping results. Then the annual rates of the groundwater recharge per piezometer was estimated based on Equation 1. According to the results, the annual recharge rate in Davarzan aquifer varies from 9 to 58 mm per year. The spatial distribution of the annual recharge rate (mm/y) was classified into five segments, viz., (I) 9–15, (II) 16–22, (III) 23–30, (IV) 34–43 and (V) 44–58 (fig.3). The lowest recharge rates occurred in the northeastern aquifer, and the highest recharge rates occurred in the northwestern aquifer.

Hydraulic conductivity

Hydraulic conductivity in the Davarzan aquifer was estimated based on the previous results of pumping tests and drilling logs. Spatial distribution of hydraulic conductivity in different aquifer areas is shown in Figure 3. According to Figure 3, the highest value of hydraulic conductivity in Davarzan aquifer is related to the northeast and the lowest value is in the southwest of the aquifer. According to Figure 3, spatial distribution of hydraulic conductivity (m/d) was divided into 3 groups: (I) 8 – 15, (II) 16 –22 and (III) 23–30.

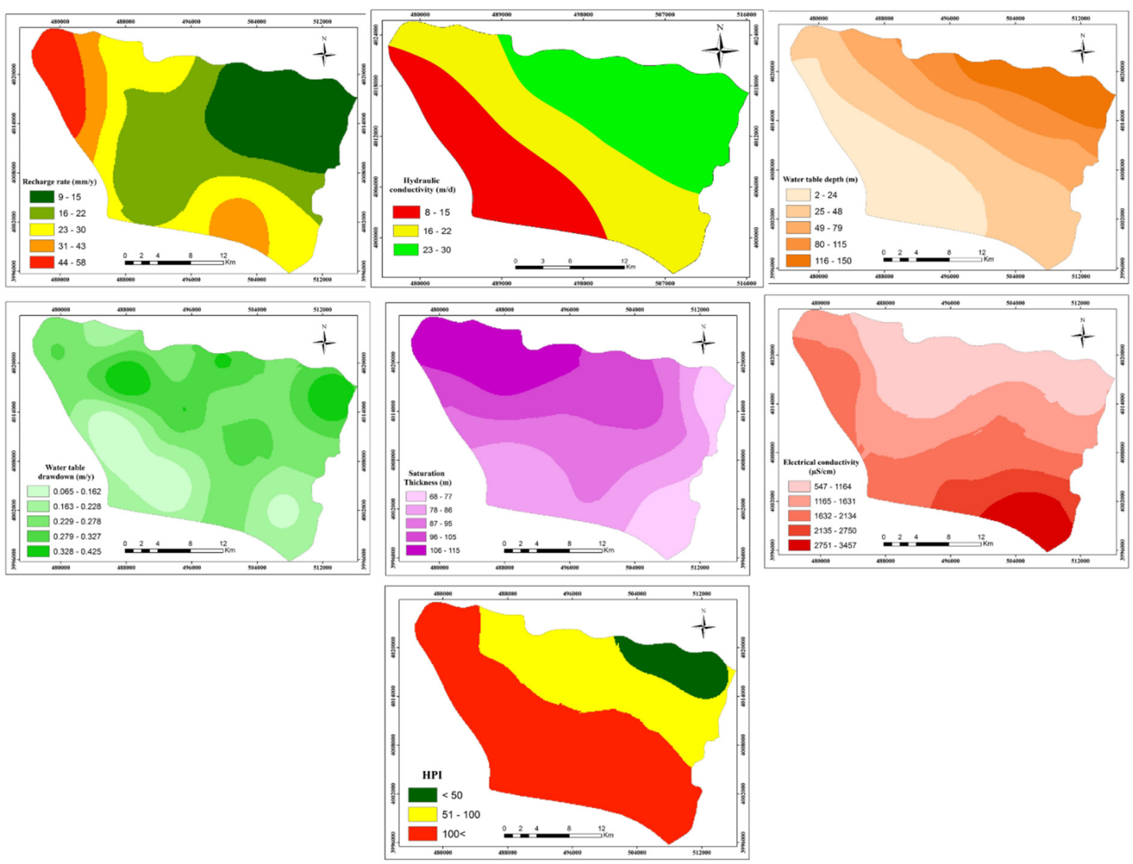

Figure 3. Spatial distribution of effective parameters in the groundwater potential zone of the study area

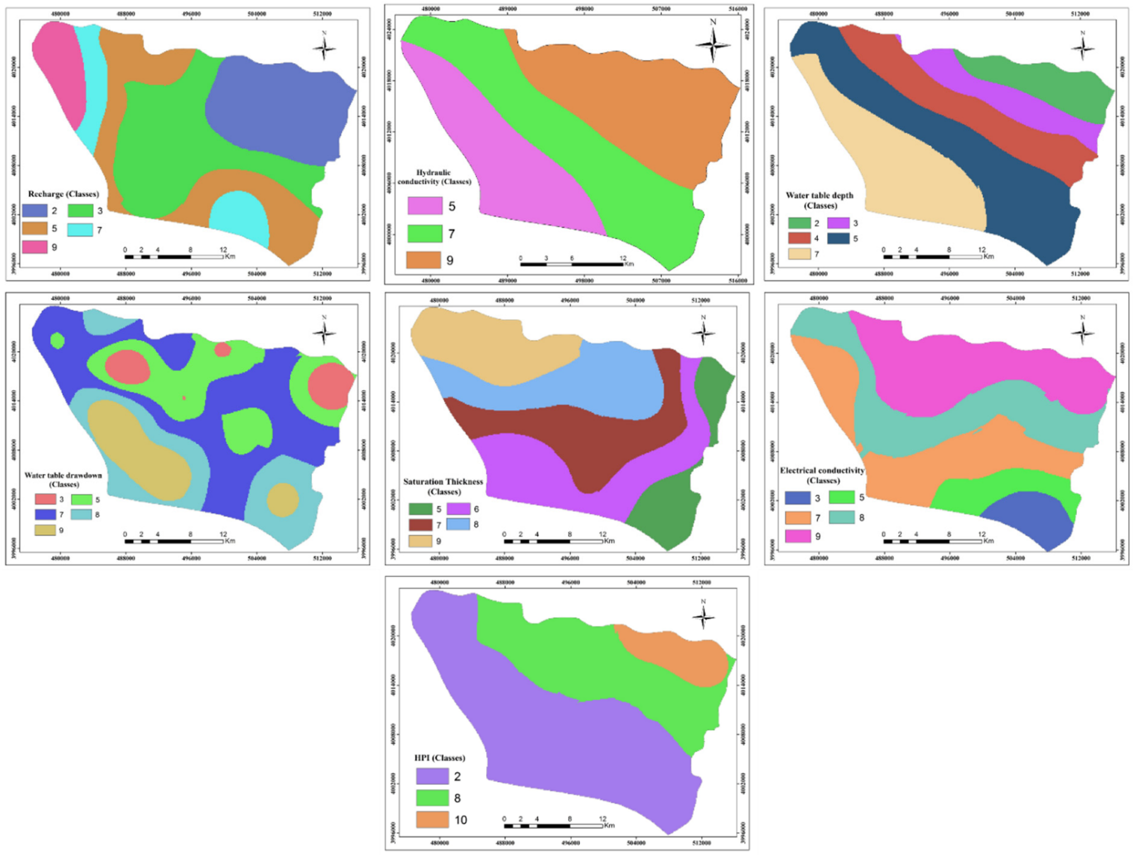

Figure 4. Ranking and classification of thematic layers

Groundwater depth

Groundwater depth data of Davarzan aquifer were collected from the piezometers around the study area. Groundwater depth varies from a minimum of 2 meters to a maximum of 150 meters in different parts of the aquifer. Spatial distribution of groundwater depth are plotted using GIS software and are presented in Figure 3. The lowest groundwater depth is in the southwestern part of the aquifer. Towards the northeast of Davarzan aquifer, the groundwater depth has increased and in the northeast of the aquifer has the greatest depth. Groundwater depth values (meter) were divided into 5 categories. (I) 2–24, (II) 25–48, (III) 49–79, (IV) 80–115 and (V) 116–150 (fig. 3).

Groundwater drawdown rate

Water table drawdown rate of 18 piezometers was calculated in the period of September 2011 to August 2020. The rate of water table drawdown during this 10–year period in the aquifer varies from 0.065 in the southwest of the aquifer to 0.42 meters per year in other parts of the Davarzan aquifer. The distribution of groundwater drawdown rate during the study period (September 2011 to August 2020) is presented in Figure 3. According to this map, water table drawdown rate was classified into 5 groups: (I) 0.065 – 0.162, (II) 0.163 – 0.228, (III) 0.229 – 0.278, (IV) 0.279 – 0.327 and (V) 0.328 – 0.425.

Saturation zone thickness

In order to investigate the thickness of the saturation zone in the aquifer, various factors can be used, including geophysical studies, drilling logs for exploratory wells and exploitation. Based on the results of drilling logs in Davarzan aquifer, the thickness of the saturation zone in different parts of it was estimated. The spatial distribution of the saturation zone thickness is presented in Figure 3. The maximum thickness is in the northwest of Davarzan aquifer and its minimum thickness is in the eastern half of the aquifer. Spatial distribution in saturation zone thickness were divided into 5 categories: (I) 68 – 77, (II) 78 – 86, (III) 87 – 95, (IV) 96 – 105 and (V) 106 – 115 (Fig.3).

Groundwater salinity

Electrical conductivity is one of the most important hydrogeochemical parameters that is directly related to the total solutes in water. By examining the changes in this parameter, we can understand the changes in the concentration of ions in the flow path. Various factors affect the amount of electrical conductivity, including rainfall, aquifer lithology, water retention time, water velocity, aquifer withdrawal, saline infiltration and sewage leakage. The amount of electrical conductivity in the Davarzan aquifer varies from 574 to 3457 µSiemens/cm. In order to study the changes in electrical conductivity in this region, the electrical conduction zoning map in the region have been drawn and shown in Figure 3. According to the map, the amount of electrical conductivity in the northern half of the aquifer is minimal and increases to the south of the Davarzan aquifer. The classification of electrical conductivity (µS/cm) is as follows: (I) 1547 – 1164, (II) 1165 –1631, (III) 1632 – 2134, (IV) 2135 – 2750 and (V) 2751 – 3457.

Heavy metal pollution index (HPI)

Heavy metal pollution index (HPI) shows the combined effect of each heavy metal on the overall quality of water (Sheykhi and Moore 2012). To calculate the HPI of groundwater, the concentration of selected metals (arsenic, barium, chromium, copper, iron, nickel, lead and zinc) was considered. HPI values were calculated for each sample. According to HPI results, the pollution category was composed of three grades as follow: low (HPI < 50), medium (HPI = 50 –100), and high (HPI > 100) contamination (Bhuiyan et al. 2010). The spatial distribution of the HPI is presented in the Figure 3. Only a small part of the northeast of the study area has lower HPI. In the northern third of Davarzan aquifer, the HPI is medium and in a large part of the aquifer, the HPI is high. The high HPI value in large parts of the aquifer is representative of high risk water that cannot be used for drinking. In other parts of the aquifer that had HPI values below the critical pollution value (100), which is indicative of low risk water that is suitable for human consumption.

Groundwater potential zoning

The two GPZ maps were produced using the qualitative and quantitative layers. The groundwater potential zone map (GPZ) was prepared by overlaying of cumulative weight assigned to all the thematic layers (recharge rate, discharge rate, groundwater depth, groundwater drawdown rate, saturation zone thickness, groundwater salinity, and groundwater pollution) using the weighted overlay techniques in spatial analysis tool of IDW method and based on Equation 1. In the weight overlay analysis process, each thematic layer was determined based on its potential for water abstraction (highest potential in terms of quantity, quality and pollution) based on their ranking and weight (Fig. 4). Higher and lower weights were given to higher and lower groundwater potentials, respectively (Fig. 4). After assigning the ranking, the weight of each layer was added and the total was grouped in the potential groundwater zone. All layers were converted into raster format and overlaid.

The groundwater potential zone map was classified into 3 classes: good, moderate and poor.

The qualitative and quantitative layer has been used to determine the potential groundwater areas for potable usage (Fig. 5). The potable groundwater potential zone mainly encompasses the northwestern, western and a small part of the center of the plain. It demarcates areas of the aquifer that are more suitable for potable groundwater abstraction in terms of quantity, quality and pollution. These areas cover approximately 210 km^2 of aquifer area (30%). The town of Davarzan as well as some small villages are located in this zone. The central part of the aquifer and some parts in the south and southwest of the study area fall under moderate groundwater potential zone. It encompasses an area of 198 km^2, which is about 28% of the total aquifer. However, the groundwater potential in a small part of the northeast and a large part of the southern half of the Davarzan aquifer is poor, covering an area of about 295 km^2 (42%).The poor groundwater potential is due to the groundwater pollution and salinization of groundwater due to saline water intrusion from the salt pan in south part of the aquifer (Fig. 1). Also, reducing the thickness of the saturation zone in this area exacerbates the poor potential of groundwater.

The groundwater pumping wells in the Davarzan aquifer are mostly drilled in the northwest and southeast of the area which are fall in the high and moderate potential zone (Fig. 5). The northwestern part of the aquifer has a higher potential to supply water to the wells due to reduced salinity, low pollution, high recharge rate of the aquifer, as well as a significant thickness of the saturation zone and less annual drawdown; while the wells drilled in the southeast of the aquifer are in a critical condition that sustainable development management in this part of the aquifer can prevent further destructive effects.

If the qualitative layers (pollution and salinity) in GPZ are ignored, very few areas will have "poor" potential for groundwater abstraction and a large percentage of the aquifer area will have "moderate" to "good" potential for groundwater abstraction.

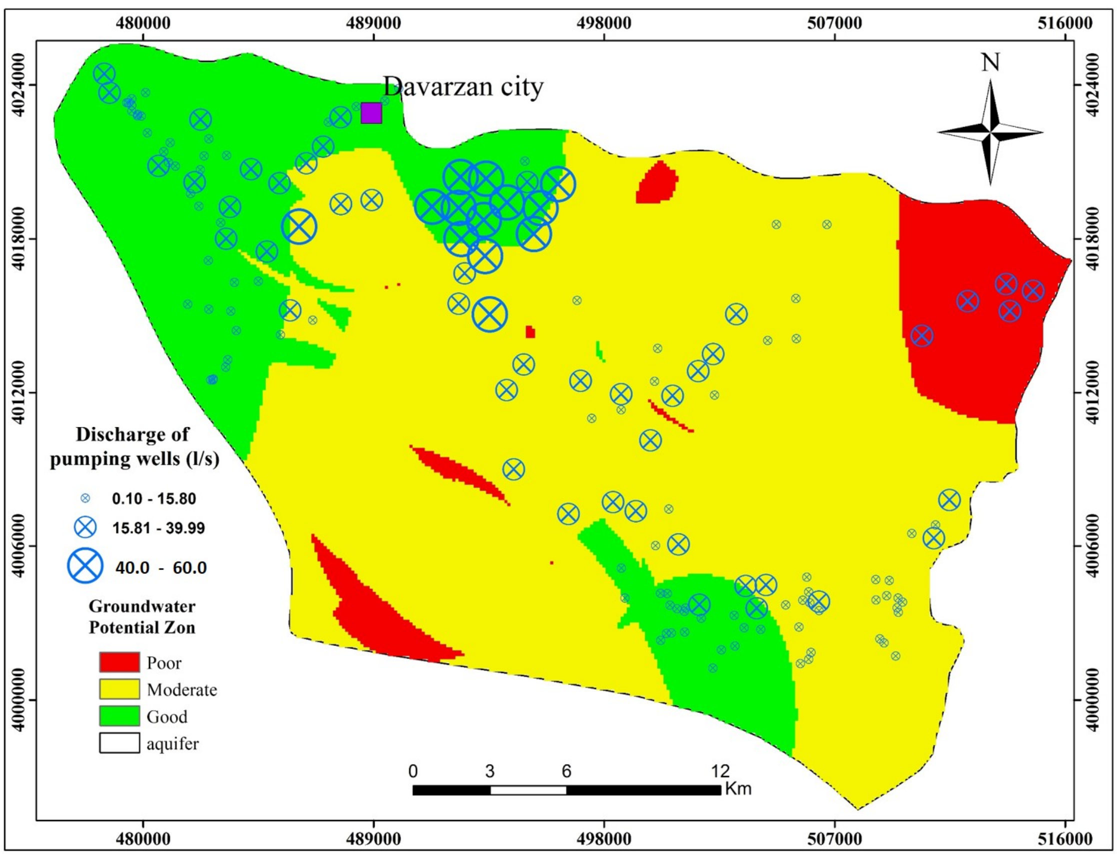

Figure 5. Potential groundwater zone in the Davarzan aquifer (without quality parameters)

According to Figure 6, if the two layers of groundwater pollution and salinity are removed, only limited parts of the northeast of the aquifer and scattered parts in the center and south of the aquifer will have red (“poor” groundwater potential) conditions for abstraction.

The modeled potentiality maps were validated by a comparison of the distribution of high GPZ values and the spatial distribution of existing pumping wells in the region. Davarzan aquifer is discharged by 185 deep and semi–deep pumping wells. The discharge rate of the wells was divided into three groups: 0.1–15, 15–40 and 40–60 (lit/s). The GPZ maps were overlaid by the spatial distribution of existing pumping wells in the study area (Figs. 5 and 6). The results showed that there is a positive correlation between the distribution of areas with “good” potable groundwater potential and the location of existing pumping wells, while areas with “poor” groundwater potential have a lower concentration of pumping wells. In addition, the highest annual discharge is related to the wells that located in the green areas (with “good” groundwater abstraction potential). This verification will also be true if the qualitative parameters are removed. As can be seen in Figure 6, the spatial distribution and discharge rate of the pumping wells are often related to the areas that have “good” potential for potable groundwater abstraction.

Groundwater budget and exploitation management of the potable groundwater

The groundwater budget is basically defined as the long–term balance between the amounts of groundwater that flows into and out of an area annually. The negative budget of ground water in Davarzan aquifer is mostly due to the decrease in the amount of recharge and excessive exploitation of the groundwater aquifer. According to the unit hydrograph (Figure 7), the aquifer of Davarzan, with a specific yield of 0.05, shows a decrease in the average annual volume of 7 MCM.

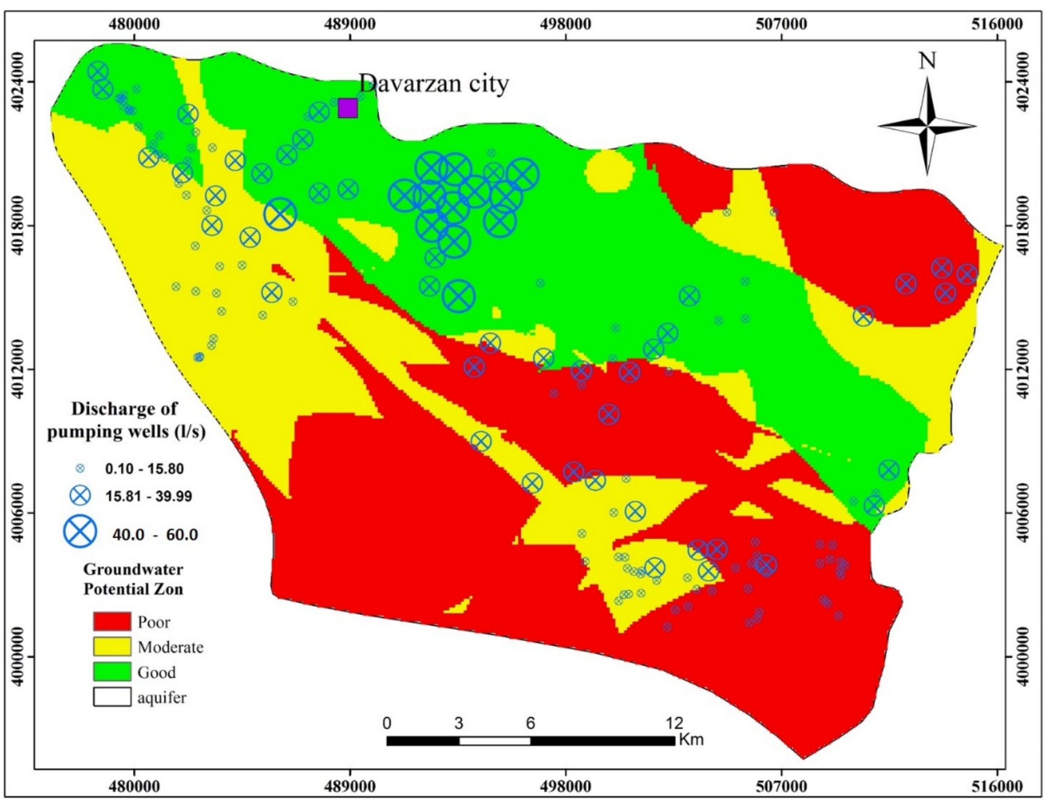

Figure 6. Potable potential groundwater zone in the Davarzan aquifer (including quality parameters)

As shown in Figure 8, the lowest water level decrease is related to the piezometers located in the southern part of the plain, show an average drop of about 0.1 meters per year. In this part, the concentration of pumping wells is relatively low, and due to the poor quality of groundwater, the discharge rate of these wells has decreased. The most important reason for the further decrease in the center, north and northwest of the region is the high concentration of pumping wells and overexploitation of the aquifer. In general, overexploitation of the aquifer has detrimental effects on the hydrogeological settings of the groundwater system, including a decline of the groundwater level, increasing pumping costs, reducing water storage, and thus reducing well yield.

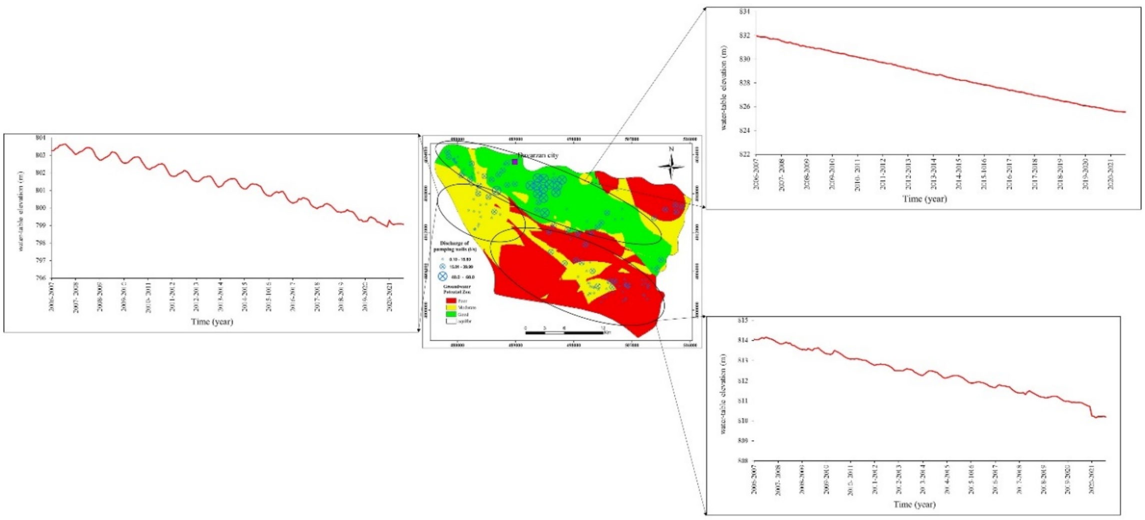

Figure 7. Unit hydrograph of the Davarzan aquifer displaying the water level change during a long period in the three zones

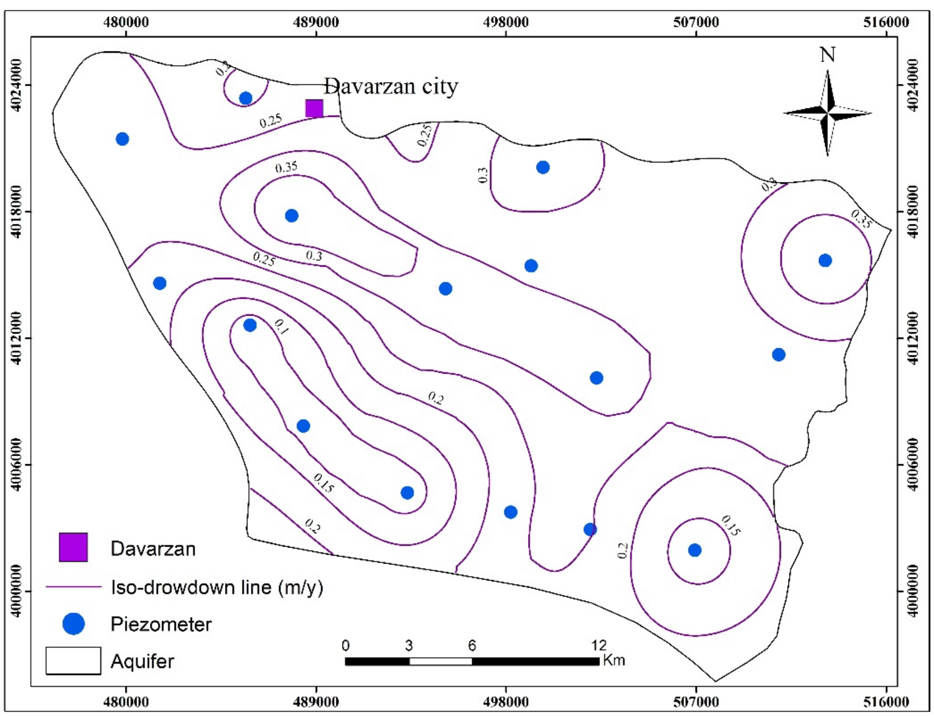

Figure 8. Values of groundwater level drop (m/year) in Davarzan plain aquifer

Although most of the north and northwest parts of the area falls under the good groundwater potential zone for potable usage, but, overexploitation of the groundwater has caused the decline of the groundwater level with rate of 0.35 m/year (Fig. 8) and consequently, the intrusion of saline water towards the aquifer from the southern salty plain. For better conservation of the groundwater in these areas, sustainable yield should be done. So that, for exploitation management of potable groundwater without causing additional storage loss in this desert region, one of the solutions could be turning potable water wells into agricultural wells.

Conclusions

This paper was an attempt to delineate potable groundwater potential availability in Davarzan crucial aquifer, Northeast of Iran. This region is overusing its groundwater resources. The most important controlling variables that affect the groundwater availability were recharge rate, hydraulic conductivity, groundwater depth, groundwater drawdown rate, saturation zone thickness, groundwater salinity, and groundwater pollution. The results showed that 30% of the total study area (the north, northwestern, and a part of the aquifer center) falls under the "good" groundwater potential zone.

The Davarzan plain aquifer, with a storage coefficient of 0.05, shows a yearly average volume reduction of 7 Mm^3. Overexploitation of the aquifer has destructive effects on the hydrogeological setting of the groundwater system in the area, including the decline of the groundwater level, increased pumping costs, water storage depletion and consequently well yield reduction. The interesting statements of this study is combining the potable groundwater mapping with exploitation management based on the hydrogeology setting. Although most of the area falls under the good groundwater potential zone for potable usage, but, for exploitation management of potable groundwater without causing additional storage loss in this desert region, sustainable yield from a hydrogeological point of view is advised. This model helps reduce the problems caused by ignoring the spatial characteristics of aquifers and more accurate exploration of groundwater sources.

Declaration competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

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Article Highlights:

Davarzan region is overusing its groundwater resources
The potable GPZ map was produced using the qualitative and quantitative layers in GIS
Exploitation management of potable groundwater without causing additional storage loss
This study is useful for better planning and management of groundwater resources

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