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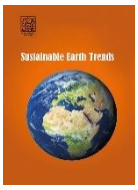

Indiscriminate exploitation of the underground water resources of Jiroft Plain and its consequences

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ABSTRACT

Jiroft Plain in the south of Kerman province with dry and semi-arid climatic conditions, relies on underground water resources, the purpose of this research is to investigate the quantity and quality of underground water in a part of Jiroft Plain, to identify and evaluate the consequences of the drop-in water level and to propose. All meteorological, hydrological, water, geological, and geographical information about the region were collected and analyzed. Using the information of quantitative and qualitative changes of underground water in the last few years, and assuming the continuation of the current process of feeding and emptying the aquifer, the situation of the next 10 years was also predicted. According to the calculations, the level of underground water in the plain has been decreasing in the past years, so from the water year 82-83 to 92-93 with an annual average of 0.5 meters, it has dropped to 64.5 meters in the period. Research results showed that the indiscriminate extraction of the plain's underground water table has resulted in consequences such as changing the quality of the underground water, and increasing the vulnerability of the plain to drought and land subsidence. They control water harvesting, determine the waters of the agricultural sector, change the cultivation pattern, and prepare the optimal cultivation pattern according to the land and climate conditions. The region, stating the problems and increasing the users' knowledge, is one of the findings of this project in management solutions.

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1. Introduction

Today, the occurrence of severe accidents and disasters related to changes in the climate in the world is increasing (Feldmeyer et al., 2020, Savari and Moradi, 2022). In recent years, the concern of most countries in the field of shortage of water resources, climate change, intensity and duration of drought and its effects, caused more attention they have been to climate crises (Khatibi et al., 2019). Lack of water in the sector's other economic effects have destructive effects and the field limits the human environment (Savari et al., 2022) and severe losses on crop production Agriculture has imported (Jia et al., 2020). In addition to being an essential resource for agriculture, water plays an important role in the social and economic development of regions it plays different roles (Savari and Amghani, 2022). Water for all kinds of economic activities, including energy production and food is needed (Marston et al., 2018) and it is closely related to the preservation of human generations (Singh et al., 2020). This is while according to the report of the Assembly Global Economy, water shortage and its crises are one of the five of the world's an important risk (Warner and Diaz, 2021). Reducing the quantity and quality of suitable water is one of the most important challenges for human consumption is the environment of the 21st century that humanity is facing (Aprile and Fiorillo, 2017; Liu et al., 2020). The growing population in Iran and as a result those land use changes and the increase of urban activities, Industrial and agricultural increase the exploitation of resources the underground water has been so that these sources in recent years, at risk of contamination, slight decline and decline are located qualitatively (Savari et al., 2020). From the first consequences of population increase, excessive pressure on water resources followed by improper management of resources there has been a quantitative and qualitative reduction of water and agricultural resources (Safa and Valinia, 2020). In such conditions, inelastic compaction occurs due to the increase of the effective stress in the soil, and the arrangement of the soil grains is disturbed, and the new arrangement causes a decrease in the volume and vertical thickness of the layer and finally settlement (Bell, 1999). Land subsidence, which is called a silent earthquake, is a type of geological hazard that can occur due to various factors such as excessive withdrawal of underground water tables, earthquakes, volcanic activities, and floods (Shahid and Hazarika, 2010), analyzed the groundwater level and rainfall times in northwestern Bangladesh. Their results showed that the increase in underground water extraction for irrigation in dry seasons and the return of droughts were among the factors of the groundwater level drop in this region, and if there was no human intervention in the groundwater system, it would be one of the factors of the groundwater drop. It was mainly related to the decrease in rainfall (Mohammadi et al., 2018) evaluated the impact of climatic factors on the drop in the underground water level of the Saveh Plain aquifer and showed that the construction of Saveh Dam on the Qara Chai River can be the main reason for the drop in the underground water level in the Saveh Plain aquifer (Khoshhal et al., 2013). Also showed that excessive withdrawal from underground water tables and long-term droughts have had a destructive effect on the drop in the water level in the Dehgolanain of Kurdistan province (Hadas et al., 1982) showed that water with a high sodium absorption ratio (SAR) decreases soil stability and eventually decreases permeability due to the dispersion of clay particles and their swelling. Such waters cause a decrease in permeability and an increase in surface sediment. The development of agriculture in the last few decades has led to an increase in the exploitation of underground water resources in the Jiroft Plain. As a result of over-harvesting and lack of feeding of aquifers, there has been a large drop in the underground water level. Therefore, the purpose of this research, with attention to the necessity of increasing knowledge and participation in society's resource management and elimination of incorrect management policies an attempt is to determine the consequences of using multi-year cross-sectional data based on the participation of farmers and experts .From extracting topwater from the underground water table, issues and water management problems in the Chardoli region of the study to be able to plan the future from the results of the research used.

2. Material and Methods

The studied area has an area of about 2085 square kilometers and is located in the Jazmurian watershed at the longitude of 28 ′29 ˚57 and ′10 ′12 ˚58 ˚E, latitude ′20 ′15 ˚28 and ″05′55 ˚N at an average height of about 700 meters (Fig. 1).

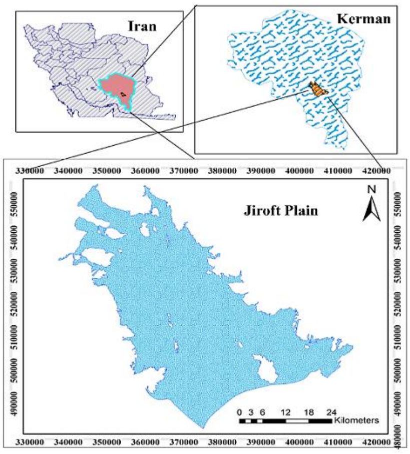

Fig. 1. Geographical scope of the study area

Jiroft Plain is a depression filled with alluvial material and its thickness reaches 300 meters in the central parts. This plain is a part of the sedimentary basin of central Iran and is the place where the upstream deposits are concentrated. The average annual rainfall in this area is 185 mm and the average monthly temperature is about 26 degrees Celsius. Jiroft Plain has always been one of the most important agricultural hubs in the country, and the presence of vast lands with agricultural use is one of its prominent features. In order to recognize and evaluate the effects of illegal withdrawal from the underground water table of the Jiroft Plain and the vulnerability of the region to this issue, first the available information related to the water and hydrogeological resources of the plain was examined and the year of 2011 was more complete than that. It became the basis of work for other years. After that, the meteorological, hydrological, geological, and geographical information of the region was collected and analyzed from different sources. In order to study the quantitative changes of underground water, the information related to the location and average groundwater level of the observed wells and using the ArcGIS of the plain was entered into the interpolation software, the map of the depth of the water level in different years was drawn and the map of the drop rate was drawn by subtracting from each other. The underground water level of the plain was prepared for these 6 years. Using water level lines and geological and topographic maps of the area, the feeding currents and the direction of the underground water flow were determined. The results of the chemical analysis of 70 rings of water samples from wells operating in different parts of the plain were used to investigate the changes in the quality of underground water. By using ArcGIS software, a map of the electrical conductivity of water in different parts of the plain was obtained for each year, as well as a map of salinity changes during this period. To show the temporal changes in water quality parameters, the values measured in two different periods of 2004 and 2014 were used, and after it was zoned with the best model, the percentage of changes was obtained using the anomaly method, which anomalous values negative values indicate the improvement of quality and positive values of anomaly indicate the decrease of quality in the plain. in such a way (Equations 1 and 2):

$$SAR_{Anomaly} = \frac{SAR_{1386} - SAR_{1378}}{SAR_{1378}} \times 100 \quad (1)$$

$$EC_{Anomaly} = \frac{EC_{1393} - EC_{1383}}{EC_{1393}} \times 100 \quad (2)$$

3. Results and discussion

3.1. The faults of Jiroft Plain and its role in the aquifer condition of Jiroft Plain

The effect of tectonic processes in the form of tensile and compressive forces has created many fractures and faults in Jiroft Plain. Vertical movements creating faults with a high angle have created faults with N-S and NW-SE trends, whose last displacement was created in the Quaternary period. These faults have caused the Jiroft watershed to become a sunken valley. After the erosion of the surrounding mountains, the alluvial sediments of this valley have been directed and deposited into the plain by the Halil and Shur rivers through channels. The most important of these faults are the Sabzevaran Fault, Jiroft Fault, Dosari Fault, and Kahnuj Fault, which have caused changes in the underground water reservoir and are very clear, which always play a role as productive zones, with potential and suitable for aquifer storage (Faryabi et al., 2010). From the hydrogeological point of view, the faults in the Jiroft plain play a very valuable and effective role in directing the underground water flows from the mountainous part to the plain and increasing the permeability on one side of the alluvial fault. There is never the same permeability on both sides of the alluvial fault on the one hand due to crushing and on the other hand due to pulverization. In general, the function of faults in enriching the aquifer is within a specific and limited radius. The effect of the mentioned faults has been seen in the sections or fronts of the groundwater entering the plain with higher permeability values.

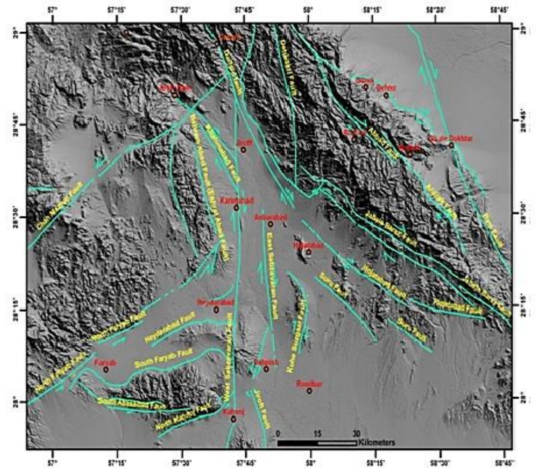

Fig. 2. The state of Faults in the Jiroft Plain and the distribution of wells in the area

3.2. The condition of underground water tables in different parts of Jiraft Plain

Jiroft Plain consists of Quaternary sediments and includes two free and pressurized aquifers. Of course, under pressure, the aquifer is limited to the edges of the plain and turns into a free aquifer. The young alluvial cones in the eastern margin of the plain, which are formed from rock fragments with weak melting, are one of the important sources of feeding the aquifer. In general, the feeding resources of the plain include rainfall, infiltration from the bed of Halil-Roudriver, canals, irrigation, drainage canals, and agricultural return water. The aquifer of Jiroft Plain is a system consisting of aquifer, permeable, and impermeable layers, which was created in a flood depression. The bedrock of this system is most likely composed of cemented Neogene conglomerate, whose topographical order is messed up due to the operation of faults. The thickness of the aquifer decreases from north to south. In the middle part of the plain, there is a thick impervious layer with a thickness of 3 to 6 meters, which has caused the formation of semi-pressure, pressure, and artesian aquifers in its lower part. The northern, eastern, and western elevations of the plain play the most important role in feeding this table, and the highest amount of discharge takes place in the southern regions. The general direction of the hydrological gradient and groundwater flow of the plain is from the north and northeast to the south and southeast, but in the southern regions, the hydrological gradient has been reversed due to high harvesting (Khatibi et al., 2019).

Fig. 3. Pictures of the studied area, a: Indiscriminate extraction of the plain's underground water.
b: The beginning of cracks in the plain

3.3. Geological condition of Jiroft Plain

According to the general geology of the region, Jiroft Plain is a vast basin of sediments of the fourth era, it seems to be an active tectonic basin. The morphology of this plain is under the influence and control of the activities of the young and main faults of Jiroft and also to a large extent of the Halil River. The diversity and expansion of the huge terraces of this river, especially in the northern areas of the plain, is the result of major factors such as climate changes and the performance of young faults in the area, especially since the course of the river is sometimes under the influence and control of the aforementioned faults. Oligocene formations including conglomerate with limestone, sandstone, marl, and finally Asmari-type reef limestones are outcropped in the vicinity of Halil River, especially 20-kilometer northwest of Jiroft. The Oligocene formations are located on the Eocene debris sediments, and the Jurassic formations including tuff, shale, and basic lavas with a different slope contact are seen under the Eocene sediments with a large expansion (Ramological map 1.100000 Jiroft). Jiroft Plain had active tectonics during the Quaternary period, faults such as Sabzevaran, Dosari, and Kahnuj faults during the Quaternary period caused morphological changes and topographical irregularities in parts of the Jiroft Plain (Shafiei Bafti et al., 2009) (Fig. 5). The effect of these displacements in the underground water reservoirs of this region is in the form of changes in the topography of the bedrock and irregularities in the water flow rate of the wells. The slope of the plain is very low and most of the parts have a slope between 0 and 2%, there is a slope above 10% in very few areas and it is mostly observed in the eastern, western, and northern foothills of the plain and Alluvial cones. The central and southern areas of Jiroft Plain have a slope between 0 and 2%. Fig. 3 this has caused the alluvial sediments of this part of the plain to be fine-grained and the alluvial materials of steeper areas to be coarse-grained. The height of the researched area affects the type and amount of rainfall, evaporation and transpiration, the intensity of radiation, the state of vegetation, and generally the climate. The largest area of the plain is located at an altitude of 600-700 meters, Fig. 4 and there are very few lands above 1350 meters in the plain, and the average height of the Jiroft Plain is 757.6 meters. Tectonic and neotectonics processes in the form of tensile and compressive forces have created many fractures and faults in Jiroft Plain (Fig. 5).

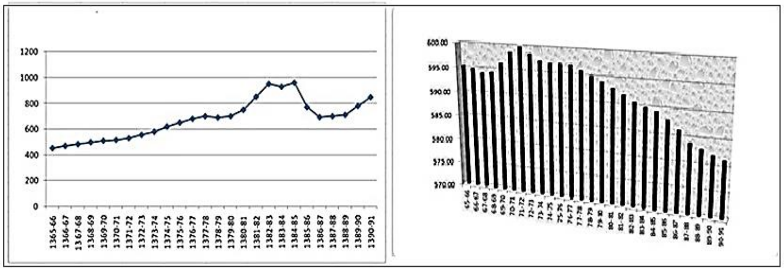

Fig. 4. Chart of changes in the amount of withdrawal from the underground water resources of Jiroft plain during the years 1986 to 2012

3.4. Groundwater status of Jiroft Plain

Extraction of water from underground aquifers for agricultural activities in Jiroft Plain by 1230 deep wells with a discharge of 637.4 million cubic meters, 3899 semi-deep wells with a discharge of 322.3 million cubic meters, 252 aqueducts with a discharge of 40.5 million meters cubic and 543 mouths of springs with a discharge of 42.9 million cubic meters. The general direction of the underground water flow in the Jiroft Plain is from the northwest to the southeast of the plain, and the depth of the groundwater is between 20 and 120 meters. The 26-year hydrograph of Jiroft Plain was drawn based on the information of the Kerman Regional Water Organization (2012) and using the average level of underground water in the observation wells of Jiroft Plain during the period 1986 to 2012 shows the changes in the amount of water withdrawal during the years 1986 to 2012. Based on this, it can be said that the process of withdrawing groundwater from Jiroft Plain is increasing and only from 2006 to 2007, a slight decrease in the amount of water withdrawal is observed. According to the hydrograph of the plain; in the period of 26 years, the drop of the water level has been estimated at an average of 0.59 meters per year. In 1366, the underground water level was 595 meters. The total drop in the underground water level of Jiroft Plain in the space of 26 years (1986 to 2012); is 14.2 meters, which shows an average drop of 0.5461 meters per year. According to the statistics of 26 years, in general, the trend of underground water level drop in Jiroft Plain is increasing and the underground water level is always decreasing. In such a way that the drop from 0.59 meters between the water years of 1986-87 has reached 0.73 meters between the water years 2010-2011 to 2011-2012. In the water year of 1390-1391, the underground water level decreased from 581.737 meters to 0.581 meters, so in this year, 0.74 meters of underground water level has been observed. The data in Table 1 shows that the underground water level has been decreasing during the last 26 years, except for the peak period of 1991-1993, 1997 and 1998.

Table 1. Changes in the underground water level in the Jiroft Plain during the years 1987 to 2012

Row	Water year	Groundwater level	Changing Procedure	Row	Water year	Groundwater level	Changing Procedure
1	1986-1987	595.4235	decrease	14	2000-2001	594.978	decrease
2	1987-1988	594.8325833	decrease	15	2001-202	594.0975833	decrease
3	1988-1990	593.9805833	decrease	16	2002-2003	593.0340833	decrease
4	1990-1991	594.283	decrease	17	2003-2004	591.8599167	decrease
5	1991-1992	596.1996667	Additive	18	2004-2005	590.75125	decrease
6	1992-1993	598.5413333	Additive	19	2005-2006	589.8565	decrease
7	193-1994	599.7963333	Additive	20	2006-2007	589.3843333	decrease
8	1994-1995	598.4864167	decrease	21	2007-2008	587.78875	decrease
9	1995-1996	597.1980833	decrease	22	2008-2009	586.10425	decrease
10	1996-1997	596.8301667	decrease	23	2009-2010	584.0355	decrease
11	1997-1998	596.90475	Additive	24	2010-2011	582.98225	decrease
12	1998-1999	596.9513333	Additive	25	2011-2012	582.1189167	decrease
13	1999-2000	595.9101667	decrease	26	2012-2013	581.2866667	decrease

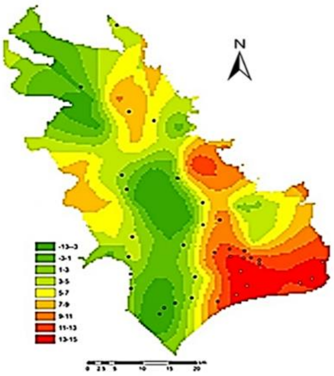

Fig. 5. Zoning of Jiroft Plain based on the level of groundwater level drop

3.5. Changes in the quality of underground water in the Chiroft Plain

In general, atmospheric precipitation that is the result of rain increases with its solubility characteristic while passing through and penetrating the mass of rock or soil in the form of surface and underground flows of its chemical salts. While the flow of underground water passes through the rock and soil layers while washing and dissolving part of the dissolved substances, the amount of salt increases, and the dissolved solutes in the underground water increase. The qualitative evolution of the aquifer is influenced by factors such as bedrock type, flow environment, water contact time with the soil layers, as well as the concentration areas of exploitation, the high level of underground water, and the formation of evaporation zones of the aquifer, which results in the release of dissolved salts. They are found in the water and are effective in the process of qualitative evolution of the aquifer. The conducted evaluations show that the quality of underground water sources is good in the margins of the highlands and alluvial cones, and gradually towards the end of the plain in the direction of the groundwater flow, the amount of dissolved salts in the water has increased, so that in some areas, the situation is unfavorable for the use of water. There is no vector. These changes are directly related to the quality of feeding water sources, geological formations, the type of alluvial layers, and the amount of exploitation.

Table 2. Statistical summary of EC and SAR data during the statistical period of 2013 (n=44)

Elongation	Crookedness	At least	Maximum	Variance	Standard deviation	Average	Variable
7.07	2.48	188.5	3442.5	390975	625.3	882.1	EC (µmhos/cm)
2.37	2.67	211	11.11	5.98	2.44	3.02	SAR
3.88	1.90	376.5	3330	392433	626.4	990.33	EC (µmhos/cm)
0.02	1.03	0.482	8.55	4.92	2.21	3.16	SAR

3.6. Zoning maps of groundwater quality parameters

In the present study, the kriging method and the best model, which are exponential and spherical models respectively, were used to prepare the EC and SAR maps in 2004-2005 and 2014-2015, the results of which are presented in Fig. 6. The zoned maps of electrical conductivity in the year 2014-2015 (Fig. 6 b) indicate that the minimum and maximum values of electrical conductivity of the aquifer area are 376.5 µmhos/cm and 3330 µmhos/cm, respectively. In the eastern and northeastern areas of the aquifer plain, the quality of underground water is the best. The underground water in this area has values less than 680 µmhos/cm. From the mentioned area to the north-west and south-west areas, the quality has gradually decreased and the electrical conductivity has increased to more than 2000 µmhos/cm. As a result, water salinity has increased by 11% on average from 2004 to 2014, although the salinity changes are not the same in the plains. However, the map of SAR values in 2006-2007 and 1999-2000 (Fig. 6 b and 6 d) shows that the minimum and maximum SAR values in the aquifer area are 0.09, 0.06, and 33.82, 66 respectively. It is 29.0 mg/liter and also the spatial changes of SAR in the plain have the same behavior as EC in both periods and it has increased by 5.51% on average. The percentage of SAR changes in the plain is very high (Fig. 6 a) so these changes are between -96.2% and 990%. Among the factors related to the sodium absorption ratio, we can mention the drop in the underground water level. As shown in Fig. 6-b, the piezometers of Binaloud restaurant at 7.23 meters, Bagheriehat9.65 meters, and Sultan Abad Namek road at11.15 meters drop during the period 2007 to 2008-2009 have a significant drop. It has had a great impact on the quality parameters, but the Taghi Abad piezometer located in the northern part of the plain, which is under proper nutrition, has a drop of -0.2 meters, which has improved the water quality in the northern parts of the plain. Extraction of underground water for agricultural purposes causes a part of the water to leave in the form of evaporation-transpiration.

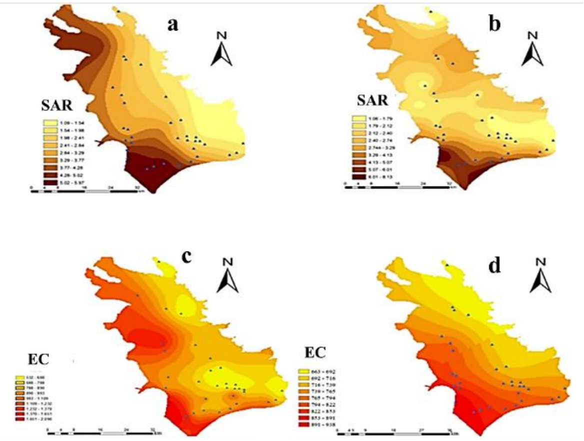

Fig. 6. CL zoned map (2004) (a), CL zoned map (2014) (b), SAR zoned map (2004) (c), SAR zoned map (2014) (d).

4. Conclusion

The results show that geomorphological phenomena are among the factors affecting the underground water resources of Jiroft Plain. Based on this, it can be said that mountainous areas and northern, eastern, and western highlands, flood plains, and alluvial cones are among the most important factors. The mountainous areas around the Jiroft Plain are the factors that absorb moisture and rainfall and provide water for the Yaz of the plain, and tectonization is an effective factor in absorbing more water in the plain. In the region and these activities caused the Jiroft and Sabzevaran faults in the Quaternary period and now cause many morphological changes and topographical irregularities in the Jiroft plain. The effect of these displacements in the underground water reservoirs of this region has been in the form of changes in the morphology of the plain changes in the topography of the bedrock and irregularity in the water level of the wells. From the hydrological point of view, the Sabzevaran and Jiroft faults play a very valuable and effective role in guiding the underground water from the mountainous part to the plain and increasing the permeability on one side of the alluvial fault. The permeability is never the same on both sides of the alluvial fault due to erosion on one side and pulverization on the other. The summary of the results obtained from the analysis of the semivariance and the evaluation of the methods in this research showed that the semivariance of the qualitative parameters of the current research follows the spherical model. The results of the analysis of electrical conductivity semivariation and sodium absorption ratio show a good spatial correlation in the whole region, which can be attributed to the climatic and hydrological characteristics of the region. Also, from the comparison of different methods of estimating qualitative parameters, it was determined that for hydraulic conductivity and total dissolved solids, the kriging method with spherical semi-variable, and for sodium absorption ratio and total hardness, distance photo distance method with powers of 2 and 3 is the most suitable intermediate method in Jiraft Plain. The results of qualitative parameters anomaly showed that the most changes are in the eastern part (Jabalbarz areas) and the northwest (Sardoye) and the least changes are in the southern parts of the plain. Also, the results of the study of time changes of quality parameters during the period of 2011 to 2015 showed that the slope of the trend line of quality parameters is increasing and with the increase of time period, the quality of underground water has decreased.

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