Hydrogeochemical processes and dissolved gases chemistry at the Gariz aquifer, Southwest of Yazd Province

Document Type: Research Paper

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Abstract

The leakage of natural gases mainly carbon dioxide into the Gariz aquifer has increased the concentration of dissolved gases and decreased groundwater quality. Therefore, the water supply of the residents of this region in various needs such as agriculture, drink, domestic, and industry, has faced some problems. Groundwater wells have been sampled to evaluate the hydrogeochemical processes of gaseous aquifers and determine the nature of dissolved gases during two-stage in July and September of 2019. Laboratory analysis includes the concentration of major anions and cations and, the dissolved gases in groundwater samples, and some physicochemical properties of water that have been measured directly in the field. On the basis of the chemistry of major ions, most of the samples have been classified as calcium-bicarbonate (Ca-HCO_3), sodium-chloride (Na-Cl), and calcium-chloride (Ca-Cl) types, although other mixing types are also recognized. The most significant processes that affect the chemical composition of the groundwater of the Gariz aquifer are water-rock interaction, leakage of CO_2-rich fluids, infiltration of saline water through faults and fractures, and silicate dissolution. Bicarbonate ion has increased in the groundwater samples due to the interaction of CO_2-rich fluids with the groundwater aquifer. The composition of dissolved gases also indicates that CO_2 is the dominant gas phase in most samples, up to 2100 times higher than atmospheric values. High concentrations of dissolved CO_2 of more than 730 cubic centimetres per litre indicate the infiltration of CO_2-rich fluids with deep origin into the aquifer. The ratio of dissolved O_2/N_2 in the aquifer is lower than in air-saturated water (ASW), therefore geochemical processes are responsible for dissolved oxygen consumption during redox reactions.

Keywords: Carbon dioxide, Dissolved gases, Gariz aquifer, Hydrogeochemistry.

Introduction

Gariz aquifer is located southwest of Yazd province in central Iran, (N 31°10′00″ to N 31°35′00″ and E 53°25′00″ to E 53°55′00). The study area comprises some 966 km^2 constrained by the Shirkuh intrusive granite, Cretaceous limestone, and Paleozoic and Cenozoic depositions to the north, and by the Tertiary volcanoes and clastic depositions to the south. The most significant landscape in the study area is formed of Paleocene dacitic domes, with Ernan dacitic intrusive mass having the highest peak at 2892 meters (AMSL). The most significant discontinuities in the region are the 350 km long Dehshir-Baft dextral strike-slip fault and its sub-branches. Gariz aquifer is the most important source of water in the study area that is used for various purposes, such as drinking, agriculture, domestic, and irrigation of pistachio orchards. Most of the wells in the Gariz area in the face of high concentrations of gases are mainly carbon dioxide. This phenomenon has caused environmental hazards and reduced groundwater quality in the study area. Natural gases in groundwater have multiple sources such as mantle, magmatic, carbonate, metamorphic and, biological processes (Mörner and Etiope, 2002). Such degassing occurs in diffuse form, especially in tectonically active regions through aquifers and soil. So far, several studies have been conducted on the hydrogeochemical characteristics of gaseous aquifers and the origin of gases, including carbon dioxide, in groundwater (Fourré et al. 2011; Grassa et al. 2006; Inguaggiato et al. 2005; Caliro et al. 2005; Caracausi and Sulli, 2019). Also, investigating the origin of dissolved gases in the aquifers of Iran has been the focus of some researchers (Delkhahi et al. 2020; Nassery and Raei, 2013). However, despite the prevailing environmental conditions in the study area of Gariz, there is not much information and knowledge available about the hydrogeochemical processes and the origin of gases in the aquifer. In this study, the concentration of dissolved gaseous species and major groundwater ions along with some physicochemical properties of selected wells have been analyzed. The purpose of this study is to analyze and characterize the hydrogeochemical processes governing the aquifer and to investigate the nature of dissolved gases in the aquifer groundwater.

Materials and Methods

The studied groundwater has been sampled in two scheduled campaigns, in July and in October 2019s. The samples were collected from nineteen and sixteen water wells (35 samples in total) in July and October, respectively. T°C, EC, and pH have been measured directly in the field by portable equipment. For laboratory analyses of concentrations of groundwater major ions, samples have been collected and stored in HDPE bottles and were filtered (PES 0.45 μm) in the field, and for cations determinations besides filtration were acidified with ultrapure nitric acid. Chemical analyses of major ions have been carried out by ion-chromatography (Dionex ICS-1100). HCO_3 content was determined in the laboratory by G20 Compact Titrator through volumetric titration with HCl 0.1 N. The chemical composition of the dissolved gases was determined based on the partitioning equilibrium of gaseous species between the liquid and the gas phase. In this method is possible to measure concentrations of the dissolved gases in the liquid phase from concentrations in the gas phase, using the partitioning coefficients of the different species (Capasso and Inguaggiato, 1998). For analyzing samples, 7 cubic centimetres of pure argon as a host gas were injected into each of the bottles filled with groundwater and for maintaining atmospheric pressure in the system the equivalent volume of water was allowed to exit through a needle. To prevent the possible loss of gases, especially helium gas, through the needle holes created in the septum of the bottles, the sample bottles were kept upside down until the analysis. Since the dissolved gas phases in the groundwater samples can be in supersaturated or undersaturated conditions, it is necessary to restore the atmospheric pressure inside the sample container before extraction. This procedure involves attaching the bottle upside-down to a tube filled with water that is exposed to the atmosphere and adding or removing a few ml of water. A portion of the gas is extracted through two plastic syringes with stopcocks for gas chromatography analysis once the samples have been returned to standard conditions (25°C, 1 atm). The concentration of dissolved gases was determined using an Agilent GC 7890B gas chromatography system with argon as carrier gas and equipped with a double detector (TCD-FID). All the analytical measurements have been carried out at the National Institute of Geophysics and Volcanology (INGV), Palermo, Italy.

Results and Discussion

Based on the field measurements and analytical results the temperature of the groundwater samples ranges from 18.3°C to 24.9°C, and more than the average regional temperature (14.2°C), the range of changes in total hardness (TH) varies from 172.5 to 2791.5 mg/l and, total dissolved solids (TDS) range from 382 to 5991 mg/l. The groundwater samples on the anionic triangular field of the Piper diagram evolved from HCO_3 to $Cl(HCO_3)$ and the sample of S7 is completely Na-Cl and also separated from the rest of the samples. Both samples of S13 and S17 are of the $Cl(SO_4)$ type, although S13 and S17 are dominated by Na and Ca ions respectively. Contrary to expectations, the highest TDS value (6001 mg/l) is related to the sample of S1 with $Na(Ca)\text{-}Cl(HCO_3)$ type, although the sample of S7 is the end member of the Cl type, its TDS value is only 3040 mg/l. Although the Cl concentrations are approximately the same in both S1 and S7 samples the HCO_3 concentration of S1 is 7 times greater than the sample of S7. This phenomenon can be due to the high solubility of lime in CO_2-rich waters. Hence, due to the high solubility of lime in the sample of S16, this sample is completely $Ca\text{-}HCO_3$ and has a TDS of 2692 mg/l, which is approximately 8 times greater than water in equilibrium with carbonate minerals. In the three freshwater samples (TDS <1000 mg/l), as the TDS increased from 384 mg/l in S6 to 526 mg/l in S9 and finally 650 mg/l in S10, the type of water evolved from $Ca\text{-}HCO_3$ to $Cl(HCO_3)$ and Ca(Mg).

Leakage of deep-CO_2 around the Ernan volcanic mass and also leakage of deep chlorinated saline water with high residence times through the faults and fractures into the shallow crustal layers have disrupted the natural hydrogeochemical evolution of the Gariz aquifer however, the mixing process of these waters can be inferred from the anionic triangular field of the Piper diagram. The trend of TDS variations versus HCO_3 and Cl shows that the samples with low Cl and high HCO_3 have TDS values of about 3000 mg/l, which is much higher than the carbonate equilibrium. This positive anomaly occurred due to the increased solubility of lime as the leakage of CO_2 into the aquifer. In contrast, Cl and low-HCO_3 samples with TDS values of about 3000-4000 mg/l are affected by the leakage of deep chlorinated saline fault-groundwater while no CO_2 leakage is observed. The samples with minimal Cl and HCO_3 values are freshwaters that underwent the natural hydrogeochemical evolution process of the aquifer. The samples with the highest TDS, Cl, and HCO_3 values are in the middle of the hydrogeochemical evolution process that is affected by both deep saline groundwater and leakage of deep CO_2. Correlations between Na and Cl also show, samples S1, S7, and S14 are separated from the other samples, which indicates the leakage of saline water into the alluvial aquifer and also, the Ca/Mg ratio of more than 2 in most of the samples indicates silicate dissolution in the Gariz aquifer. According to the chemical composition of the gases dissolved in the groundwater of the study area, CO_2 is the dominant dissolved gas phase in most samples. All groundwater samples show greater CO_2 contents than those at equilibrium with the atmosphere (ASW at 25 °C). However, the wide range of CO_2 contents may be either or both associated with different hydrogeological conditions or complex fault systems that control fluid transfer at depth. On the other hand, it can be seen that almost all samples have a lower O_2/N_2 ratio than ASW. The decrease of oxygen relative to nitrogen is likely due to oxygen consumption during redox reactions. Almost the highest values of dissolved CO_2 contents in the Gariz aquifer are related to wells that are located surrounding Ernan dacitic intrusive body and along sub-branches of the Dehshir-Baft fault. These sub-brunches have cut off the eastern and western flanks of the Ernan volcanic mass and created natural channels that transport deep gases toward the surface increasing the acidity of groundwater. It seems deep tectonic discontinuities have a significant role in the migration of deep-sourced fluids towards groundwater resources in crustal layers and the Gariz aquifer.

Conclusions

On the basis of major ion composition, most of the samples are classified as calcium-bicarbonate (Ca-HCO_3), calcium-chloride (Ca-Cl), and sodium-chloride (Na-Cl) types, although other mixing types are also recognized. The main factors influencing the chemical composition of the groundwater are the mixing process and silicate dissolution. Leakage of deep-CO_2 and deep-chlorinated saline water into the Gariz aquifer have disrupted the natural hydrogeochemical evolution process. Most samples are close to saturation with respect to calcite, dolomite, and aragonite, while are all undersaturated with respect to gypsum. The dissolved gas composition indicates CO_2 is the dominant dissolved gas phase in groundwater samples and much more than air-saturated water (ASW), suggesting the leakage of deep-sourced CO_2 to the Gariz aquifer. Concentrations of the dissolved gas show that all the samples have O_2/N_2 ratios lower than air-saturated water (ASW), suggesting geochemical processes that are responsible for dissolved oxygen consumption during redox reactions. The rate of changes in the concentration of dissolved gases in the Gariz aquifer shows that the fault systems and the network of discontinuities play an important role in the immigration of deep gases to the shallow aquifer. Although in this study, the hydrogeochemical processes governing the Gariz aquifer have been identified based on the chemistry of the major ions of the groundwater and the concentration of dissolved gases, the relative impact of each process on groundwater quality with respect to depth cannot be determined by this study and further studies will be needed to clarify this issue.

Study of the Development of Greenhouse Estates and Its Impact on Groundwater Levels of Ajichay Basin Aquifers Using SWAT Model

Document Type: Research Paper

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Abstract

Greenhouse crop production is one of the major strategies for managing the optimum use of water resources due to creating desirable conditions for plant growth over the year, multiplying production and reducing water usage. In the present study, two scenarios were adopted according to the current policies for the development of greenhouse towns in Iran and an ideal scenario (third scenario) was also considered for the development of greenhouse towns. The soil and water assessment tool (SWAT) model was used to evaluate the impacts of the implementation of development scenarios of greenhouse towns. Statistical indicators showed very high accuracy in simulating hydrometric stations of the study area, as for Akhola hydrometric station (basin outlet), the statistics of correlation factor, Nash-Sutcliffe efficiency (NSE), and root mean squared error (RMSE) in the calibration period were 0.77, 0.62, and 6.21 $m^3 s^{-1}$, respectively, and in the validation period were 0.83, 0.66, and 3.09 $m^3 s^{-1}$, respectively. The development of greenhouse towns with an area of 1875 ha in the Ajichay basin for the first and second scenarios resulted in an average drop of 11.68 m and 4.41 m in the groundwater level of the aquifers in the Ajichay basin compared to the initial conditions. Simulation of the third scenario increases the groundwater level of aquifers of Tabriz, Azarshahr, Damaneh Shomali Sahand, Bostanabad, Duzduzan, Mehraban, Bilverdi, Asbforoshan and Sarab by 4.12, 2.73, 1.45, 8.88, 10.93, 2.90, 4.79, 2.99, and 3.31 m, respectively, and also have compensated a large amount of their negative balance. The results revealed that the development of greenhouse towns using new water resources can increase agricultural crop production and also intensify the downward trend in groundwater levels.

Keywords: Ajichay basin, Greenhouse town, Groundwater, SWAT model.

Introduction

In arid and semi-arid regions, meeting the environmental need of rivers and natural lakes is drastically diminished due to climate changes, drought, and mismanagement of the water supply and distribution in agricultural activities. The closed basins, like Lake Urmia basin, are more sensitive to reducing the environmental need, climate change and drought. In the Lake Urmia basin with arid and semi-arid climate, water shortage and high demand for water consumption in agricultural activities have caused to increase in the free accessibility of the extraction of surface water and groundwater resources. Therefore, in arid and semi-arid regions, it is very necessary to implement an integrated dynamic system (IDS) for water consumption management in all sectors of water consumption, including drinking, industrial, and agriculture needs to stabilize the groundwater resources; hence, the optimal use of water resources to increase production capacity per unit of water consumption is a fundamental solution to meet the nutritional needs of humans and improve the economic conditions of operators. Greenhouse crop production is one of the major strategies for managing the optimum use of water resources due to creating desirable conditions for plant growth over the year, multiplying production and reducing water usage.

Materials and Methods

The Ajichay basin with an area of 12,600 km^2 is one of the greatest sub-basins of Lake Urmia (Fig 1). The average annual temperature of this basin is 11.3^{oC} and the average annual precipitation is 320 mm. The soil and water assessment tool (SWAT) model was used to evaluate the impacts of the implementation of development scenarios of greenhouse towns. The Soil and Water Assessment Tool (SWAT) is considered a comprehensive hydrological model to evaluate the impacts of different factors such as climate changes, land use variations, changes in irrigation methods, agricultural management, and greenhouse development on runoff volume and groundwater level fluctuations. In this study, the SWAT model has been calibrated and verified using a 30 m digital elevation model (DEM), a soil map with 217 homogeneous zones, 5 land use maps for 1987 to 2015, data gathered from 10 hydrometric stations and more than 50 meteorological stations, hydrological studies and field measurements. In the present study, two scenarios were adopted according to the current policies of greenhouse town development in Iran and an ideal scenario (third scenario) was also considered for the development of greenhouse towns.

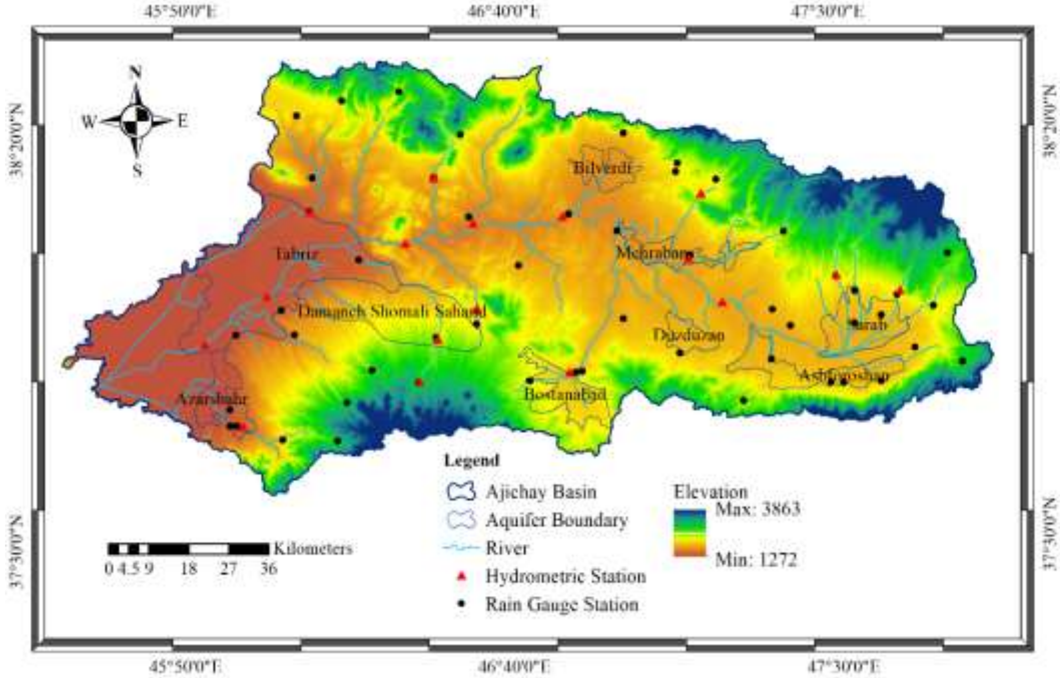

Fig. 1. Location of rain gauge station, hydrometric station, river, aquifer boundary and elevation map of the Ajichay catchment.

In modelling the Ajichay basin, the periods of 1987-1991, 1992-2009, and 2010-2016 have been assigned to the model adaptation to the basin conditions, calibration, and verification, respectively. The statistical criteria comprising correlation coefficient (CC), Nash-Sutcliffe efficiency (NSE), and root mean square error (RMSE) have been utilized to evaluate model performance for stream flow simulation in hydrometric stations.

Results and Discussion

Statistical indicators showed very high accuracy in simulating hydrometric stations of the study area, as for Akhola hydrometric station (basin outlet), the statistics of correlation factor, Nash-Sutcliffe efficiency (NSE), and root mean squared error (RMSE) in the calibration period were 0.77, 0.62, and 6.21 $m^3 s^{-1}$, respectively, and in the validation period were 0.83, 0.66, and 3.09 $m^3 s^{-1}$, respectively. Statistical indices for calibration and validation periods for all stations are shown in Table 1.

Table 1. Statistical indicators of flow simulation in hydrometric stations of Ajichay catchment.

Hydrometric Station	Calibration period			Validation period		
	R	NS	RMSE (m^3s^{-1})	R	NS	RMSE (m^3s^{-1})
Sad Nahand	0.73	0.53	0.93	0.79	0.56	0.72
Harzeh Varz	0.71	0.46	0.51	0.80	0.51	0.29
Mirkoh Haji	0.87	0.75	0.83	0.91	0.80	0.47
Sahzab	0.69	0.48	0.69	0.75	0.52	0.45
Lighvan	0.85	0.69	0.45	0.92	0.74	0.36
Hervi	0.83	0.65	0.46	0.81	0.64	0.32
Bostanabad	0.62	0.51	0.99	0.66	0.57	0.28
Vanyar	0.82	0.71	5.62	0.85	0.73	2.54
Akhola	0.77	0.62	6.21	0.83	0.66	3.09
Sarin Dizaj	0.74	0.60	5.49	0.78	0.61	1.88

The development of greenhouse towns with an area of 1875 ha in the Ajichay basin for the first and second scenarios resulted in an average drop of 11.68 m and 4.41 m in the groundwater level of the aquifers in the Ajichay basin compared to the initial conditions. Simulation of the third scenario increases the groundwater level of aquifers of Tabriz, Azarshahr, Damaneh Shomali Sahand, Bostanabad, Dozduzan, Mehraban, Bilverdi, Asbforoshan and Sarab by 4.12, 2.73, 1.45, 8.88, 10.93, 2.90, 4.79, 2.99, and 3.31 m, respectively, and also have compensated a large amount of their negative balance. The results revealed that the development of greenhouse towns using new water resources can increase agricultural crop production and also intensify the downward trend in groundwater levels. The second scenario has caused a negative balance in the aquifers due to the elimination of the water withdrawal under the traditional irrigation system from the hydrological cycle. Only in the third scenario, the removal of nearly ten hectares of farmlands for the development of one hectare of greenhouse has caused the aquifers of Ajichay basin to have an increasing trend of groundwater level. Figure 2 shows the water level changes of the Tabriz aquifer and Damaneh Shomali Sahand aquifer for three evaluated scenarios. The main reason for the drop in groundwater level in this aquifer is the transfer of water from this aquifer for the drinking water supply in Tabriz.

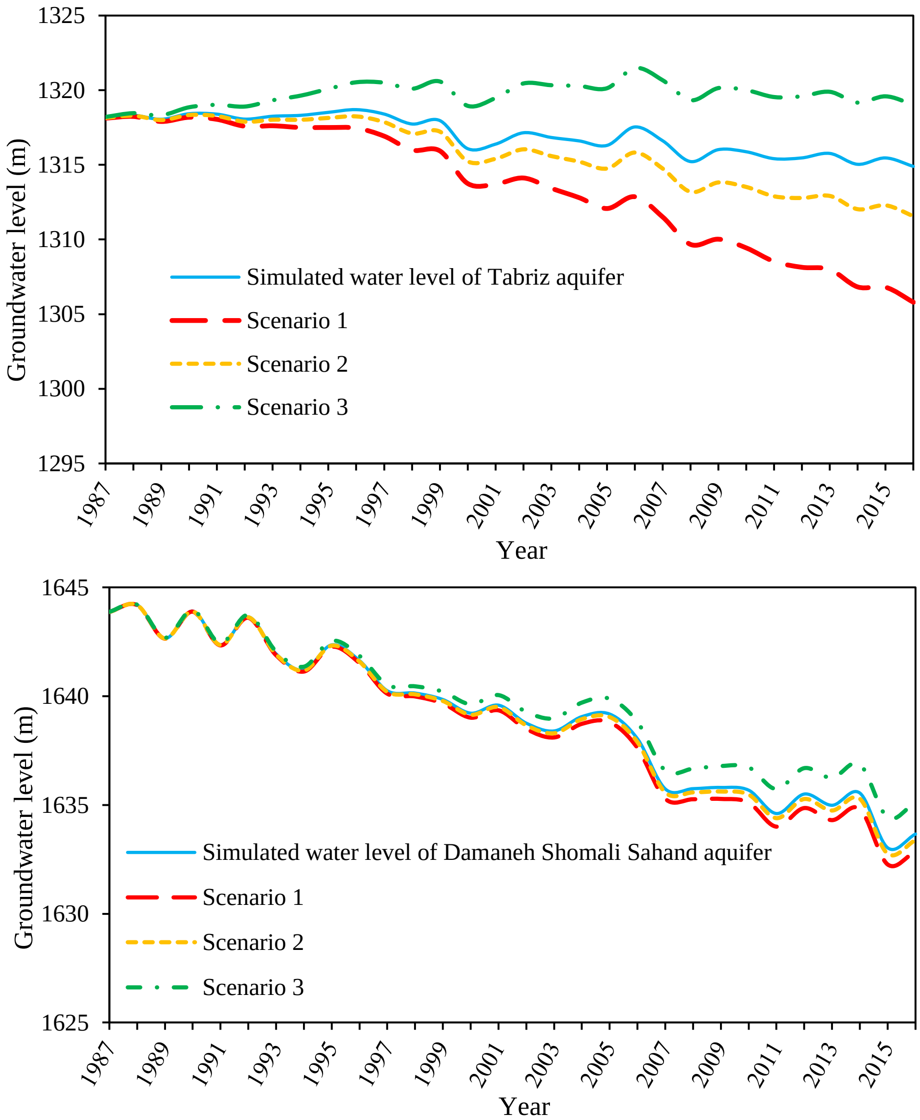

Fig. 2. Observed and simulated groundwater levels in Tabriz and Damaneh Shomali Sahand aquifers.

Conclusions

The results of the implementation of the scenarios to develop greenhouse towns revealed that the type of policies and how to implement the development of greenhouse towns can enhance agricultural production capacity as well as decrease/increase the groundwater level in the aquifers of the Ajichay basin. The adverse effect on groundwater resources occurs when the administrative institutions' approach is focused only on increasing production capacity. Furthermore, when the ratio of replacing traditional farmlands with greenhouse towns is not commensurate with the corresponding irrigation efficiencies, it applies more stress to the groundwater resources to meet the evapotranspiration need of the greenhouse plants. The positive effect on aquifers and increase in groundwater level takes place when the actual evapotranspiration of the plants cultivated in greenhouse towns is less than the eliminated traditional farmland.

Applicability of GLDAS precipitation dataset in estimating green and blue water footprints of wheat and maize in Qazvin plain station using Aqua Crop model

Document Type: Research Paper

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Abstract

Remote sensing technology, due to its valuable features such as taking multi-temporal and multi-spectral images, appropriate and varied temporal resolution and radiometric capability, wide and integrated view of the region, can be used in many agricultural tasks such as crop yield prediction, soil moisture measurement, information about the amount of drought and frost should be effective. In this study, to evaluate the networked meteorological datasets GLDAS-AgMERRA, GLDAS-CRU, and GLDAS-AgCFSR in estimating the blue and green water footprints of wheat and blue water footprints of maize and comparing it with the estimated values of Qazvin plain during 1980-2010. Statistical evaluation was performed using R^2, NRMSE and ME indices. The average total water footprint of wheat in the study area was estimated at 869 (m^3/ton) in which the share of green water footprint was 47% and the share of blue water footprint was 53%. Estimated data in scenarios 1 (Precipitation and evapotranspiration of GLDAS-Temperature of CRU) and 3 (Precipitation of GLDAS-Temperature and evapotranspiration of CRU) for green water footprint of wheat and for blue water footprint, scenario 5 (Precipitation and evapotranspiration of GLDAS-Temperature of AgCFSR) and Scenario 3 have the highest correlations for wheat and maize, respectively. The results show that these datasets are not suitable for estimating the water footprint of maize plants, but for estimating the green and blue water footprints of wheat plants, the information of networked meteorological datasets can be used with appropriate accuracy.

Keywords: AgCFSR dataset, AgMERRA, CRU, Crop model.

Introduction

Rapid population growth, socio-economic development of communities, global abstraction of fresh water and increasing levels of water pollution are signs of water scarcity and crisis (Mekonnen and Hoekstra, 2010; Postel,2000). The agricultural sector is one of the main consumers of water resources, accounting for 85% of surface and groundwater resources (Shiklomanov,2000; Moldrn,2007). Cereals and their products have the first place in the food basket of the people and therefore have a greater share in the collection of freshwater consumption. According to a 2010 World Food Organization report, more than 50 percent of the world's food intake came from grains and processed foods. Also, Karandish and Hoekstra stated that among the 26 dominant products consumed by Iranians, cereals have the largest share in the diet of individuals (Karandish and Hoekstra., 2017). The Water Footprint Index was introduced by Hoekstra in 2002, which is one of the newest indicators in the discussion of sustainable water resources management. Water footprint analyzes the relationship between human consumption of fresh water and the use of water in the manufacture of a particular type of product (Hoeksta et al., 2011).

Using satellite imagery and remote sensing techniques, a wide range of projects can be completed globally, regionally, nationally, provincially and locally with less cost and time. In addition, the ability to retrieve satellite data at intervals of several hours to several days during the month or year has made it possible to study changes and monitor terrestrial phenomena.

In this research, GLDAS-AgMERRA, GLDAS-CRU, and GLDAS-AgCFSR networked meteorological databases have been evaluated in estimating the blue and green water footprint of wheat, and the blue water footprint of maize and its comparison with the values of Qazvin synoptic station.

Materials and Methods

Potential evaporation (W m-2) and precipitation (Kg m-2 s-1) data from GLDAS-2.0 products on a monthly basis from GLDAS-2.0 products on a daily basis for the period 1980 to 2010 were obtained from the Giovanni site. To transform the potential evaporation to the evapotranspiration of the reference plant, the evaporation pan method and Equation (1) were used.

$$ET_0 = K_{pan} \times E_{pan} \quad (۱)$$

In this equation ET_0: evapotranspiration of the reference plant, K_{pan}: coefficient of the pan and E_{pan}: the amount of evaporation from the pan. The coefficient of the pan depends on the location of the pan and its surroundings and its value varies between 0.5 to 0.85 (Alizadeh, 2010). In this study, a pan coefficient of 0.5 was used to convert potential evaporation to evapotranspiration of the reference plant. CRU, AgCFSR and AgMERRA temperature data were received monthly for the period 1980-2010 and the transpiration evaporation of these bases was calculated by the FAO Penman-Monteith method.

For the Aqua Crop model input data, in the climatic section of precipitation, temperature and evapotranspiration data of Qazvin Synoptic Station and GLDAS, CRU, AgCFSR and AgMERRA models separately under different scenarios, in the plant section of the model from FAO wheat crop data from 1980 to 2010 in other sections, Qazvin station information was used. The scenarios are given in Table 1.

Table 1- Introduction Scenarios

Description	Scenario number
Precipitation and evapotranspiration of GLDAS-Temperature of CRU	S_1
Precipitation and evapotranspiration of GLDAS-Temperature of AgMERRA	S_2
Precipitation of GLDAS- Temperature and evapotranspiration of CRU	S_3
Precipitation of GLDAS- Temperature and evapotranspiration of AgMERRA	S_4
Precipitation and evapotranspiration of GLDAS- Temperature of AgCFSR	S_5
Precipitation of GLDAS- Temperature and evapotranspiration of AgCFSR	S_6

Results and Discussion

Statistical evaluation of blue and green water footprint simulated with Aqua Crop model in Qazvin Synaptic Station and scenarios are given in Table 2.

Table 2- Statistical evaluation of green and blue water footprints of wheat and maize of Qazvin synoptic station with

Crop	Water footprint	Scenarios	R^2	NRMSE (%)	ME
Wheat	Green WF	S1	0.66	19.6	332.3
		S2	0.64	21.3	351.1
		S3	0.66	19.58	332.3
		S4	0.64	21.4	352.4
		S5	0.63	22.1	366.5
		S6	0.63	22.1	366.4
	Blue WF	S1	0.48	28	344.7
		S2	0.50	23.5	248.4
		S3	0.47	26.7	416.1
		S4	0.51	52.6	358.8
		S5	0.56	25.8	245.1
		S6	0.54	60.7	393.1
Maize	Blue WF	S1	0.06	16.3	132.4
		S2	0.00	23.3	417.9
		S3	0.19	22.3	179.9
		S4	0.02	41.6	293.5
		S5	0.07	16	129.6
		S6	0.00	43.21	293.1

The coefficients of explanation for irrigated blue and green water footprint of wheat in Table 5 show that the estimated data and synoptic station data in scenarios 1 and 3 for green water footprint and Scenario 5 for wheat water footprint and for maize water footprint Scenario 3 are the most correlation. The NRMSE index shows that the error rates in scenarios 1 and 3 are in the good category for green water footprint and in scenarios 2, 3 and 5 for wheat water footprint in the middle category and for the maize plant scenarios 1 and 5 are in the good category. The ME index in scenarios 1 and 3 is more desirable for green water footprint and in scenarios 2 and 5 for blue water footprint of wheat and for maize scenario 5 is more favorable than other scenarios.

The reason for the differences in the outputs of the databases may be related to how these databases are configured and how observational data are analyzed in the region (Haji Hosseini et al., 2013). Bahrololum et al. (2020) used data from meteorological databases to evaluate the yield and water requirement of wheat in the Qazvin synoptic station, similar results were obtained and the correlation coefficient for the AgMERRA database shows 0.88. Aligholinia et al. (2016) estimated and evaluated water and green water footprints in the Urmia watershed. The water footprint of 5 major crops including wheat, sugar beet, tomato, alfalfa and maize were examined and the results showed that the share of green water footprint and blue water is 25% and 75% respectively and the share of water is higher. Which is consistent with the results of the present study.

Conclusions

Today, water footprint has been considered in the direction of modern management of water resources with an integrated approach. In order to properly assess water consumption in the agricultural sector, it is necessary to examine the water footprint index.

In this study, GLDAS-AgMERRA, GLDAS-CRU, and GLDAS-AgCFSR networked meteorological databases have been evaluated in estimating the blue water footprint of maize, the blue and green water footprint of wheat and comparing them with Qazvin synoptic station during 1980-2010. In Scenarios 1 and 3 for green water footprint and Scenario 5 for blue water footprint in wheat plants and Scenario 3 in blue water footprint for maize plants have the highest correlation. The average total water footprint of wheat in the synoptic station was estimated at 869 (m^3/ton) in which the share of green water footprint was 47% and the share of blue water footprint was 53%. The high share of blue water footprint compared to green water indicates a low rainfall rate and indicates the stability of arid and semi-arid climates in terms of agriculture (Aligholinia et al., 2019). The results show that these bases are not suitable for estimating the blue water footprint of the maize plant, but for estimating the green and blue water footprint of the wheat plant, the information of networked meteorological bases can be used with appropriate accuracy.

For a more accurate evaluation, it is recommended that more stations be considered in different climates to achieve better results. You can also evaluate more products. Due to the fact that the GLDAS model data is updated and modified on a monthly basis, it is recommended to conduct the present study once every 6 months before using the GLDAS surface model data.

Predicting and zoning of groundwater quality using geographical information system (GIS) models and machine learning methods (case study: Zahedan plain)

Document Type: Research Paper

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Abstract

In recent decades, the growing population, limited water resources, and overexploitation of aquifers have caused irreparable damage to the quantity and quality of the country's aquifers. In the current study, geographical information system (GIS) models and machine learning (ML) techniques using available groundwater quality variables were applied for the prediction and zoning of salinity and SAR of groundwater in the Zahedan plain and then the accuracy of these methods were compared .The input data were based on water quality sampling in 2018 from 59 observation wells. The study of parameters showed that in Zahedan plain, EC, SAR, and TDS parameters had high variability (CV>41%) and acidity showed low variability (CV = 4.16%). The results of the geostatistical analysis showed that the IDW model represented better results with the power value of 2 for TDS and EC parameters while for pH and SAR parameters, the ordinary Kriging method revealed the best result with minimum RMSE in the test stage. Performance evaluation of ML models showed that all three models RF, ANN, and SVM showed acceptable results with R2 above 90% and NRMSE values below 15% for all parameters (except acidity). However, better estimations were observed in the training step than in the test step. A comparison of different GIS models and ML also revealed the notable superiority of ML models in estimating these parameters. Finally, it can be concluded that under a shortage of field facilities for the assessment of groundwater quality, data-driven methods can be a reliable alternative to water quality monitoring.

Keywords: Data-mining, Electrical conductivity, Random forest, Sistan and Balouchestan, Water resource monitoring.

Introduction

Iran's renewable water resources are less than one percent of the world's resources. Therefore, one of the most important limiting factors of agricultural development in the coming decades can be called the limitation of water resources. Proper management of water resources is one of the most important strategies to increase water quantity and quality. Therefore, the relationship between water resources management and its quantitative and qualitative study is a two-way relationship.

A sufficient database of quantitative and qualitative parameters of available resources requires quantitative and qualitative monitoring of aquifers. Groundwater quality monitoring is very costly and time-consuming. Statistical methods provide a convenient, low-cost, and reliable tool for a better understanding of the status of water resources. Since there are a limited number of laboratory or field measurements of well-distributed variables, appropriate interpolation methods such as geostatistical methods can be applied for the zoning of those parameters.

Bameri and Khaleghi (2021) conducted a study with the aim of zoning groundwater depth using geostatistics and GIS techniques in the agricultural lands of the Sistan plain. The results showed that the deterministic method of inverse distance weighted with power 2 (IDW2) revealed a better prediction for groundwater depth zoning than Kriging and Cokriging methods. Ahmed et al. (2019) used several different ML algorithms and input parameters such as acidity, temperature, turbidity, etc. to classify water quality. These researchers finally stated that the multilayer perceptron (MLP) method showed the highest accuracy in predicting and classifying water quality.

Zahedan plain, due to its geographical location and location in low latitudes, has less humidity than other parts of the country while water crisis is always one of the largest issues in this region. Therefore, a careful study of the quantity and quality of water resources, especially groundwater in this region is more necessary than in other regions of the country. This study aimed to predict the salinity and sodium uptake ratio of groundwater (two important parameters for water quality classification) using different geostatistical models ML techniques including random forest (RF), support vector machine (SVM), and artificial neural network (ANN) while comparing the results of these models. There have not been similar studies on the application of these methods for assessing groundwater quality in the study area so far.

Materials and Methods

Characteristics of the study area

The current study was conducted in Zahedan plain, which is located in Sistan and Balouchestan province. This plain with an area of approximately 210 km^2 is located at an altitude of 1385 meters above sea level. The average annual rainfall in this area is 72 mm. The city of Zahedan is located in a smooth plain with a gentle slope of about 0.3% to 0.5% and is surrounded by relatively high mountains. The general slope of the plain is from south to north and its lateral slope is from west to east

Models implemented in the study

Different GIS-based interpolation methods including Kriging, Cokriging, and Inverse Distance Weighting (IDW) methods were applied. Also, ML models, as a new generation of data mining techniques, have been greatly developed in the last two decades, and can also be used to discover and extract knowledge from databases and to create prediction models. In this research, three models of artificial neural network machine (ANN), support vector machine (SVM) and random forest (RF) were used to predict the quality parameters of groundwater.

Data collection and implementation of models

To implement GIS and three ML models, the samples were collected from 59 observation wells in Zahedan plain in the water year 2018 (October 2018-October 2019), taken by the Research Department of the Regional Water Organization of Sistan and Balouchestan. Then, qualitative characteristics, including salinity, sodium, magnesium, potassium, acidity, chloride, sulfate, TDS, SAR, total hardness, and bicarbonate were evaluated. Geostatistical methods had two stages; the first step was to calculate the experimental semivariogram and model it using a suitable theoretical model, and the second step was to use the semivariogram coefficients in estimating the variable at unknown points. ML methods in this research were implemented using R software. During the modeling process with ML methods, all data were divided into two categories: Training data and testing data, so that in this study 80% of the total data were used for model training while the remaining 20% were introduced to the model as test data. The selection of training and test data was done randomly by the software and it is obvious that the data from one stage was not used in another stage.

Model evaluation criteria

To evaluate the models' simulation, several statistical criteria such as root mean square error (RMSE), mean error deviation (ME), correlation coefficient (R^2), and normalized root mean square error **(**NRMSE) were used**.**

Results and Discussion

In this study, different GIS and ML models were performed on the controlled data. Finally, the output of the mentioned methods was statistically analyzed and evaluated. According to the classification of Wilding et al. (1983), the studied parameters in the Zahedan plain showed high variability, except for the acidity. Based on the results obtained from plotting the experimental semivariogram and fitting the models, the exponential model was the best-fitted model for the parameters of acidity and sodium adsorption ratio and the best-fitted model for the electrical conductivity and total soluble salt parameters was a spherical model. Also, experimental semivariogram analysis showed that the evaluated parameters had a strong structure and spatial correlation.

According to the spatial distribution map, the concentration of all investigated parameters, except for acidity (pH), showed a decreasing trend from the north and northwest of the researched area to its southeast. The reason for this is probably more extraction from underground resources and different types of uses due to the higher population peak in that area.

Performance Evaluation of GIS models

Evaluation of the Kriging, Cokriging, and IDW methods for the electrical conductivity parameter showed that according to the RMSE index, the simple Cokriging method had the best efficiency in the training phase. But in the test phase, despite the small difference between the RMSE values, the IDW2 model performed better than the other models. For the acidity parameter, the ordinary Kriging method had the lowest RMSE value in both stages. For the SAR parameter, the ordinary Cokriging method had the best performance in the training phase and the ordinary Kriging method had the best performance in the test phase. For the training phase, the simple Cokriging method had the best estimate for TDS. For the test phase, the IDW2 method with the minimum RMSE value was the best TDS estimator.

Performance Evaluation of machine learning Models

After modeling and analysis of different GIS models, analysis of groundwater quality data was performed by R software using various ML methods such as RF, ANN, and SVM. The results of ML methods for the electrical conductivity parameter showed that all three models had high accuracy in estimating this parameter. Correlation coefficients above 0.95 in both stages and all models indicated the acceptable accuracy of the models. The ANN model showed better accuracy in estimating the acidity parameter. To estimate the SAR and TDS, the SVM model has revealed better performance, however, the other models had an acceptable result for SAR and TDS modeling. The high values of the correlation coefficient in all the models showed the high accuracy of the models in estimating the parameter of SAR and TDS.

Comparison of performance of models and zoning of parameters

Based on the NRMSE values for all four qualitative parameters studied, it is quite obvious that the performance of ML models has been better and more accurate than GIS methods. In GIS models, the Cokriging geostatistical method showed better and average performance than the other two methods. Zoning for each qualitative parameter was performed based on the best estimator model for that parameter. Accordingly, for the EC and TDS variables, the SWM model; for the SAR variable, the ANN model, and; for the pH, the RF model, were selected and zoned in R software. Spatial changes in water quality in this plain show that water quality in the northern half, especially the northeastern plain has decreased compared to the southern half. As a result, for quality management, more focus should be placed on the northern part, especially the northeast of the plain, and management solutions should be searched to increase the water quality of the aquifer.

Conclusions

Considering that the agricultural sector in Sistan and Baluchistan province consumes a significant amount of underground water resources for the production of agricultural products, therefore, it is necessary to investigate the quantitative and qualitative situation of underground water resources. Knowing about the quality parameters of aquifers will help to manage water resources properly. However, groundwater quality monitoring is very costly and time-consuming. In the present study, six models of GIS including simple and ordinary Kriging methods, simple and ordinary Cokriging, and IDW with the power of one and two, and also three different models of ML including ANN models, SVM and RF were evaluated and compared to predict groundwater quality parameters such as electrical conductivity, SAR, acidity, and TDS in Zahedan plain. The results of the evaluation of GIS models showed relatively poor performance of these methods. However, in general, based on NRMSE values, the Cokriging method performed better than other methods.

The results of the performance evaluation of ML models also indicated the high efficiency of all three models in predicting the three parameters EC, TDS, and SAR with correlation coefficients above 90% and NRMSE values below 15% indicating the high accuracy of the models in the estimation of parameters. However, all three models did not show acceptable results for estimating the acidity parameter. Finally, it can be concluded that new statistical models such as ML methods with an acceptable level of reliability can be considered to be a powerful and efficient tool for quality monitoring and optimal management of groundwater resources.

Performance Assessment of Numerical Solutions in Groundwater Simulation (case study: Birjand aquifer)

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Abstract

The extensive knowledge of groundwater resources' status has double importance for the planning of a sustainable future in arid regions. Strictly, without an efficient model with accurate simulation, it is impossible to have a good understanding of groundwater behavior. Since groundwater modeling in real problems comprises irregular boundaries, heterogeneity, anisotropy, and conceptualization, there exist many challenges in the simulation process. Due to proper acceptable performance, this study aims to present a proper framework to simulate groundwater flow based on Finite Difference (FD), Finite Element (FE), and Meshfree (Mfree) methods. The governing equation of groundwater flow was discretized through FD, FE, and Mfree approximations, and their performance was examined in two case studies: hypothetical case and field study. The findings of this study revealed that the Mfree has more applicability than others because some noticeable challenges were found in the simulation process of the FD and FE. A comparison of analytical solutions and simulated values in the hypothetical aquifer indicated that all methods are compliant. In terms of the RMSE criterion, the Mfree, FE, and FD were evaluated respectively, 0.005, 0.016, and 0.018 m. However, the numerical methods' act, especially the mesh-based methods (FD and FE) in the field study, becomes less accurate. Performance assessment of the FD indicated that this method has good ability in a simple test case with regular geometry, while in an aquifer with irregular geometry associated with isotropy and heterogeneity, its accuracy is greatly diminished. So, the RMSE for FD methods in field study was evaluated at 1.77 m. The same results may be obtained from the FE method, such that its RMSE was obtained at 0.36 m. Investigations of this study showed that the FE needs time-consuming preprocessing practices to implement in the different aquifers. The results of the Mfree application indicated that this method is more efficient than others due to its very high flexibility in irregular geometry with isotropy and heterogeneity issues. The RMSE for the Mfree in the field study obtained 0.26 m.

Keywords: Arid Region, Finite Element, Mesh Less, Structure Uncertainty Weighted Residuals.

Introduction

In mathematical modeling the groundwater process has been defined by Partial Different Equations-PDEs and numerical methods solved it to obtain an approximated solution. Governing equation on the groundwater process is derived from mass conservation and continuity laws. The accurate solution of this equation in real problems is not easily achieved, so it should be approximated by some numerical methods such as Finite Difference (FD), Finite Element (FE), Finite Volume (FV), Iso Geometric (IG), and Meshfree (Mfree). Groundwater modeling based on the FD is widely used due to its simplicity and frequent FD-based softs. While the applicability of this method in real problems with irregular geometry is challenging. Some sophisticated numerical methods such as FE and FV enhanced the inherent structure uncertainty of FD. Hence, the obtained results by these methods are more reliable in particular in real conditions. However, there are always some serious deficiencies with the use of these methods. For example, FE, FV, and IG methods need to define a mesh and element matrix across the problem domain, while this step is both intricate and different for each problem. Moreover, the implemented element matrix across the problem domain does not cover the problem domain completely and it can propagate the total uncertainty. Almost these mentioned issues there are in all numerical mesh-based methods. Whoever, numerical meshless method such as Mfree relax these challenges and overcome them due to reflexibility in similar situations. Mfree does not require to definition of a regular mesh and there is no specific preprocess measurement for modeling.

The literature review indicated that most performed related studies have merely focused on the application of the single numerical methods and the comparative performance of different methods received less attention. Among those rare studies, the comparison of FD and FE ability in simulating groundwater process is more common (Simpson and Clement, 2003; Kulkarni, 2015; Mohtashami et al., 2017; Sarakorn, Vachiratienchai, 2018; Matiatos et al., 2019). However, some of these studies only conducted the examination in a hypothetical aquifer. Also, there are few studies that emphasize some different numerical methods in groundwater modeling. Moreover, the examination of related studies determined that most of the studies employed ready-made software for the numerical modeling of groundwater. Despite some comparative advantages (time savings, no need for high expertise in numerical methods, ready-made modeling packages), these models have certain weaknesses having additional packages and code; they do not have editing and personalization capabilities; they need to be updated; and finally, they sometimes have limited applications due to their commercial development. In addition, if modeling consists of processes such as preprocessing, optimization, calibration, uncertainty, and post-processing, or if the combination of several models together is required, the application of ready-made software is a more complex and time-consuming process. However, in studies such as current research, where modeling is done as open-source coding, the processes mentioned above will be much easier to operate.

Considering the above discussion, the main contribution of this work is to present a programmable framework for the situation for examining different numerical methods' abilities in groundwater modeling. This work aimed to compare the effectiveness of three numerical methods, including FD, FE, and Mfree in simulating groundwater modeling with real complicated aquifer and hypothetical aquifer tests.

Materials and Methods

Governing equation on groundwater flow

The governing equation of steady-state and two-dimensional for homogenous, isotropic, and unconfined aquifers can be expressed as the following (Eq. 1):

$$K\frac{\partial}{\partial x}(h\frac{\partial h}{\partial x})+K\frac{\partial}{\partial x}(h\frac{\partial h}{\partial y})+Q(i,j)=0 \qquad (1)$$

Considering the following boundary and initial conditions (Eq. 2):

$$\begin{aligned} &T\frac{\partial h}{\partial \Gamma t}=q_t \quad on \quad \Gamma=\Gamma t \\ &h(x,y,t)=\bar{h} \quad on \quad \Gamma=\Gamma u \\ &h(x,y,o)=h_0 \quad on \quad \Omega \end{aligned} \qquad (2)$$

Where, K and h are conductivity (m/d) and potential head (m), while Q indicates the recharge or abstraction term (m^3/d). Also, $qt,\bar{h},h_0$ are known inflow rate (m2/day), constant groundwater level (m), and initial head (m) respectively. While $\Gamma,\Gamma t,\Gamma u$ denote the global, essential (Dirichlet) and natural (Neuman) boundary conditions respectively, and Ω indicating aquifer domain.

Numerical methods

The Equation (1) is approximated by three numerical methods, the FD equation is given by Eq. (3):

$$v_{i,j}=\frac{(v_{i+1,j}+v_{i\text{-}1,j}+v_{i,j+1}+v_{i,j\text{-}1})+(2.a^2.Q_{i,j}/K)}{4} \qquad (3)$$

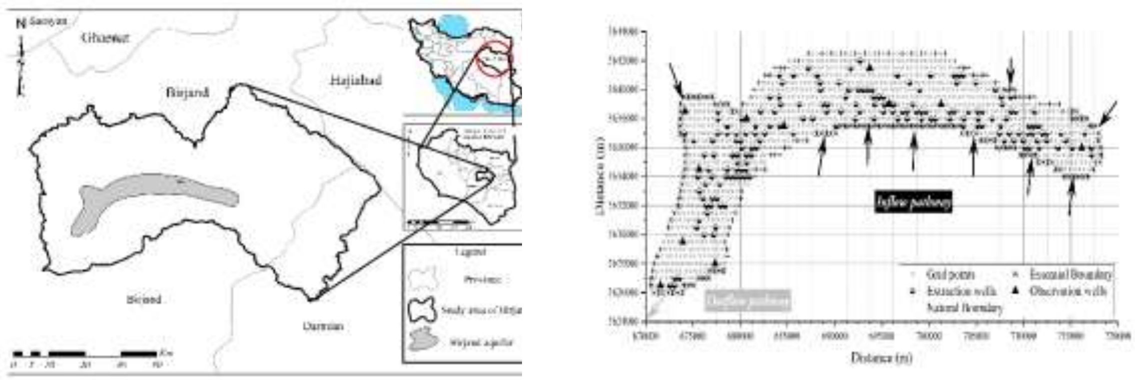
Where, $v=h^2$ and $a=\Delta x$. Also, the FE and Mfree formulation can be expressed as the following (Eq. 4):

$$[G].\{h^2\}=\{B\}+\{F\} \qquad (4)$$

Where, [G] is the conductivity matrix, {B} denotes the boundary vector, and {F} indicates the force vector. The used shape function in the FE model was linear triangular, while the shape and test functions in the Mfree were Radial Point Interpolation and Quartic Spline. Since the current study intends to provide a numerical framework in an open-source scale coded in MATrix LABoratory (MATLAB) environment, the verification of the numerical methods is performed in a hypothetical test and numerical simulations were compared to analytical solutions. After, a verification examination of numerical methods, their ability was compared to simulate the groundwater levels in the Birjand aquifer (a real complicated aquifer).

Conceptual model

In order to numerically simulate the groundwater flow, a mesh comprising 1059 nodes with horizontal and vertical distances of 500 meters was defined on the Birjand aquifer. In this aquifer, there are nine inlet sections and one outlet section and the boundary conditions of these sections were considered as constant height (Sadeghi-Tabas, et al 2017). The location of extraction and observation wells, and employed mesh are shown in Figure 1. Boundary conditions, homogeneous zones of hydraulic conductivity, were considered based on Sadeghi-Tabas et al. (2017).



a b

Figure 1. Location of Birjand aquifer(a) and (b) defined mesh, boundary conditions, extraction wells and piezometer wells.

The accuracy of different numerical methods in simulating groundwater levels was evaluated by RMSE criteria.

Results and Discussion

The results of the verification examination are presented here. Figure (2) shows the simulated groundwater levels versus the analytical solution next to RMSE. It is obvious that Mfree works better than FE and FD respectively. Based on the obtained results, it can be expressed that the validity of these numerical methods can be largely confirmed.

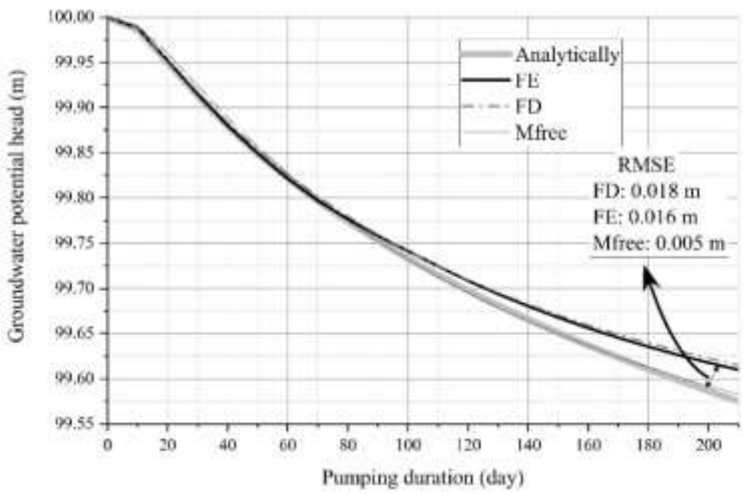


Figure 2- Comparison of analytical solution and numerical values simulated by Mree, FE, and FD in the hypothetical case study

After confirming the numerical models' performance, their ability in simulating groundwater levels in the Birjand aquifer was investigated. The groundwater level simulation was obtained for all nodes in the aquifer domain, in particular observation wells listed in Table 1. Also, the difference between simulated and observed values was presented through the RMSE index.

Table 1. Comparison of simulated and observed groundwater levels in separate of different piezometers

Piezometer NO	Measured potential head (m)	Simulated potential head		
		FD (m)	FE (m)	Mfree (m)
13	1264.07	1263.44	1263.94	1264.28
53	1299.10	1299.53	1299.22	1298.95
85	1291.00	1289.08	1291.06	1290.60
212	1296.60	1295.84	1296.83	1296.61
393	1392.91	1393.02	1393.01	1392.97
568	1322.76	1317.64	1323.03	1322.63
644	1310.08	1308.35	1310.14	1310.15
631	1307.29	1307.10	1307.11	1307.07
760	1363.28	1363.55	1363.36	1363.44
811	1358.05	1357.48	1357.54	1357.64
995	1342.68	1343.00	1343.57	1343.19
RMSE(m)		1.7738	0.338	0.26
Run time (s)		17.31	165.36	490.55

Derived results reveal that the ability of the Mfree method is significantly better than the FE methods, and FD.

Performance comparison of the numerical models in the hypothetical field study aquifer confirms the structure uncertainty of numerical methods and indicates its importance. Although in both aquifers, the same conceptual model was considered for three numerical methods, the outputs of numerical models were different confirming the structure uncertainty of mathematical modeling.

Conclusions

The finding of this study reveals that the proposed numerical models developed in this study are capable of simulating groundwater modeling even in real and complicated conditions. Also, this study indicated that Mfree's ability is very better than FE and FD models respectively. Moreover, the derived results clarified the structure uncertainty of mathematical modeling which researchers ignore it generally in the uncertainty assessment.

Investigating the relationship between springs and rivers, geological and tectonic factors (Case study: Kamyaran city)

Document Type: Research Paper

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Abstract
Spring distribution and flow rate are influenced by a variety of factors such as tectonics, climate, geology, distance from the drainage network, geomorphology, etc. The current study aims to determine the effect of structural parameters, lithology, and drainage network on two indicators related to springs, notably the number and annual water flow in Kamyaran, Kurdistan province. Correlation relationships have also been investigated between springs in watersheds and hydrometric stations downstream of them. A correlation coefficient of 0.947 exists. The correlation between the number of springs and the distance from the river is significant and is around 0.76. But there is no significant relationship between these two parameters with the amount of spring water. The discharge variable has a significant relationship with the formation type, with the sand limestone formation having the most annual drainage and the andesite, micro granite, and silty shales having the least. The results of the correlation between springs and hydrometric stations revealed that there are significant relationships between temperature parameters and annual discharge, but no significant relationships between pH and EC indicators.

Keywords: Discharge, Fault, Kamyaran city, River, Spring.

Introduction
Springs are important in understanding groundwater circulation and water-rock interactions because they are natural outlets of groundwater systems. Springs are the most significant natural groundwater drains that occur on the earth's surface under the impact of many factors, and the existence of many human groups, particularly in rural regions, are dependent on their effects. Surface indicators such as geological features and linear structures are commonly used by researchers to estimate underlying hydrological conditions. Each spring has its own set of indications, the most essential of which are the dispersion and volume of discharge. Tectonics, geology, geomorphology, surface cover, and other factors influence these indicators. Identification of lineaments is very important in hard formation hydrogeology because fractures are rock units that serve as transmission and concentration points for groundwater. Although human, animal, and plant life all rely on water, and springs are one of the primary sources of supply, they must be studied. The area of Kamyaran city is especially affected by tectonized Pearl faults and has several fractures in it; this area comprises different geological formations and has experienced many elevation changes due to its mountainous nature; the goal of this study is to investigate the factors affecting the emergence and flow of springs, and the effective factors in these two parameters were calibrated according to the environmental conditions of the study area; The current research also looks into the interaction between springs and hydrometric stations situated downstream. A variety of factors were investigated, including pH, electrical conductivity, temperature, and annual discharge time, and correlation links were established between each hydrometric station and springs in their upstream basins.

Materials and Methods
The Geological Survey of Iran generated a 1: 100,000 geological map of the studied region for this investigation. The layer representing the main faults and tectonic fractures of the required area is then digitized in ARC GIS software. The drainage network of the research region was derived from a digital elevation model with a pixel scale of 12.5 meters acquired from the Alaska site using the ARC HYDRO

extension of the ARC GIS program, and the findings were validated using satellite images and Google Earth. In addition, information about springs in the watershed was obtained from the Iran Water Resources Management Company, and after regulating the data and deleting missing and unnecessary statistics in EXCEL software, 2817 springs served as the foundation for the research. Among the available spring variables, two indicators of number and annual discharge based on cubic meters were chosen, and the structural and lithological features, as well as the drainage network of the watershed, were analyzed. To explore the link between springs and hydrometric stations, the catchment region upstream of hydrometric stations is first retrieved using ARC GIS software. The springs in the individual basins are then recognized and separated. The relationships between each of the indicators evaluated, such as temperature, electrical conductivity, annual discharge, and pH.

Results and Discussion

Each of the independent variables, including the formation material, elevation factor, distance from the river and distance from the fault to the two discharge index values, and the number of springs, were examined and their correlation in the study area was evaluated in order to achieve the research objectives.

Distance from the fault

First, the research area's faults were detected using information layers and a geological map, and the springs near them were categorized up to 500 m from the faults' 5 km distance. The distance from the fault and the number of springs have a 0.947 correlation. The greatest number of springs are found closest to the faults, and the distance from these tectonic fractures steadily lowers the number of springs. However, there is no special link between the flow rate of springs and the distance from the fault.

Distance from the river

The next section investigates the link between the distance from the river, the discharge, and the number of springs in the research region. Existing springs up to a distance of 2 km from the drainage network are categorized in 100-meter increments for this purpose. The reason for selecting 100-meter lengths is connected to the size of the studied region and the density of its rivers. The findings of this parameter also show that the number of springs decreases by moving away from rivers. However, the connection between the two is smaller than the fault's distance. The average annual discharge has no significant association with the distance from the river, and the correlation between these two parameters is smaller than the distance from the fault. Interestingly, the number of springs decreases almost uniformly with distance from the fault; however, in relation to the river, the greatest number of springs are at a distance of 0-100 meters, and then the number gradually decreases; this point should be considered in relation to the hydraulic slopes of the underground layers.

Formation material

The geological parameter and formation material are investigated in the research of spring flow rate. According to the findings, the flow rate of springs has a strong relationship with the nature and substance of their geological genesis. As a result, the sandy limestone formation has the maximum quantity of discharge, and the average annual discharge. In 14 springs analyzed in this formation, it is around 120 thousand cubic meters per year. Then there's shale rock, which has an average discharge of 36,000 cubic meters per year, diorite, which has an average discharge of 21,600 cubic meters per year, and a mixture of shale and another formation, which has an average discharge of 19500 cubic meters per year. Andesite, silty shales, and micro granites have the lowest discharge.

Numerous studies have been published on this topic; nevertheless, the interaction between tectonics and hydrogeological conditions with springs and wells has received more attention than the relationship between these elements and geomorphological landforms and rivers. In particular, studies on springs are limited in the country, and such studies are often sufficient to study the effect of fault lines on the emergence of springs; the results are consistent with the results of this part of the current study, and there is a high correlation between the number of springs in the proximity of faults and tectonic lines.

As a result, the current study differs from others in that it investigates geological, tectonic, and geomorphological aspects of spring emergence and discharge. In addition to the number and spatial distribution of springs, the discharge rate was investigated in connection with the aforementioned criteria.

Investigating the relationship between springs and runoff in basins

To explore the link between springs and basin runoff, data from hydrometric stations in Kamyaran city were collected, faults were identified, and upstream basins were extracted using the ARC Hydro extension in ARC GIS software. Then The springs in each sub-basin were separated, and the annual discharge, temperature, electrical conductivity, and pH of springs and hydrometric stations were compared. The results of this section revealed a significant relationship with a correlation coefficient of 87 percent between the total annual discharge of springs and the total annual discharge of hydrometric stations; however, the main reason for this significant relationship is related to a large number of springs in the vast basins of a number of hydrometric stations under study.

The average discharge water temperature of springs and hydrometric stations has also been researched in this regard, with a correlation value of 0.56. This shows that the water temperature is high as it exits the springs and progressively decreases as the river flows and reaches the hydrometric station in respect to the outside air. This temperature difference is significant in the Zivieh and Alak basins, reaching 7-8 degrees Celsius. However, in Biar station, the temperature lowers by about one degree.

The findings show that there is no significant relationship between the EC and pH parameters of the springs and hydrometric stations analyzed, and the correlation is zero. Except for the Palangan basin, where the electrical conductivity of the hydrometric station is less than that of the springs, the opposite is true in the other basins. This can be attributed to the karst creation of Palangan watershed structures. In all basins, the amount of pH reported in the hydrometric station is more than the average of springs, ranging from 0.28 in the Ramesht basin to 1.23 in the Palangan basin, which may be related to the karst formations in the Palangan basin. The alkalinity of the springs and hydrometric stations analyzed is the common denominator of all measured pHs. Meanwhile, the alkalinity of the Palangan basin springs' outflow water is the lowest and closest to neutral. The majority of study on this topic has explored the interaction between surface water and groundwater, as well as some shared characteristics between them, such as hydrochemical parameters. Facts that have simply been concerned with surface water have frequently addressed the link between rainfall and runoff and may be described as research that evaluates the relationship between springs in basins and downstream hydrometric stations.

Conclusions

Several criteria influence the distribution of springs and their flow rate. In this study, the influence of structural characteristics, lithology, and drainage network on two spring indicators, including the number and annual discharge, was explored.

The correlation between these two values is 0.947, indicating a close association. The number of springs and distance from the river has a lower connection, which is mostly attributable to two factors: the hydrological slope of the aquifers and the density of springs at lower altitudes. The number of springs and the distance from the river have a 0.76 correlation. However, there was no significant relation between the two factors of distance from the fault and river and spring flow rate. The type of geological formations of springs was examined in order to determine the effective factor in their discharge rate, and it was concluded that there is a significant correlation between these two indicators; thus, sandy limestone formation has the highest annual discharge and andesite, silty shale, and micro granite have the lowest relevant values.

Furthermore, investigations have shown that there is no substantial correlation between the average height of springs in distinct formations, regardless of the type of each formation at any altitude level.

The correlation links between springs and hydrometric stations in the research region were also investigated in this study. This section's findings revealed that there are significant connections between temperature and yearly discharge parameters. Because of the large number of springs in big basins, the link between the yearly discharge of springs and basins is natural. The average water outlet temperature of springs correlates with the average water temperature of hydrometric stations by 56%; the water temperature is high when leaving the springs and gradually decreases within the river and reaching the hydrometric station with interaction with the outside air. However, there was no statistically significant link between pH and EC indicators.

Investigation of Temporal and Spatial Variations of Groundwater Quality in Sefiddasht Plain and Suitability Evaluation for Agricultural Use

Document Type: Research Paper

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Abstract

Groundwater resources are valuable resources to supply water for various uses in all areas, especially arid and semi-arid areas. Due to the limited resources and increasing population and the growth of agriculture and industry, the optimal use of groundwater needs more attention. In this research, the temporal and spatial variation of groundwater quality of Sefiddasht plain located in Chaharmahal and Bakhtiari province and its capability for agricultural purposes have been investigated. For this purpose, the time series of qualitative variables collected in 9 sampling stations (including 6 wells, 2 qanats and a spring) in the Plain during a 29-year period (1991-2018) was used. The trend of changes in groundwater quality variables of this plain was investigated using the modified Mann-Kendall test (after the complete elimination of the autocorrelation effect). The trend line slope was also calculated for each time series using the Sen slope estimator. The results showed that groundwater quality has decreased in recent years in some places, especially in the southern parts of Sefiddasht. In order to draw zoning maps of qualitative variables at the beginning and end of the studied period, the accuracy of various geostatistical methods, including inverse distance weighting (IDW), Kriging, Co-Kriging, etc. for Sefiddasht plain was evaluated and the IDW method was selected for this plain. A comparison of zoning maps of qualitative variables at the beginning and end of the studied period showed that the groundwater quality of this plain has decreased during the considered 29 years. Finally, the usability of groundwater in Sefiddasht plain for agricultural use was evaluated using the USSL diagram for the beginning and end of the studied period. The results indicated a decrease in the quality of groundwater for agricultural use in this plain during the studied period.

Keywords: Groundwater quality, Inverse distance weighting (IDW), Mann- Kendall, Trend, USSL diagram.

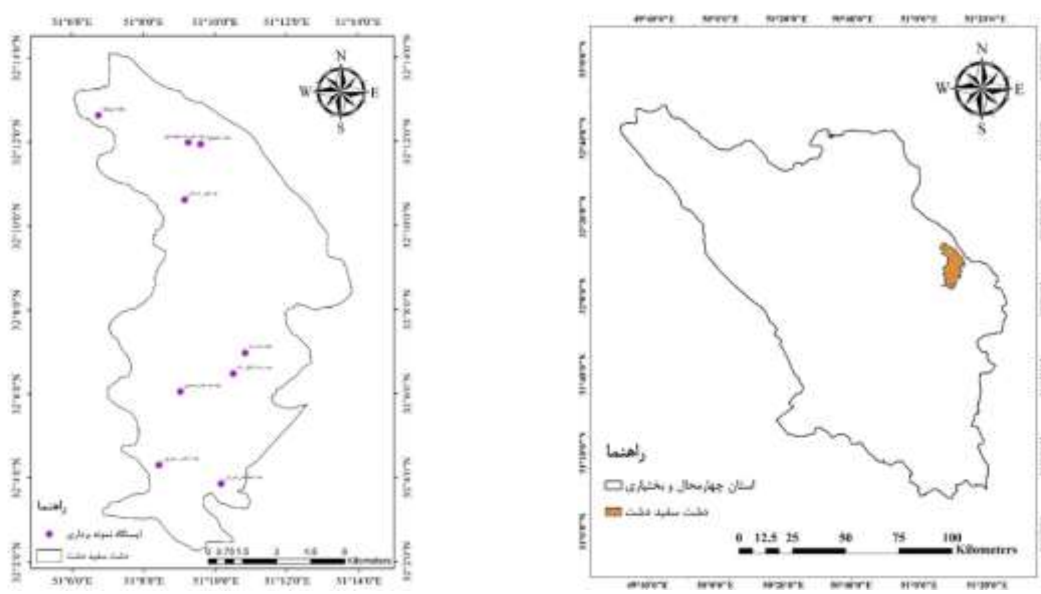
Introduction

Water consumption has increased continuously since the industrial revolution with the increasing development of cities and the rising population. The occurrence of severe droughts and over-exploitation in recent years has not only decreased the quantity of groundwater, but also led to groundwater quality deterioration, which is undoubtedly a serious environmental challenge. Considering the shortage of available water resources in the near future and the existing risks, investigating the reduction of the water table and its impact on the groundwater quality and finding effective factors in this issue is a necessary issue for water resources planners and managers. Analyzing trends in observed hydrological data is one of the requirements for designing appropriate policies in water exploitation. So far, several non-parametric statistical tests such as Spearman and Mann-Kendall tests have been developed to determine the trend of the time series and the Sen Slope estimator method to estimate the slope of the trend line. Geographic Information System (GIS) is one of the most common tools for the qualitative evaluation of water resources and geostatistical techniques are of the most important capabilities of this system. Maps obtained from geostatistical techniques are used as primary selection tools for decision-making systems in groundwater management strategies on a local and regional scale. Usually, in order to determine the suitability of groundwater quality for different uses, after sampling, chemical analysis tests are carried out on the samples and by comparing their results with standard values, the suitability of water quality for each type of use is determined. The USSL diagram, which is one of the most important classifications in this field, is used to determine water quality in terms of usability for agricultural purposes.

Materials and Methods

Sefiddasht plain is located between Borujen and Shahrekord cities in Chaharmahal and Bakhtiari province. Sefiddasht plain with an area of 134 square kilometres is about 0.81 percent of the area of Chaharmahal and Bakhtiari province. Also, the average height of this plain around Sefiddasht village is 1190 meters above mean sea level. The mountainous climate is the dominant climate in the study area. In this study, in order to evaluate the groundwater quality of Sefiddasht plain in terms of agricultural uses, qualitative data from 9 sampling stations (including 6 wells, 2 Qanats and one spring) were used in the 29-year period (1991-2019). Figure 1(a) shows the location of Sefiddasht plain in Chaharmahal and Bakhtiari province. To delineate the qualitative variables (i.e., TDS, TH, SAR, EC, Total Cations and Total Anions) of the Sefiddasht plain, at first, the accuracy of different geostatistical techniques, including the inverse distance weighting (IDW), Kriging, Co-Kriging, etc., was compared. The results showed that the percentage of standard errors in the IDW method for Sefiddasht plain was lower than other methods and therefore, the IDW was selected for the delineation of groundwater quality parameters. Zoning maps of groundwater quality variables at the beginning (1991) and the end (2019) of the studied period were plotted on GIS and compared. Figure 1(b) shows the Sefiddasht plain and the location of the sampling stations.

In this study, the trend of the time series of the selected qualitative variables in the study area was investigated using the Mann-Kendall non-parametric test (MK). The prerequisite for using this test is the lack of significant autocorrelation in the time series of data, however, the data may have significant autocorrelation. Therefore, first, the autocorrelation effect of the data should be eliminated before using the MK test. For this purpose, the autocorrelation coefficient for the data is calculated. In cases where the autocorrelation of the data was significant at the desired level, first, the autocorrelation effect of the data is eliminated, then the new data set and their trend were examined by the Mann-Kendall test. The Mann-Kendall test after removing the effect of all significant autocorrelation coefficients is shown as MMK. The Sen slope estimator is a very useful indicator in investigating the slope of the trend line of a time series. In this study, the trend line slope was calculated using the Sen method and tested at a significant level of 1, 5 and 10 percentages.



(b) (a)

Figure 1- (a) Location map of Sefiddasht plain in Chaharmahal and Bakhtiari province, and (b) the Sefiddasht plain and the location of sampling stations

Results and Discussion

In this study, at first, the trend of groundwater quality variables (TDS, TH, SAR, EC, Total Cations and Total Anions) of Sefiddasht Plain was investigated using the modified Mann-Kendall test (MMK). For each time series, the trend line slope was calculated using the Sen Slope estimator. The results showed that the groundwater quality has decreased in some places, especially in the southern parts of the Sefiddasht plain in recent years. Then, the zoning maps of qualitative variables were plotted at the beginning and the end of the studied period (1991-2019) using GIS software and the geostatistical technique of inverse distance weighting method (IDW) for the Sefiddasht plain. A comparison of zoning maps at the beginning and the end of the studied period indicates that the groundwater quality of this plain has dropped during these 29 years. Finally, the usability of groundwater in Sefiddasht plain for agricultural purposes was compared based on the United States Salinity Laboratory (USSL) diagram for the beginning and end of the studied period. The results showed a decrease in the quality and classification class of groundwater for agricultural purposes.

Conclusions

In the present study, the temporal trend of changes in groundwater quality variables of Sefiddasht plain during 29 years (1991-2019) was investigated using the modified Mann-Kendall test (MMK) and at three significant levels of 10, 5 and 1%. The results showed that the most qualitative variables and sampling points at Sefiddasht plain had a significant increasing trend and the number of series with a significant positive trend was more than the number of series with a significant negative trend. Kheybar Sadeghi well, Shadikhar Qanat and Vakilzadeh well in most groundwater quality variables (TH, TDS, SAR, EC, Total Cations and Total Anions) had no significant trend and only Kheybar Sadeghi well in TH qualitative variable had a significant positive trend. The Shadikhar Qanat and Vakilzadeh well had a significant negative trend only in the SAR variable. Also, Ali Mohammad Tahmasebi well and Soltanali Shirani well have significant increasing trends among the studied stations in all the studied qualitative variables (TH, TDS, EC, Total Cations and Total Anions) except SAR in which there is a significant decreasing trend.

Then, using Arc GIS software, the zoning maps of qualitative variables at the beginning (1991) and the end (2019) of the studied period were plotted and compared. The results showed that from 1991 to 2019, the groundwater quality of the Sefiddasht plain has changed and the concentration of qualitative variables in the southern parts of the Sefiddasht plain is higher than in other parts. The concentration of qualitative variables has increased from the north of this plain to the south, and the quality of groundwater in the plain has decreased.

The groundwater quality of Sefiddasht plain in terms of agricultural uses was investigated using the USSL diagram. The results showed that at the beginning of the studied period (1991), the groundwater quality of most of the stations was in the C2-S1 class (i.e., slightly salty and good quality) which is suitable for agricultural uses and has no restriction. At the beginning of the studied period, Pirkooh spring with the C1-S1 quality class (i.e., very good quality) is completely harmless for agricultural purposes and has the best water quality among other studied stations in this plain. Also, Soltanali Shirani well with the C3-S1 quality class (i.e., saline and medium quality) has the weakest groundwater quality in terms of agricultural uses among the studied stations in Sefiddasht plain. Although, it can be used for agricultural purposes. The results also showed that at the end of the studied period (2019), the groundwater quality of most of the studied stations was classified in the C2-S1 class (i.e., slightly salty and good quality), and was suitable for agricultural purposes and had no limitations. Ali Mohammad Tahmasebi well and Shadikhar Qanat located in the C3-S1 class (i.e., saline and average quality) have the weakest quality in terms of agricultural uses among other stations this year, but they can be used for agricultural purposes. Therefore, it can be concluded that the significant decreasing trend in groundwater level and quality of groundwater resources in the Sefiddasht plain is due to over-exploitation by wells for agriculture, reduction of precipitation and the occurrence of consecutive droughts in recent years. Also, during the studied 29-year period, it can be noted that although groundwater quality has decreased in the Sefiddasht plain, based on the USSL diagram, the quality class of most stations in the study period has not changed remarkably.

Prediction of short-time and long-time of land use change in groundwater vulnerability by DRASTIC index and TerrSet software

Document Type: Research Paper

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Abstract

Today, due to widespread land use changes, including increasing urban population and drinking needs, industrial and agricultural growth of communities on the one hand and further reduction of surface water resources, on the other hand, has increased the use of groundwater resources. Therefore, it is necessary to evaluate the effect of land use change on aquifer vulnerability. Since the potential for pollution in different parts of an aquifer is different in terms of contaminants reaching the groundwater, predicting the extent of vulnerability changes in aquifers by predicting future land uses. In this study, for the first time, the effect of the future land use changes on the vulnerability of the Hashtgerd aquifer for the periods of 2025, 2035 and 2045 has been investigated and compared with the current situation in 2018. In this regard, first, using the Markov chain method in TerrSet software, land use changes for the three periods of 2025, 2035 and 2045 were extracted. Land use mapping was performed using Landsat satellite images for 1998, 2008 and 2018 in ENVI 5.3 software. The generated maps were added as a parameter to the DRASTIC vulnerability method and finally, DRASTIC-Lu was predicted for three periods. This study shows that the vulnerability in high and very high classes in 2045 will increase by 34% and 83%, respectively. Furthermore, the increasing trend of vulnerability in the classroom is very high for three incremental periods and will increase from 14% in 2025 to 20% and 83% in 2035 and 2045. This study shows that in the coming years, in order to preserve groundwater resources, it is necessary to consider special monitoring measures in the northern and northeastern regions of the aquifer.

Keywords: DRASTIC, Hashtgerd Aquifer, Land use Change, TerrSet Software, Vulnerability.

Introduction

Today, groundwater aquifers are considered the most important sources of water supply, especially in arid and semi-arid regions of the world. These resources have faced quantitative and qualitative degradation due to the increasing demand in drinking, industry and agriculture, as well as climate change and reduction in recharging (Javadi et al., 2011; 2017). Therefore, it is necessary to provide protective management solutions to preserve these valuable resources. In this regard, preparing vulnerability maps can be the most optimal and economical solution in this field (Kardan et al., 2017).

The DRASTIC method has been used in many researches in the world's aquifers since the last decade to assess vulnerability (Kardan et al., 2011; Javadi et al., 2011) (Allouche et al., 2017; Neshat et al., 2014; Nahin et al., 2020; Kumar et al., 2020; Machiwal et al., 2018). Hao et al. (2017) showed that by adding aquifer thickness (M), groundwater exploitation (E) and land use (L), the modified DRMSICEL method gives a better answer than the standard DRASTIC. Asadi et al. (2017) used the DRASTIC-LU method by adding the land use layer in their studies, and the results obtained from the modified methods were better than the standard DRASTIC. In Iran, Ahmadi et al. (2012) evaluated the vulnerability of the Khizrabad plain aquifer using the DRASTIC method. They combined the maps of geomorphology, land use and vegetation type and extracted its work unit. Mohammadpour et al. (2019) investigated the fluctuations of groundwater in Ahar plain under the influence of climate change and the improvement of irrigation method.

Their research results showed that if climate scenarios are applied for the future, due to the lack of water in the region, its water resources will have good conditions in the future will not experience.

In this research, for the first time, the effect of land use changes in the next 30 years on the vulnerability of Hashtgerd plain has been studied.

Materials and Methods

Case Study

Hashtgerd plain with an area of about 410 km^2 is located in the central part of Alborz province. The type of Hashtgerd aquifer is unconfined, although there are perched aquifers in some parts of the aquifer, which are not significant in terms of size. According to De-Martonne's climate division, the index value is 10.5. According to this index, the climate of Hashtgerd Plain is semi-arid. In general, the slope of the plain decreases from the north to the south, and the direction of the surface and groundwater flow is from the northeast to the southwest. Also, in the southern half of the plain, there is a multi-layered and confined aquifer, and due to finer-grained sediments compared to the northern half, the wells yield less water than the northern and eastern parts. The type of Hashtgerd aquifer is unconfined, although there are perched aquifers that are not significant in terms of size.

DRASTIC method

The most common method for assessing aquifer vulnerability is the DRASTIC method, which was developed by the National Groundwater Association in cooperation with the US Environmental Protection Agency (Aller et al., 1987). The United States Environmental Protection Agency (EPA) developed this method to determine the potential of groundwater pollution, and it has been used in many researches in recent years. According to the importance of the effect of each parameter on the transmission of pollution, each parameter is given a weight between one and five, where #5 is the most important and #1 is the least important. DRASTIC determines the intrinsic vulnerability of an aquifer to pollution using seven hydrological, hydrogeological, geological, and topographical indicators. This method includes 7 parameters including depth of groundwater (D), recharge (R), aquifer area (A), soil media (S), topography (T), the influence of unsaturated zone (I), and hydraulic conductivity (C). Each DRASTIC parameter is ranked based on the feature in the form of a raster map, where a numerical value between 1 and 10 is considered for each parameter (Almasri. 2008).

According to the conditions of the region and the characteristics of the aquifer, a rank is assigned to each of the parameters of the DRASTIC index. The basis for ranking these parameters is based on the table provided by Aller et al. (1987) (Table 1).

Table 1- Weighting of DRASTIC index parameters.

Parameter（DRASTIC）	weighting coefficient
Depth to water (D)	5
Net Recharge (R)	4
Aquifer Media(A)	3
Soil Media (S)	2
Topography (T)	1
Impact of Vadose Zone (I)	5
Hydraulic Conductivity(A)	3

DRASTICLu method

By predicting land use in the future, it is possible to check the changes in the vulnerability of aquifers. As a parameter, (Lu) added to the DRASTIC vulnerability method. The land use layer is prepared according to the urban use map, and agricultural use map, as well as the coverage status and type of land use in the study area, and it is divided into four classes residential, agricultural, pasture, and barren use, which in table 2, the ranking related to different land use classes is shown. Also, the weight considered for the land use parameter is five according to previous studies (Secunda et al., 1998).

In this method, the land use map is added to the DRASTIC vulnerability method and finally, DRASTIC Lu is calculated. In Table 2, the ranking of different classes of land use is given.

Table 2- Land use parameter class ranking

Rating	Land use category
8	Irrigated field crops
5	Pasture
1	Open area
10	Built up area

Extraction of land use maps (Lu)

In order to predict land use changes, it is necessary to extract this map using satellite images for different periods of time. Therefore, in this study, ENVI 5.3 software and data from ETM+ and OLI sensors of Landsat satellite were used to prepare land use maps. The images used included ETM+ Landsat 7 sensor images from 1990 and Landsat OLI 8 sensor images of 2005 and 2018, respectively.

The Kappa coefficient was used to evaluate the generated maps and classification accuracy. The results of the Kappa index for land use maps prepared in 1990, 2005 and 2018 were 87, 89 and 92% respectively. The evaluation of the results indicates that the highest Kappa coefficient is related to 2018 due to the stronger radiometric resolution of the images.

Results and Discussion

DRASTIC map of the current situation of Hashtgerd Plain

The DRASTIC index of Hashtgerd plain was calculated by considering the values and weights presented in Table 1. The information collected in both raw and digital formats could be used based on the needs of the index parameters. Several GIS tools were used to integrate index elements to analyze parameters. In the case of well locations that exist as point files in GIS, the kriging interpolation technique was used to convert the groundwater depth information into a continuous surface.

The final index varies between 63 and 132 in the range under study, and according to the numerical range of vulnerability, the resulting zoning is based on the classification of Aller et al. (1987). It was classified into four classes. It included low vulnerability with 36.2 percent, medium vulnerability with 11.9 percent, high vulnerability with 30.4 percent, and finally very high vulnerability with 21.5 percent of the entire study area. Finally, it was determined that the northeastern parts of the study area have a very high vulnerability potential.

DRASTIC Lu map of Hashtgerd Plain

In this study, according to the coverage status and type of land use for 2018, the studied area was divided into 4 classes residential use, agriculture and gardens, pasture and barren land. The results of this research show that high and very high vulnerability will increase by 34% and 83% respectively in 2045. Also, the increasing trend of vulnerability in the class is very high for three increasing periods and will reach from 14% in 2025 to 20% and 83% in 2035 and 2045. In other words, in order to preserve groundwater resources for the coming years, it is necessary to consider special monitoring measures in areas with high and very high vulnerability, especially in the northern and northeastern regions of the aquifer.

Conclusions

Land use changes, if done without management and planning, will cause severe environmental consequences. In other words, changes in land use from pastures or barren lands to agriculture and residential areas will cause environmental damage to rivers and aquifers in the absence of management. Therefore, in this research, for the first time, the effect of land use changes in the future on the vulnerability of groundwater was evaluated. In this regard, using satellite images, land use was predicted for the near (2025) and distant years (2035 and 2045) and it was determined that the two levels of agriculture and residential areas will increase significantly in the future. The results showed that in the coming years, the level of residential land will be 1.5 times. On the other hand, agricultural land will increase by 100% compared to the current situation (2018). As a result, the effects of increasing the levels of residential areas and agricultural lands can have destructive effects on the vulnerability of underground water tables. In the following, these effects were investigated by combining the vulnerability map of Hashtgerd plain with the DRASTIC method and the land use map. The results showed that in 2025 and 2035, DRASTIC-LU vulnerability values in the very high-risk class will increase by 14% and 20%, respectively, compared to 2018. Also, this increase was more noticeable in 2045, so the high and very high vulnerable values of this year will be 34% and 83%, respectively, compared to 2018. The results of this research show that with the increase of agricultural levels and residential areas in the future, either urban sewage or agricultural drainage must be managed, or groundwater monitoring in the northern and northeastern regions of this plain should be done regularly. The practical results and the superiority of the methodology of this research show that by accurately predicting land use changes, it is possible to identify areas more sensitive to pollution. In other words, by identifying the polluted areas in the future, it is possible to prevent the further penetration of pollution by monitoring those areas or quality management.

Investigating the hydraulic relationship of karst structures with hydrogeochemical and isotopic methods of water resources in Izeh region, north of Khuzestan province

Document Type: Research Paper

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Abstract

Proper water resources management relies on recognizing and evaluating the factors affecting the quantity and quality of the water resources. In the present study, the hydraulic relationship between the karstic structures of the Izeh territory located has been assessed using hydrogeochemical and isotopic information on water resources. To investigate the number of 31 water samples (17 wells, 8 springs and 6 rain samples) in the areas of Kamarderaz, Mongasht, Shavish-Tanosh, Anticlines and the Naal-e-Asbi (Horseshoe) Syncline were taken on June 1398 and June 1400, and hydrogeochemical as well as isotopes δ18O and δ2H were examined until to the hydrogeological and hydraulic behavior of this complex karstic system. The results of hydrogeochemical analysis of the specimens showed that the concentration of ions is influenced by the dissolution of calcareous rocks. The isotopic content of groundwater samples is from 5.62 to 3.49- ‰ and from 20.97 to 12.29- ‰ for $\delta^{18}O$ and $\delta^{2}H$. Investigating the isotopic content of water wells and springs of the region indicates three groups of water. The first group of indentation springs is fed from altitudes and snow from altitudes. Fast water in the canal system caused a low latency in these springs. The second group is enriched more than the first group, and in addition to precipitation, the mixing of underground water is also effective in providing their water. The third group has longer than other samples due to evaporation and distances longer than the feeding site and the enrichment system. The decrease in Sr^{+2} and incremental Ba^{+2} of dolomitic limestone samples (Shavish-Tanosh and Mongasht) to water samples of chemistry and hinges, as well as structural and isotopic data indicate the probability of nutrition. The karstic aquifers of the region are from the anticline, as well as the hydraulic relationship between these structures.

Keywords: Hydrogeochemistry, Hydraulic connection, Isotope, Izeh, Karst.

Introduction

For groundwater supply to be managed sustainably in water scarce regions, understanding the sources of recharge and flow pattern of groundwater in these regions is imperative. The hydrochemical and stable isotope techniques have been commonly employed to identify groundwater recharge mechanisms and flow paths (Connor et al. 2017; Morsy et al. 2018; Mokadem et al., 2021; Slabe et al., 2016; Scanlon et al., 2002; Gates et al., 2008; Chen et al., 2018; Bourke et al., 2015). During the last three decades, chemical constituents and the isotopic composition of water have been widely used to characterize the groundwater recharge sources, recharge rate and flow pattern and therefore address associated resource problems (Bajjali, 2006; Edmunds et al., 2006; Ma et al., 2013). Karst regions have a specific hydrogeological character (Milanovic, 1981; Ford and Williams, 1989, 2007) because the constituent rocks, like limestone and dolomite, are highly susceptible to chemical dissolution (Milanovic, 1981; Goldscheider and Andreo, 2007; Ford and Williams, 1989, 2007). In the karstic regions, the study of chemistry is essential (White, 2015) because hydrochemical properties reflect the mechanism of groundwater flow in karstic rocks (Ford and Williams, 1989; Ford and Williams, 2007). Karst aquifers have heterogeneous characteristics owing to the three media-based systems through which groundwater flows, namely pores, fractures, and cavities (Goldscheider et al., 2007) . The chemical constituents of groundwater illustrate a key role in evaluating the quality of water. In unpolluted groundwater systems, major and minor ion composition is controlled by several factors like geology, water-rock interaction and recharge water (Jebreen et al., 2018; Ventura et al., 2021; Pracny et al., 2017; Krienen et al., 2017). As it is known, water contains dissolved ions that affect the physical and chemical properties of water. Therefore, scientists continue to investigate the physical and chemical properties of groundwater (Wang et al. 2018; Rehman et al. 2019; Farid et al. 2020; Haldar et al. 2020; Yasin and Kargın 2021). Studies of karst hydrogeological systems using hydrochemical and stable isotope analyses (18O and 2H) have been conducted by, Ashjari and Raeisi, 2006, Setiawan et al., 2020, Alemayehu et al., 2020); Dimitriou and Tsintza, 2015, while the more specific study employing multivariate hydrochemical analysis has also been conducted by, e.g., Valdes et al., 2007; Narany et al., 2014; Chihi et al., 2015 and Yuan et al., 2017. These studies generally explain hydrochemical processes such as the dissolution and precipitation of carbonate minerals, and identification of karstic hydrogeological systems, including; the process of karst groundwater recharge, flow pattern, and discharge. The isotopes 18O and 2H are conservative (Heydarizad et al., 2021; Tian et al., 2021; Mokadem et al., 2021; Vreca and Kern, 2021; Tillman et al., 2014; Murillo et al., 2015 and Sun et al., 2016), that is, not seriously affected by water–rock interaction processes at low temperatures (Marfia et al., 2004). These isotopes have been used in studies of groundwater recharge and flow direction (Marfia et al., 2004; Rodgers et al., 2005; Blasch and Bryson, 2007; Ryu et al., 2007; Singh et al., 2013), the heterogeneity of aquifer hydraulic properties (Marfia et al., 2004; Doveri et al., 2013), residence time of groundwater (Rademacher et al., 2003; Mahlknecht et al., 2006), and also the mixing of groundwater from different sources (Coplen 1993). Several studies have suggested the application of hydrochemical and isotopic tracers to elucidate sources of dissolved ions and hydrogeochemical processes that controls the chemical variability in the multilayered aquifer system (Wang et al., 2018; Liu et al., 2019). Hydrochemistry and stable isotopes are employed for spring discharge studies (Doctor et al., 2006; Hatipoglu-Bagci and Sazan, 2014). Likewise, delineation of the recharge area and distinguishing sources of recharge to the karstic springs have been accomplished by applying hydrochemistry and stable isotopes (Blasch and Bryson, 2007; Bhat and Jeelani, 2015). Karst aquifers in Izeh region (wells and springs) are very important in terms of drinking water supply for Izeh city and surrounding villages. The geological formations of the Izeh complex karstic terrain are mainly calcareous, but with respect to lithology, morphology and structure are more or less different (Existence of anticlines and synclines with different lithology). Integration of the abundant information gathered from different sources is crucial for developing knowledge about the karstic aquifers and their interconnection. As hydrochemistry and stable isotopes provide key information to characterize hydraulic connectivity so, in this work, hydrochemistry including major and minor ions and stable isotopes (δ18O and δ2H) of the main karst springs and exploitation wells in the Izeh area were taken into account- to designate the hydrochemical and isotopic behavior of the Izeh karstic terrain and to determine hydraulic interconnection among the karstic aquifers.

Materials and Methods

A total of 25 groundwater (8 springs and 17 wells) in the same locations were sampled twice in January 2020 (wet season) and May 2021(dry season) and 6 rainwater samples from selected locations. For evaluation of the stable isotope content of rainwater (rainwater samples were sampled from higher altitude feeding areas and lower altitude discharge areas), the main karst springs and wells in the karstic aquifer system, samples were analyzed. The samples were taken from pumping wells and springs across the study area (Fig. 1) Water from wells in the area is extracted using pumps. Physical parameters such as pH, temperature, electrical conductivity, and total dissolved solids were measured in situ using standard field equipment such as Mercury in glass thermometer, digital mvRedox pH meter, conductivity meter, WA 3000, and spectrophotometer respectively. Major anions and cations were analyzed using titration, chromatography and flame tests in the Zagros Abshenas Laboratory respectively. The trace elements were measured using inductively coupled plasma-mass spectrometry (ICP-OES), using the acid digestion method with hydrofluoric acids, sulfuric acid, nitric acid and Perchloric acid in the Zarazma Laboratory. The isotopic samples (30 samples in two seasons (6 rainwater samples in January 2020, 7 spring samples and 17 well samples in two seasons, table 4) were analyzed for δ2H and δ18O values with precision ±0.1‰ for δ18O and ±1‰ for δ2H in the Mesbah Energy Laboratory of Arak with the use of Off- Axis-integrated- Cavity- Output- Spectroscopy (OA-ICOS).

Stable isotope ratios are reported in parts per mile (‰) using the conventional delta notation. For hydrochemical interpretation and to get knowledge about the hydraulic connection between karstified and water-bearing structures various graphs, including, Gibbs (1970) and Langelier and Ludwig (1942) were taken into account.

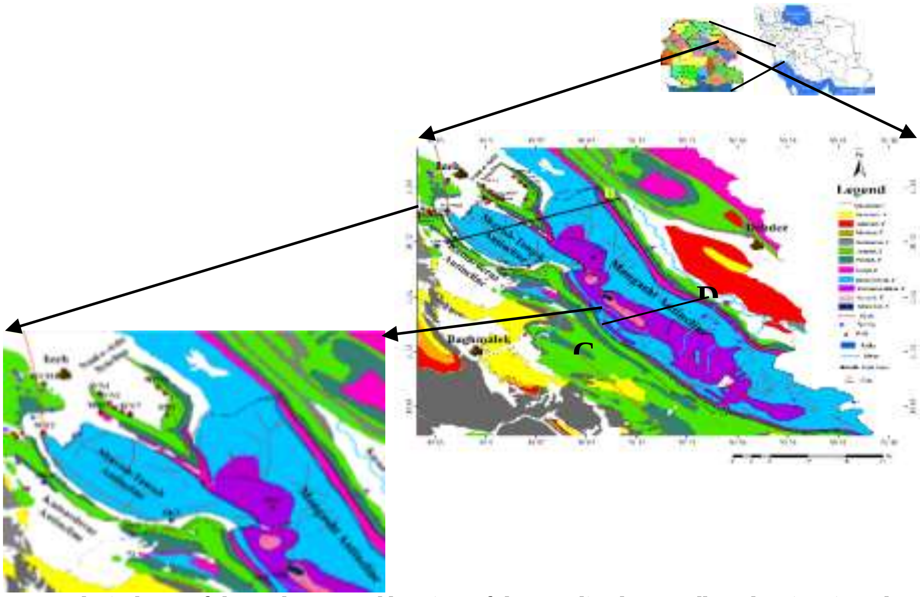

Figure1- Geological map of the study area and locations of the sampling karst wells and springs in Izeh catchment

Results and Discussion

The hydrochemical properties of groundwater samples for two seasons (wet and dry) are shown in Tables 1a and 1b, and the chemical ionic balance is also presented. The pH of groundwater samples is slightly alkaline and varies from 7.18 to 8.22. The temperature varies from 12.8 to 24.8°C with a mean value of 19 °C. The EC and TDS of the groundwater samples varied from 278 to 1325 µS/cm and 209 to 944 mg/l respectively. The rise of EC in wells WN_1, WN_2 and WN_4 located in the Naal-e-Asbi can be considered a result of reversing groundwater flow direction from the alluvial aquifer into the Naal-e-Asbi karstic aquifer. Reversing the flow direction is due to recent droughts and excessive water abstraction from the calcareous aquifer, which caused the karstic aquifer water level to recede' with respect to the alluvial aquifer (Kalantari et al. 2009).

The Ilam-Sarvak (Upper Cretaceous) and Asmari (Oligocene to Miocene) calcareous-dolomites formations in the Zagros structural belt have formed a promising karstic groundwater horizon. The results enabled us to understand various components influencing water resource recharge. In this assessment samples from the karstic springs and wells of the Mongasht, Shavish-Tanosh, Kamarderaz anticlines, the Naal-e-Asbi (Horseshoe) Syncline and meteoric water were collected in order to understand the hydrochemical and isotopic characterization, hydrogeologic and hydraulic behavior of the Izeh karstic system. Meteoric and groundwater samples were analyzed to determine major and minor ion concentrations as well as $\delta^{18}O$ and $\delta^{2}H$ isotope ratios. The isotopic content ranges from −31.6 to −2.9‰ and from −6.32 to −1.87‰ for $\delta^{2}H$ and $\delta^{18}O$, respectively, and the d-excess values were high and positive. Examination of the isotopic content of water samples of springs and wells in the region shows three groups of water sources. The first group, which is related to the Mongasht anticline springs, has lower isotopic values, indicating to be fed by rainfall at high altitudes and snow melting. The isotopic value of the second group is richer than the first group, depicting rainfall recharge as well as groundwater mixing (examples of Naal-e-Asbi Syncline and Shavish-Tanosh anticline). The highest value in the third group (Kamarderaz anticline samples) is slightly due to evaporation and the long distance from the feeding site to the discharge point as well as the diffusion system. The trend of Sr^{+2} decreasing and Ba^{+2} increasing of the samples in the dolomitic limestone formations (Shavish Tanosh and Mongasht anticline) compared to the water samples of the Kamarderaz anticline and Naal-e-Asbi Syncline, indicates, the possibility of the karst aquifers feeding of the region from the Mongasht anticline and the existence of the hydraulic relationship between these structures

Conclusions

Having in mind the fact that Iran is located at the heart of the thirst of the Middle East, the karst aquifers in the Zagros area are of great economical and social importance and, thus, challenging. The presented dataset is the first compilation of stable isotope hydrological data in Izeh. The water stable isotope data demonstrate spatial distribution in various hydrogeological settings across the Izeh and provide input for future hydrogeological studies and direction for groundwater management. This research was conducted to assess the hydrochemical characterization and isotopic measurements of the Izeh watershed and also to determine hydraulic relationships among the water-bearing structures. The command area recharges mainly from rainfall, but the Mongasht aquifer experiences rejuvenation from rainfall as well as snow. The study results suggest that hydrochemical and isotopic data are applicable to understanding the flow paths of springs (e.g., conduit flow through carbonate rocks) and storage. The dominant cations and anions in groundwater were Ca^{+2}, Mg^{+2} and HCO_3^-, SO_4^{-2} and the sources of ions are mainly calcite and calcite-dolomite formations. The chemical concentration of ions in the samples of the Shavish-Tanosh, Kamarderaz Anticlines and the Naal-e-Asbi Syncline was considerably higher than the Mongasht Anticline samples. The higher ion concentration is chiefly on account of the water-rock interaction and relatively long residence time. The water type is dominantly calcium-bicarbonate, although some samples illustrating Ca-SO_4fancies, display, the gaining of carbonate aquifers from the within reach alluvial aquifers. The Mongasht Anticline springs, are placed on higher altitudes with short flow paths indicating depleted $\delta^{18}O$ and δ^2H isotopes. While the Kamarderaz, Shavish-Tanosh Anticlines and the Naal-e-Asbi samples, as a result of merely rainfall recharge, diffuse flow, longer travel path, more water-rock interaction and groundwater mixing are showing relative isotopic enrichment. The results are congruent with the topographic distribution of permeable areas and the position of the springs and karstic wells. In addition, they allow assumptions regarding the flow paths of groundwater drained by different springs and a possible hydrogeological connection of the Izeh aquifers with the adjacent permeable outcrops. The TDS vs. $\delta^{18}O$ indicates that the most depleted isotopic values and the lowest ion concentration are in the Mongasht samples as compared to the Kamarderaz, Shavish-Tanosh and Naal-e-Asbi samples, illustrating the importance of the Mongasht Anticline to recharge the lower reaches of the area. The d-excess value of the Mongasht Anticline samples is higher than the other samples, including the Kamarderaz, Shavish-Tanosh Anticline and the Naal-e-Asbi Syncline. The decreasing amount of groundwater d-excess by increasing of $\delta^{18}O$ signature shows that the groundwater is mixed with different degrees of percolated evaporated recharge water in the flow direction from the Mongasht Anticline to the lower reaches. The collected results from the major ions, trace elements, correlation coefficients, composite diagrams, $\delta^{18}O$, δ^2H and d-excess values along with a hydrogeological cross-section reveal the common origin of water, flow pattern and interconnection among the geological structures.

Comparison of hydrogeochemistry and hydrogeology of Asmari and Sarvak Formations as a reservoir of large karst springs of Zagros in the northeast of Khuzestan

Document Type: Research Paper

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Abstract

Zagros Mountain, southwest Iran, includes karst springs with high discharge; so, the large springs in Iran are discharged from the limestone (Sarvak and Asmari formations) of this mountain. The hydrochemistry and hydrogeology of eight large springs located in the northeast of Khuzestan province, with an average discharge of more than 1.5 m^3/s have been investigated from April 2018 to November 2019. Initially, the location of large karst springs in Iran has been determined based on the available data. The location of these springs in relation to the distribution of karstic formations and the digital elevation model (DEM) as well as the relationship between the average discharge, altitude and electrical conductivity have been investigated. Piper diagram has been used to determine the type of spring water. The ion ratios and saturation indices were used to identify the dissolution intensity of carbonate rocks as well as water residence time in the karst system. The results show the relationship between the spring's altitude and the electrical conductivity with the discharge is inverse. The predominant type of the spring's water is HCO_3-Ca and in some springs discharge, from Asmari limestone is Ca-SO4 and Na-Cl due to recharge via Gachsaran Formation.The lack of significant change in the Mg^{2+}/Ca^{2+} concentration in Sarvak springs indicates a long residence time in the karst system. The large springs of Sarvak and Asmari with high discharge (including Brahim Mardun, Chalshah Sarbazar, Sabzab, and Bibi Tarkhun) have a large catchment area, the base flow is more than quick flow in most of the springs. The Keynow anticline is the richest aquifer with a high dynamic reservoir in Zagros Mountain.

Keywords: Hydrochemistry, Hydrograph, Khuzestan, Large karst spring, Zagros.

Introduction

According to Ford and Williams (2007), about 20% of the planet's surface is covered by karst rocks. According to recent estimates (Chen et al. 2017) about 14% of the Earth's land surface consists of carbonate rock outcrops that form a karst. In some regions such as in the Middle East and Central Asia, karst terrains occupy about 25% of the land surface. Karst aquifers usually provide rich and abundant groundwater resources, so they are a valuable resource for drinking, industry, and agricultural uses. Several of the largest karst springs in the world are located in the eastern Mediterranean and the Middle East countries: Dumanli, Turkey (about 50 m^3/s); Khabour Ras el Aın, Syria (38.7 m^3/s); Kirkgozler, Turkey (22 m^3/s); Aın ez Zarka, Lebanon (12.9 m^3/s); El Sinn, Syria (10.5 m^3/s); and Figeh, Syria (7.5 m^3/s). Karst springs are the place of natural discharge of karst aquifers and their common character is the relationship between precipitation and the amount of discharge. The emergence elevation of karst springs indicates the base level of erosion in the karst system and their discharge and hydrogeological characteristics depend on factors such as catchment area, effective porosity, lithology, and so on. In fact, springs represent the dynamic storage capacity of karst aquifers and provide important information about hydrogeological and hydrochemical processes, especially in complex flow systems (Manga, 2001). Some of the springs located in Khuzestan province have been studied by some researchers.

Kalantari et al. (2011) have evaluated Bibi Tarkhun spring as one of the largest karst springs in Khuzestan province using hydrograph analysis. Hamidizadeh et al. (2012) have studied the Anari spring from the hydrogeological viewpoint. Mohammadi Behzad et al. (2015) have investigated the hydrogeological behavior of Sabzab Spring, one of the largest karst springs in Khuzestan province. Karimi Vardanjani et al. (2013) with hydrogeological, geological, and hydrochemical studies showed that the main discharge of Susan Spring (the largest spring in Iran) at the Keynow Anticline with an average flow of 24 m^3/s, is related to the base flow. Kalantari and Rouhi (2018) by assessing the multi-year hydrograph of Barme Jamal Spring (discharge about 1.3 m^3/s) concluded that the dominant flow in the aquifer system is the diffuse flow.

Therefore, as mentioned, point and scattered studies have been carried out on the large karst springs of the Zagros located in the northeast of Khuzestan Province, but a study for comparing the location of the all-large springs in relation to each other and other large springs of Iran has not been done. The main purpose of this paper is to present the spatial distribution of the large karst springs in Iran located in the Zagros Mountains and to investigate the hydrogeological and hydrochemical characteristics of the springs located in the northeast of Khuzestan based on physicochemical parameters measured in the 2018-2019 water year.

Materials and Methods

The study area is located in Folded Zagros zone with a northwest-southeast trend of the structures. Paleozoic, Mesozoic, and Tertiary sediments, with the same slope trend, form the eastern continental covers of the Arabian Plate, which is deformed and folded in the Pliocene. The geomorphology of the study area is mainly affected by the influence of faults action, folds, erosion, and sedimentation in the basins. The trend of folds in the study area follows the Folded Zagros (northeast-southeast). The studied karst springs are discharged from Asmari (Oligocene-Miocene) and Sarvak (Albian-Santonin) formations. Sarvak Formation consists of grey and red limestone with a thickness of about 450 - 700 meters, enclosed between the Kazhdumi Formations (bottom) and Gurpi (above). Asmari Formation consists of medium to thick cream-colored limestone with a thickness of about 300 meters between the Pabdeh Formation (below) and Gachsaran Formation (above). Gachsaran Formation (Early Miocene) had been deposited in swampy, continental, and subcontinental conditions on top of the Asmari Formation. This formation consists of anhydrite, halite, gray-marl, thin layers of limestone and shale.

The largest karst springs of Iran are located in the northeast of Khuzestan Province, among Brahim Mardun (S1) and Chalshah Sarbazar (S2) with the discharge of 5 - 22 (mean 11.7) m^3/s, 3.5 - 15 (mean 8.7) m^3/s, during April 2018 to December 2019, respectively. These springs are discharged from Sarvak Formation in the Keynow Anticline at a close distance (less than 300 meters), so they are practically called Susan Sarbazar Spring. Sabzab Spring (As1) with a flow rate of 7 - 17 (mean 11.5) m^3/s is also one of the large karst springs in Khuzestan Province. In general, the maximum and minimum discharge of the studied springs are recorded in the spring season and fall seasons, respectively. According to the location of the large karst springs in Khuzestan Province (with a flow rate above 1.5 m^3/s), the altitude of Asmari springs (370 to 570 m a.s.l) is less than Sarvak ones (620 to 950 m a.s.l). Assessment of the relationship between the mean discharge of the studied springs and their altitude as well as the mean electrical conductivity (EC) shows a reverse relation between the altitude of the springs with discharge rate and electrical conductivity. In some of Asmari springs, due to anomalies caused by recharging via Gachsaran Formation, electrical conductivity has high values. The electrical conductivity of most springs has increased in the dry season in comparison to the wet season. The EC value of Barme Jamal Spring (As4) has not shown significant change and in the Chalshah Susan Spring (S3) in the dry season less than in the wet season.

Samples of spring water were collected to analyze the major ions, and quality changes of water resources during the wet season (March 2019) and dry season (September 2019). The parameters of pH, temperature, and electrical conductivity (EC) of water samples were measured with the HACH HQ40 portable device on site. Two samples were taken from each spring during sampling in polyethylene bottles to analyze anions (without acidification) and cations (nitric acid was used to stabilize cations and $pH<2$). The saturation indices (SI) of calcite and dolomite have been calculated using the geochemical code PHREEQC (Parkhurst and Appelo, 1999). The shape of the spring hydrograph reflects the response of the aquifer to the recharge. In particular, the shape of the recession curve provides important information about the storage, structural characteristics of the system, and drainage performance of the karst system (Kersick and Bonachi, 2010). To investigate the characteristics of the groundwater flow system in the springs, the separation of base flow from the quick flow is carried out by the local minimum method using Hydro Office software. The ratio of maximum to minimum discharge and discharge coefficient have been used to evaluate the karst development in the catchment area of the springs.

Results and Discussion

The location of Iran's large springs (with mean discharge of more than 1 m^3/s) based on published articles and data of Iran Water Resources Management Company in relation to the distribution of karst formations and digital elevation model (DEM) show large springs of Iran are located in Zagros Mountain Range. Investigation of the relationship between electrical conductivity with HCO_3 and SO_4 concentration of Sarvak and Asmari springs indicates the sulfate concentration of both groups of springs except Barme Jamal Spring (As4) are less than bicarbonate concentration. Also, with increasing electrical conductivity SO_4 concentration of springs water has increased. In Barme Jamal Spring, due to recharge via Gachsaran Formation, the amount of sulfate and electrical conductivity is higher than in other springs. The mean concentration of HCO_3 in Asmari springs in wet and dry seasons is 3.41 and 3.9 meq / l, respectively, and for Sarvak springs in wet and dry seasons is 3.38 and 3.18 meq / l, respectively. The HCO3 concentration of springs decreases with increasing electrical conductivity. The mean concentration of SO4 in Asmari and Sarvak springs in wet and dry seasons are 3.35 and 4.19; 0.46 and 1.85 meq/l, respectively,

Results show the predominant type of springs' water based on the Piper diagram is HCO_3-Ca and some of the Asmari springs are SO_4 (Cl)-Na type, due to the recharge of the Gachsaran Formation. The water samples of Sarvak springs with high discharge (Chalshah Sarbazar and Brahim Mardun) have high chemical components, especially Ca^{2+} and HCO^-_3 ions, indicating high residence time, large catchment area or deep flow, and water-carbonate rocks interaction. Increasing of sulfate concentration in Brahim Mardun and Chalshah Sarbazar springs in the dry season is due to the effect of the Pabdeh-Gurpi Formation- and the movement of sulfate-rich waters through fractures and faults. The increase of sulfate concentration of Arpanah Spring in the dry season is due to the influence of the Kazhdumi Formation (shale and marls) and the movement of water through Sorkhbud Thrust. The ratio of Mg/Ca in Sarvak springs is less than in Asmari ones. The minimum value of this ratio is observed in Chalshah Sarbazar and Brahim Mardun springs while the maximum value is observed in Bibi Tarkhun and Sabzab springs. In all of Sarvak and Asmari springs, except Barme Jamal, the ratio of HCO_3/SO_4 is more than one, so the dominant process is carbonate dissolution. In Sarvak springs, except Chalshah Susan, the ratio of Mg/Ca has increased in the dry season, so that indicates increasing in residence time in the karst system.

In all Sarvak and Asmari springs, except Arpanah Spring (As4), the percentage of base flow is more than quick flow. Also, the percentage of discharge changes and the ratio of maximum to minimum discharge in this spring is more than in other springs indicating the conduit flow is dominant in its catchment area. The lowest percentage of discharge changes and the lowest value of maximum to minimum flow is observed in the Bibi Tarkhun (As2) and Sabzab (As1) springs. In the other words, discharge changes of these springs are less than others. The base flow of the Chalshah Sarbazar spring (S2) is more than other springs, as regards its proximity to Brahim Mardun spring (S1), they have a common reservoir and a large catchment area. Due to the extent of their catchment area and the elongation of the Keynow Anticline as the main reservoir of these two springs, the quick flow does not show its effect, then the diffuse flow is dominant. The hydrograph shape of Chalshah Sarbazar spring at the end of summer (dry season) as well as the decrease of the recession curve slope of Brahim Mardun Spring show the recharge via snowmelt in their catchment area. The response of Chalshah Susan Spring (S3) to the precipitation is slow and stepped, so that has increased with a delay of about one month after the precipitation event. Also, its high base flow indicates that the flow is diffuse-conduit in the S3 spring. In Arpanah Spring (S4), the base flow is less than the quick flow.

Conclusions

Springs with high discharge in Zagros Mountain indicate the karst development in this mountain range. Considering the average discharge of Brahim Mardun, Chalshah Sarbazar, Sabzab, and Bibi Tarkhun springs in the northeast of Khuzestan (April 2018 - November 2019) it can be concluded these springs are the largest karst springs in Iran, so their mean annual discharge equal 11.7, 8.6, 11.5, and 6 m^3/s, respectively. The ratio of maximum to minimum discharge and the percentage coefficient change in Asmari springs is less than in Sarvak ones. On the other hand, hydrochemical studies such as Mg^{2+}/Ca^{2+} ratio in the wet and the dry seasons show fewer changes in Sarvak springs than in Asmari ones due to more purity of the Sarvak Formation. Also, the change of Mg^{2+}/Ca^{2+} ratio in the dry season similar to the wet season in Sarvak springs indicates a long residence time in the karst system and flow stability. According to the inverse relationship between the discharge with the emergence altitude of springs and their electrical conductivity value, similar to other large springs in the Zagros, the results of this article can be applied to other springs in the Zagros region.

Comparison of the performance of algebraic methods and statistical context in determining spatial changes in groundwater quality in Tabriz plain

Document Type: Research Paper

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Abstract

Groundwater quality is an important subject in hydrologic studies and the study of its qualitative parameter variations is very crucial for determining its suitability for drinking, agricultural or industrial consumption. Information on spatial variations of groundwater quality is a way for tracing the effect of forcing elements alike contaminants. In the present study, geo-statistics methods were applied for studying groundwater qualitative parameters (e.g. Chlorine, Sulfate, Total Hardness, Total Dissolved solid, Electric conductivity, Sodium Adsorption Ratio, Magnesium, Sodium, Calcium, pH) in Tabriz plain during a 15-years period. The employed techniques included Inverse Distance Weighing, Radial Basis Functions and Kriging. The obtained results showed that the concentration of these parameters has increased in the Northwestern, west and southwestern parts of the plain, revealing the degradation of water quality in those regions. Also, the accuracy of the two methods of Radial Basis Functions and kriging, depending on the type of parameter studied, was found to be suitable for modeling. In general, comparing the maps prepared for the parameters, it is observed that the zones specified for these parameters follow almost a specific pattern and the minimum and maximum of all parameters are located in common areas of the plain.

Keywords: Algebraic methods, Geo-statistical methods, Groundwater quality, Interpolation, Variogram, Wilcox

Introduction

Groundwater is one of the main sources of water supply in arid and semi-arid regions. The uncontrolled increase in population and, as a result, the over-exploitation of aquifers, has exposed groundwater resources to a sharp decline and a decline in water quality. Many factors such as: precipitation, soil characteristics, the topography of the area, geological structure of the basin, groundwater recharge and human activities on land affect the quality of groundwater. Proper management of groundwater resources is crucial to meet the growing demand for water. In addition, understanding the spatial distribution of groundwater quality helps officials develop strategies for the optimal management of groundwater resources to ensure the sustainable development of society. Numerous studies have been conducted to assess groundwater quality using geostatistical techniques worldwide.

Haidarzadeh and Moezzi (2019) analyzed the groundwater quality of the Amol-Babol plain using GIS. They concluded that the pollution situation is more critical due to land use around industrial areas and densely populated cities. Also, by examining the discharge status and distinguishing between wet and dry periods and normal years, the relationship between the pollution increase with drought duration was analyzed. Pirzadeh and Asvar (2021) used geostatistical methods (simple kriging, ordinary kriging and IDW) and GIS to analyze the spatial and temporal changes in groundwater quality parameters in Sirjan plain. Among the interpolation methods, the simple kriging method showed the best results for most of the samples. The present study aimed at assessing the groundwater quality parameters of Tabriz plain using geostatistics and algebraic methods.

Materials and Methods

Study area

Tabriz plain with an area of 3,000 hectares is located in northwestern Iran in East Azarbaijan province. The western boundary of Tabriz plain is limited to salt marshes along Lake Urmia. The highest percentage of the Tabriz plain area is Tabriz, Ahar, Bostanabad, Harris, Marand and a small part of it is Shabestar, respectively. In this plain, two types of normal and pressurized aquifers can be identified. The normal aquifer which is located throughout the plain and in the gaining areas of the plain, has better water quality along the Ajichai river and at the end of the plain the water is completely saline. The main river of the plain is Ajichai which flows towards Lake Urmia.

The data used in this study were received from the East Azerbaijan Regional Water Organization. These data are related to 67 wells and aqueducts in the basin from 2001-2015. 10 qualitative parameters including sulfate, chlorine, pH, total soluble solids, total hardness, sodium adsorption ratio, electrical conductivity, sodium, magnesium and calcium were used to determine the spatial distribution of groundwater quality parameters in the study area. In estimating spatial distribution with a geostatistical approach, interpolation methods are used in two ways: deterministic and geostatistic. In the definitive method, only mathematical functions are used (IDW and RBF methods), while the statistical method (kriging) is based on the regional variables theory and depends on mathematical functions.

IDW method

One of the most important interpolation methods is the inverse distance weighting method (IDW). In this method, the weight of the sample points on the unknown point is calculated based on the distance between the known and the unknown points. These weights are controlled by the weighting power, so that the larger powers reduce the effect of points farther from the estimated point, and the smaller powers distribute the weights to a more uniform length between neighboring points.

RBF method

Radial basis function networks are the leading type of networks with an intermediate layer that was first introduced by Brommahd and Love (1988). In this method, the transfer function in the middle layer is the Gaussian function, while it is linear in the output. RBF network training is generally divided by two parts. The first part is mainly unsupervised learning, which uses clustering methods to determine the parameters of the basic functions using input information. In the second part, which is supervised learning, the weights between the middle and output layers are determined using the Slope reduction method. The RBF method is one of the interpolation methods in which the estimated level exceeds the observed values. This method is a mode of artificial neural networks.

Kriging method

The kriging interpolation method is a method for optimal linear interpolation with a minimum mean internal error. Kriging is known as an accurate estimator. When the data is normally distributed, only the neighborhoods of the estimated data are sufficient to estimate the structure of the region variables. The spatial variability of a regional variable and estimation of unmeasured locations is described by a semi-variogram.

In order to evaluate and validate the predicted data and select the best interpolation method, two criteria, namely, root mean square error (RMSE) and mean error (ME) were used.

Results and Discussion

Tabriz plain is of great importance due to its high population density. In addition to surface water, groundwater resources are used to supply drinking water and agricultural uses for this population. The reduction of groundwater volume has been caused by uncontrolled abstraction as well as the human activities and drying conditions of Lake Urmia, which causes saline water leakage in the aquifer. A quantitative and qualitative study of groundwater is required for drinking and irrigation purposes. According to the mentioned cases, the purpose of the present study is to evaluate the ability of geostatistical methods in zoning the quality parameters and investigating the change of groundwater quality in Tabriz plain from 2002 to 2016. For this purpose, in addition to conventional statistical methods (kriging and IDW), the RBF method was used and groundwater quality was compared in two years with respect to the past 15 years. According to the maps prepared for zoning the hydrochemical parameters of groundwater in Tabriz plain, the status of various parameters, including sulfate, chlorine, pH, total soluble solids, total hardness, adsorption ratio of sodium, electrical conductivity, sodium, and surface were determined.

According to different interpolation methods, the IDW method does not work well in any of the cases, and the kriging and RBf presented almost similar results. It is definitely not possible to suggest a method for all qualitative parameters, even over time the appropriate method for a parameter has changed. In general, because the results of the Kriging and RBF methods are slightly different, each of these methods can be substituted for the other. In the RBF method, in most cases, the Spline with voltage model is selected as the optimal model. In the Kriging method, the Exponential model has provided the best results in most parameters. The results of the groundwater quality of the plain and the drawing of zoning maps of the parameters show that the concentration of ions in the southern part of the plain is almost constant during the study period. The study of studies also showed that interpolation methods, depending on the type of variable and characteristics of the region, the density of measuring points and their arrangement provide different accuracy and the results of one region cannot be easily generalized to other regions. Given what has been said, statistical methods are suitable for analyzing the results of groundwater samples analysis and can be used as an auxiliary tool in the spatial variation of water quality variables in decision-making.

The Wilcox diagram is generally used to classify groundwater for irrigation. In this diagram, water quality for agriculture is determined based on two factors: sodium absorption ratio (SAR) and electrical conductivity (EC). Figure 1 shows the classification map of groundwater quality for agricultural purposes in Tabriz plain.

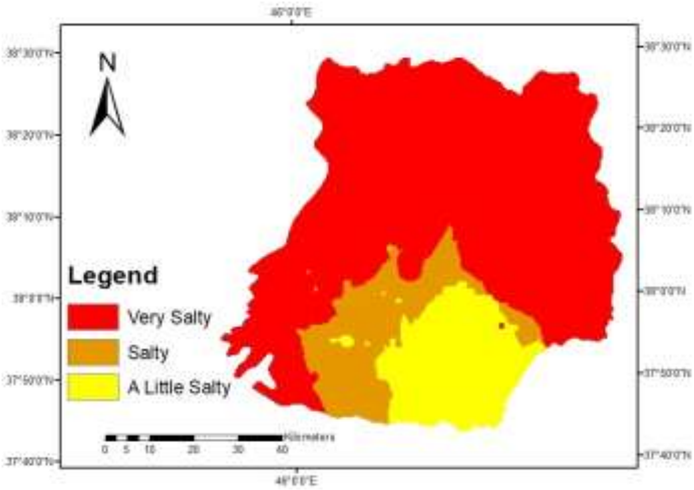

Figure 1- Groundwater quality classification map for agricultural uses.

Conclusions

The results showed that the concentration and density of parameters in the northwest, west and southwest of the plain have increased in the study period, which indicates a decrease in water quality in this area compared to other areas of Tabriz plain. Also, the accuracy of two methods of radius basis and kriging functions, depending on the type of parameter studied, was found to be suitable for modeling. In general, comparing the maps prepared for the parameters, it is observed that the zones specified for these parameters almost follow a specific pattern and the minimum and maximum of all parameters are located in common areas of the plain.

Underground dam construction site selection using Boolean logic and analytical hierarchy process methods using GIS (Case study: Hassanabad watershed in Kermanshah province)

Document Type: Research Paper

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Abstract

One of the main challenges facing water resources management is groundwater conservation and its sustainable use. Building an underground dam can be one way to solve this problem if it is possible to do. Hassanabad watershed lies between the Shiyan and Mahidasht plains in Kermanshah province. However, despite the same rainfall in the region, this basin has more unfavourable conditions in terms of water resources, vegetation and type of agriculture than the two adjacent plains. The purpose of this study is to identify suitable areas for the construction of an underground dam in the Hassanabad basin. To achieve this goal, after preparing different layers of information in Arc GIS, areas with potential were investigated using the Boolean method based on slope, material and land structure criteria, hydrological conditions and land use. Consequently, 7 axes were selected as potentially suitable locations for underground dam construction on the southern margin of the Hassanabad Plain. In the next step, these axes were prioritized by the analytical hierarchy process method based on general socio-economic criteria, dam reservoir, dam location and water characteristics, and axes 6, 7 and 1 took the first to third orders, respectively. According to aerial photography maps, field visits, structural geology analysis, and groundwater flow direction, axis 6 is identified as the most optimal axis for the construction of the dam.

Keywords: Analytical hierarchy process, Boolean logic, Hassanabad watershed, Underground dam.

Introduction

Iran is a dry country with low rainfall (Dorfeshan et al., 2013) so the rainfall in Iran is less than one-third of the average rainfall and the annual evaporation is three times the world average (Alizadeh, 2014; Gharezi et al., 2015). The construction of underground dams is one of the effective ways to deal with water shortage and sustainable management of water resources (Kurdi et al., 2015). An underground dam is a hydraulic structure that stores and controls groundwater (Onder and Yilmaz, 2005). Underground dams have various advantages, including high stability and safety, preventing the evaporation of stored water, long useful life, storing water with good quality and without occupying land with surface water, cost-effectiveness and easiness of construction, proper use of renewable sources and proximity to the place of consumption. Since creating this type of structure it is not possible everywhere, many researchers research site selection possibilities. In this study, the Hassanabad watershed has been studied which is located in Kermanshah province. It lies between the Shiyan and Mahidasht plains, but despite the same rainfall in the region, this basin has more unfavourable conditions in terms of water resources, vegetation and type of agriculture than the two adjacent plains. Due to this difference in water resources for a relatively small area, it seems that groundwater flow to neighbouring plains reduces the water amount in the plain, which has many consequences. Due to the special location of the study area in terms of population, access to the main road, and location between two very fertile plains, the study of the feasibility of constructing an underground dam to control and sustain the use of groundwater seems necessary in this basin.

Materials and Methods

The Hassanabad watershed lies between 34° 05′ and 34° 13′ north altitude and between 46° 36′ and 46° 49′ east longitude. In terms of structure and geological situation, this region is located in the Zagros mountain belt and the folded Zagros belt. Geological formations in this area are affected by folding and the general shape of the region is formed by successive anticlines and down dips. Figure 1 shows the location of the study area.

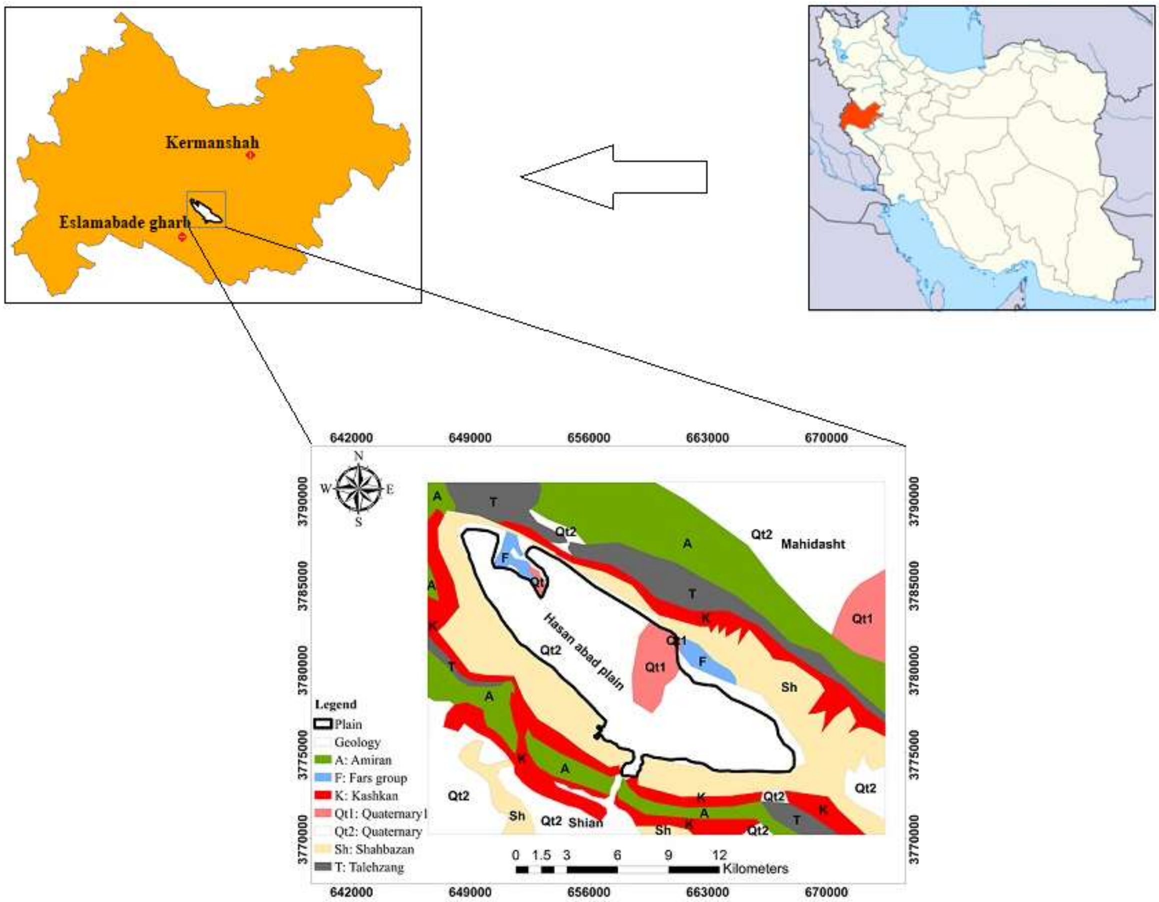

Fig. 1- The study area

This research consisted of two main stages. In the first stage, after preparing the initial data, the required information layers were prepared in a suitable format in Arc GIS and then, unsuitable areas for constructing an underground dam were removed based on the elimination criteria using the Boolean logic method. These criteria and their appropriate ranges were selected based on the available information and conditions of the region and previous research, which include slope, land type, fault structure, category of waterways, underground water and land use. In the second stage, after selecting suitable axes, based on different criteria, these axes were compared and prioritized. Based on the hierarchical analysis method, the options are located at the end of the decision tree and include access to the village, access to the road, agricultural water and drinking water, reservoir permeability, reservoir volume, rock slope of the reservoir bottom, soil material of the dam axis, length The focus of the dam is the quantity and quality of water, the secondary criteria include the access and use of water, and the main criteria include the socio-economic situation, the dam reservoir, the dam construction site and water, and the purpose is to prioritize the suitable construction sites. It is an underground dam. Assuming the same importance of the main criteria, prioritization was done. Based on the determined values and by pairwise or binary comparison, the normalized weight of each criterion was calculated and the compatibility rate of the comparisons was checked by ExperChoicece software. Finally, the final favourable axis was selected using aerial images and field geology considering the characteristics of lithology, land use, and hydrology and investigating some control points.

Results and Discussion

The results of these studies showed that Hassanabad plain is a double plunge syncline like a bowl, that collects the water of the basin and directs it to Shiyan plain. The isopieze map confirms the outflow of groundwater to the adjacent plain.

Axis 6 has a special position compared to other locations. There is a gorge in this area that transfers groundwater downstream to the Shiyan plain. The presence of a green zone around this site (Figure 2) and the outflow of a spring at the gorge, are evidence of the claim. The construction of an underground dam in the Hassanabad watershed is more justifiable than the existence of a surface dam in the Shiyan plain. The reason for this can be attributed to the risk of destruction of the surface dam and flooding downstream villages that are very close to the dam, unsuitable bedrock of the surface dam (Marli formation), the drying of the Shian River, the high cost of construction and maintenance of the surface dam and active tectonics in the area. The construction of a dam on Axis 6 can be done with the least cost and the highest speed due to the narrow width of the valley and the uplift of bedrock. Besides that in terms of evaporation, security against pollution and the issue of passive defence can be a better option for water storage.

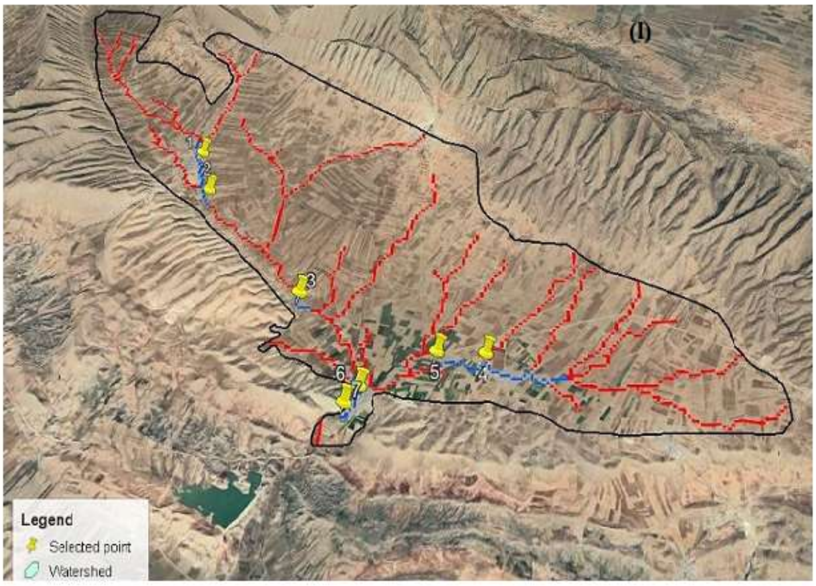

Fig. 2- The watershed and drainage system

Conclusions

The present research was carried out to verify the feasibility of constructing an underground dam in the Hassan Abad basin using Boolean logic and hierarchical analysis. Results indicate that underground water flow is flowing towards the Shian plain. Due to the discharge of underground water, this plain has less water storage than the Shian plain and the neighbouring plains. The issue has made the construction of an underground dam more interesting. Based on the results of the Boolean logic method, 7 suitable locations were identified which are located on the southern margin of the Hassanabad plain. All these locations are in complete compliance with the hydrogeological conditions of the region. Storage of groundwater in these areas has caused water to leak during geological time. The construction characteristics of the dam in different areas were determined based on the results of the analytical hierarchy process method. Axes 7 and 1 were ranked first and third, respectively. As a result of the field visit, structural geology study, and groundwater flow direction, axis 6 is identified as the most suitable axis for dam construction.