Forecasting the flooding in the site of the Zabol gas transmission line, in the Hamoun Wetland, using climate change and hydrological models

Document Type: Research Paper

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Abstract

Hamoun wetland includes Hamoun Pozak, Saberi and Helmand as the largest freshwater lake in Iran and one of the most important wetlands of international importance. This wetland is located in the southeast of Iran in Sistan and Baluchestan provinces. Due to the increase in rainfall in Afghanistan and eastern Iran in 2018-2020, there is a possibility of flooding of the gas transmission pipeline from Dashtak Launcher Station to Zabol city in a part of Helmand wetland. Based on the Projection of the General Circulation models (GCMs), in the future, there is a possibility of increasing temperature and decreasing rainfall in Sistan area. Therefore, based on 5 models and two scenarios, RCP4.5 and RCP8.5, first the precipitation and temperature values in the period (2020-2040) were calculated and then the hydrological variables were predicted. In order to simulate water level changes in Hamoun Wetland, various scenario of the floods with different return periods in unstable flow mode was performed using HEC-RAS software and flood zoning was calculated as the maximum water depth at any point in Hamoun Wetland. Examination of rainfall and water discharge of Sistan and Helmand rivers showed that most river floods and flooding of wetlands occur annually in the period from February to May. The actual monthly hydrograph flood of the Helmand River (October 2002 to October 2012) showed that the peak of this flood has a return period of about 130 years. The simulation showed that the flooding of the gas pipeline will occur in places located at 20, 30, 68, 80 and 104 km of Dashtak crossroads and especially in the location of Shila waterway and the water depth varies between 1.5 to 5 meters. Therefore, in the above-mentioned places, the necessary measures should be taken to prevent the gas pipe from floating.

Keywords: Floods, HEC-RAS Model, Hydrograph, Simulation.

Introduction

Hamoun wetland, including Hamoun Pozak, Saberi and Helmand, is the largest freshwater lake in Iran and one of the most important wetlands of international importance. This wetland is located in the southeast of Iran in the Sistan and Baluchestan province, near Zabol city. Owing to high variations in its meteorological and consequently hydrological parameters, the recent decades' droughts have caused the drying of either large parts or sometimes the entire wetland. On contrary, due to the significant increase in rainfall across western Afghanistan and eastern Iran in 2018-2020, there is a possibility of a broken gas pipeline in a part of Helmand wetland.

Materials and Methods

Based on the Projection of the General Circulation models (GCMs), in the future, there is a possibility of increasing temperature and decreasing rainfall in the Sistan area (Fig 1). Therefore, based on 5 models and two scenarios of RCP4.5 and RCP8.5, first, the precipitation and temperature values in the period (2020-2040) were calculated and then the hydrological variables were forecasted. In order to simulate water level changes in the Hamoun Wetland, various scenarios of flooding with different return periods under the unstable flow mode were conducted using HEC-RAS software and the corresponding zoning maps of flooding were prepared, overlaying the maximum water depth at any point in the Hamoun Wetland.

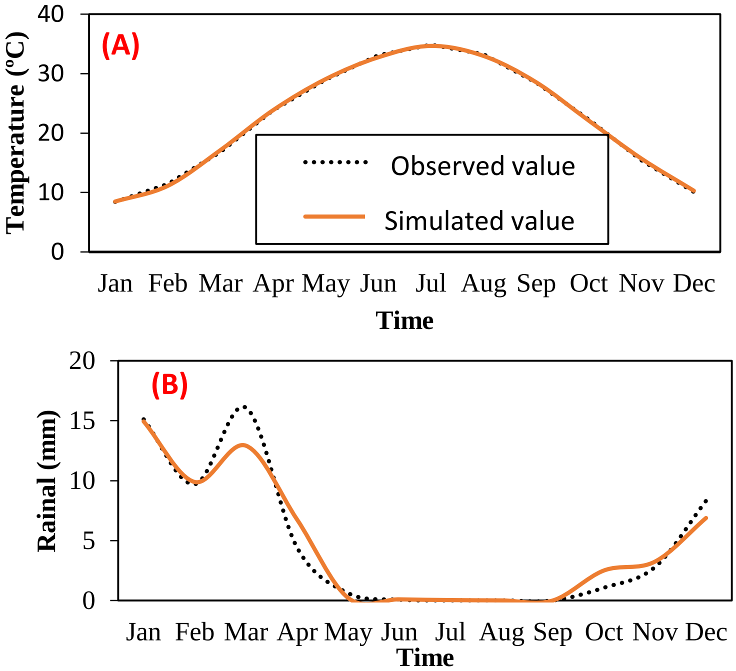

Fig. 1. (A) Observed and simulated temperature (B) Observed and simulated rainfall in the Zabol station

Results and Discussion

Given the forecasting of the climate change model for the Sistan region, there is a possibility of increasing temperature and decreasing rainfall in the near future. Examination of rainfall and water discharge of Sistan and Helmand rivers showed that most river floods and flooding of wetlands occur annually in the period from February to May. The actual monthly hydrograph flood of the Helmand River (October 2002 to October 2012) showed that the peak of this flood has a return period of about 130 years. In order to simulate water level changes in the Hamoun Wetland, various scenarios of flooding with different return periods under the unstable flow mode were performed using HEC-RAS software and flood zoning was calculated as the maximum water depth at any point in Hamoun Wetland (Fig 2). The simulation showed that in 20 km of Dashtak crossroads in the place of Shileh waterway (channel) due to a real flood, the water depth reached approximately 1.5 m. Also, at a distance of 68 to 80 km from the gas pipeline route from Dashtak crossroads along with the pipeline, the water depth reached 2.5 m. At a distance of 104 m, there was a place with the potential to float the pipeline. For floods with a return period of 260 years (similar to real floods), at a distance of 20 km and 68 to 80 km, exist areas prone to the broken gas pipeline. Moreover, a simulation of the maximum water depth of the wetland according to the flood with a period of 30 and 65 years showed that along the gas pipeline route, at a distance of 68 to 80 km from the Dashtak place, there are some areas where are prone to the possible flotation. Water depth in these areas will vary between 4 to 5 m. Finally, the flood with a return period of 650 years also indicated that in addition to the previous distances, in 30 km of the gas pipeline, there is a possibility of flooding the transmission line. Therefore, in the above-mentioned places, the necessary measures should be taken to prevent the gas pipe from floating.

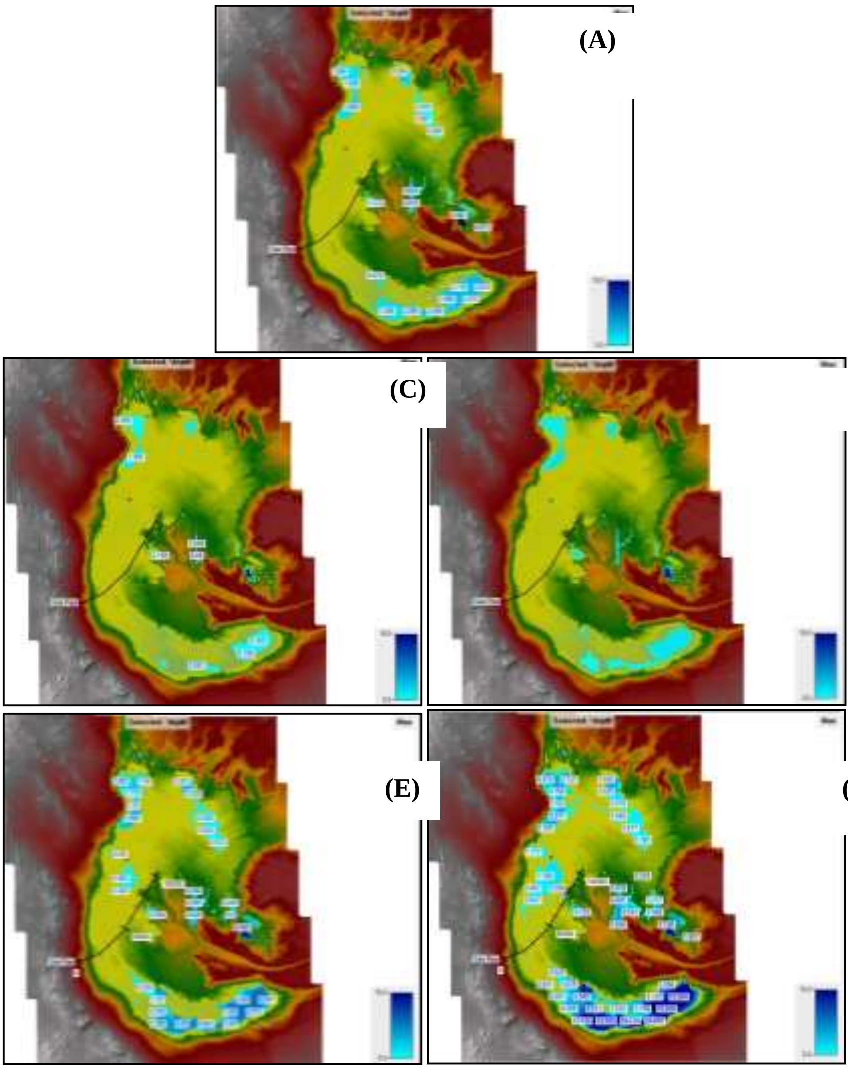

Fig. 2. Simulation of maximum water surface depth in the Hamoun wetland according to (A) actual rainfall (B) rainfall with a return period of 30 years, (C) rainfall with a return period of 65 years, (D) rainfall with a return period of 260 years and (E) rainfall with return period 650 years.

Conclusions

Examination of rainfall, water discharge of Sistan and Helmand rivers and simulation of water level changes in Hamoun wetland for the coming 20 years show that river flowrate and the wetland water level will be at their highest level during a period from February to May of the water year. Therefore, in order to facilitate access to the pipeline and service by operating and repair agents on the line, attention should be paid to the month of the year and it should not coincide with the above-mentioned time period as much as possible. It is noteworthy that the simulation of climate change in this study based on rainfall and temperature data of the Sistan region showed that in this region the probability of occurrence of floods over a long period is low. Furthermore, due to the lack of knowledge of rainfall and temperature data at the source of the Helmand River in Afghanistan, as well as the decision of Afghans to open or close the Kajaki Dam gates, sudden floods from Afghanistan to Hamoun Wetland cannot be reasonably predictable. Therefore, the possibility of flooding with a long return period should be considered. Simulation of real floods and artificial floods with different return periods show in the locations located at 20, 30, 68, 80 and 104 km of Dashtak crossroads and especially in the location of Sheila waterway (channel the necessary measures are needed to prevent the gas pipe from floating). The results from the simulation show that the water depth will vary between 1.5 and 5 meters, and this time the hydraulic load will be able to damage the gas transmission pipe. Therefore, the above-mentioned neighborhoods need the necessary engineering measures to prevent gas pipe flotation and corrosion.

Predicting the effects of overuse on Zarandieh plain aquifer (Markazi province, Iran) using GMS software

Document Type: Research Paper

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Abstract

The studied aquifer is located in the Zarandieh Plain of Markazi Province with an area of about 1200 square kilometres. Therefore, in order to identify and protect the optimal use of groundwater resources, a mathematical model of the aquifer was constructed using the MODFLOW code under the 7.1 GMS interface. For this purpose, first, a conceptual model is prepared and then a numerical model based on it, based on water level changes using water table statistics of 14 piezometric wells in the region, in a time step of one month for steady state (October 2010) and a period of 12 months (November 2010 Until October 2011) for the unstable state, was calibrated manually and automatically. During this stage, the initial values of hydraulic conductivity (K) were optimized. At the end of calibration, in the steady state, the RMS amount reached 1.265 meters and in the unstable state, the RMS amount reached 2.145 meters, which is less than the allowable error value of ± 2.5 meters and is acceptable. Also, the validity of the model was performed in another period of 12 months (November 2011 to the end of October 2012) and at the end of validation, the RMS value was calculated to be 2.46 m. Due to the appropriateness of the RMS values of the simulated model, it has the ability to predict the future status of the aquifer. Then, after confirming the accuracy of the model in the validation phase, the future conditions of the aquifer were predicted and the results showed that in the next 3 years, with the continuation of the current trend of harvesting from exploitation wells, in some parts of the aquifer will decline.

Keywords: Calibration, Groundwater modeling, Management and planning, Sensitivity analysis.

Introduction

The mathematical model involves a set of differential equations that govern the flow. The certainty of predictions based on groundwater models is related to the extent to which the model can estimate the actual conditions. In constructing a model, it is necessary to use simplifying hypotheses, because natural conditions are so complex that it is not possible to accurately simulate them with the model. Mathematical models have been used for simulation in various aquifers in Iran and other parts of the world. Among peasant studies (2002), Shafiee Motlagh (2005), Naseri (2006), Mir Abbasi et al. (2007), Alim Mohammadi and Hosseinzadeh (2009), Jumonia (2009), Azari Bakhshi (2010), Mahdavi (2011), Mehdi Rost et al. (2015), Aghajani et al. (2016), Ariaei Mehr et al. (2017), Karimi et al. (2015), and Jafari et al. (1397) at home and Feng Yang et al. (2009), It can be mentioned. Therefore, due to the lack of comprehensive information about the cultivation of plants in the region, to estimate the demand, they used the land use combination and the FAO-56 crop coefficient method with the remote sensing method (Madis images). Finally, by obtaining the results of land use and evapotranspiration from the groundwater flow model (MODFLOW) and transferring their results to VIP, they created a decision support system. The simulations showed that 83 months out of 84 months have an average budget deficit of 15 and the last month has a budget deficit of 39 million cubic meters. The results also showed that this operational decision support system is able to examine alternative planning and facilitate its communication with water users. They used monthly statistical data of piezometer levels for 5 wet years (2009-2010 to 2013-1014) related to the water table of 8 piezometers of the Lor-Andimeshk plain aquifer. Using Modflow groundwater conceptual model and gene expression simulation Meta model, the aquifer reagent hydrograph was modeled and the results were compared. The results showed that the Modflow conceptual model with an explanation coefficient of 0.7366 in the test stage has a better performance than the meta-model of the gene expression simulator with an explanatory coefficient of 0.739 with a very small difference.

Research goal

In the study area of Zarandieh plain, so far no research has been done on the prediction and management of the aquifer using a mathematical model. Therefore, in this study, the GMS mathematical model is used to predict the effects of overuse on the aquifer of Zarandieh plain of Markazi province and also to provide management solutions. Has been paid. In the process of validating the model by adapting the mathematical model to the natural conditions of the aquifer, the question of whether the mathematical model in this aquifer can be used to help manage the aquifer or not.

Materials and methods

Zarandieh plain is located in the north of Markazi province. The cities of Mamuniyeh, Zavieh, Khoshkroud and Parandak are the population and industrial centers of the Zarand study area. It covers a square kilometre of a plain and 1702/985 square kilometres of a mountain and leads from the north and east to the catchment area of the Shoor River and from the west and south to the catchment area of the Qarachai River. The GMS provides the appropriate tools for each stage of groundwater simulation, including a description of the study area, conceptual modeling, networking, geostatistics, calibration, visualization, sensitivity analysis, and graphical representation. At this stage, topographic map, floor rock level, and meteorological information such as; Rainfall and evaporation in order to calculate the aquifer feeding rate and statistics and information about exploitation wells including location, type of consumption, and annual discharge to drain the aquifer and from observation wells to draw a groundwater level map and determine water inlet and outlet areas. Underground and for processing it from software such as; GIS and Excel and GMS software was used to build the concept model.

Predict the future state of the aquifer

The results of the sensitivity analysis of the model show that the zero point of the changes for the mentioned parameters is the best mode of model execution because in this case the amount of computational RMS error has the lowest value. The calibrated model shows the lowest amount of RMS error and in a way, it can be said that its accuracy can be verified (Figure 1).

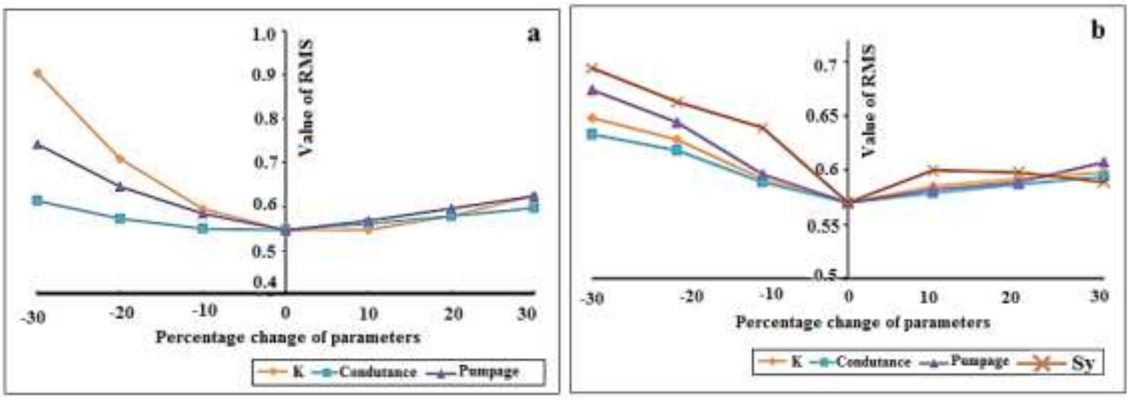

Figure1 Results of steady-state analysis (a) and unstable (b)

One of the important goals of this study is to predict the condition of the aquifer against hydraulic stresses. For this purpose, after the verification stage and gaining relative confidence in the correctness of the model made; the future conditions of the aquifer were predicted for 3 years, from October 2017 to October 1401. With a view to not knowing the possible future stresses of the study aquifer, and in order to obtain the possible precipitation in each month of the year in the forecast period, a 15-year average of precipitation has been used. Parameters such as hydraulic conductivity, storage coefficient, and boundary conditions were fixed and entered into the model as in the validation step. It should be noted that due to the ban on harvesting in this plain; Overdraft in wells is not considered, and assuming the continuation of the current trend, the pre-harvest phase is considered constant. After entering the effective parameters in the forecasting process, the model is implemented and then the results are presented as groundwater potential curves. Figures 2 and 3 show the groundwater potential lines at the beginning and end of the forecast period. The results show that with the continuation of the current trend of groundwater abstraction in the study area, from the beginning of the period to the end of the forecast period, we will see a further decline in groundwater levels; This increase in decline is more and more evident in the central areas and near the west of the aquifer (which is the area with a high concentration of exploitation wells) and especially the geographical area west and northwest of Hosseinabad village.

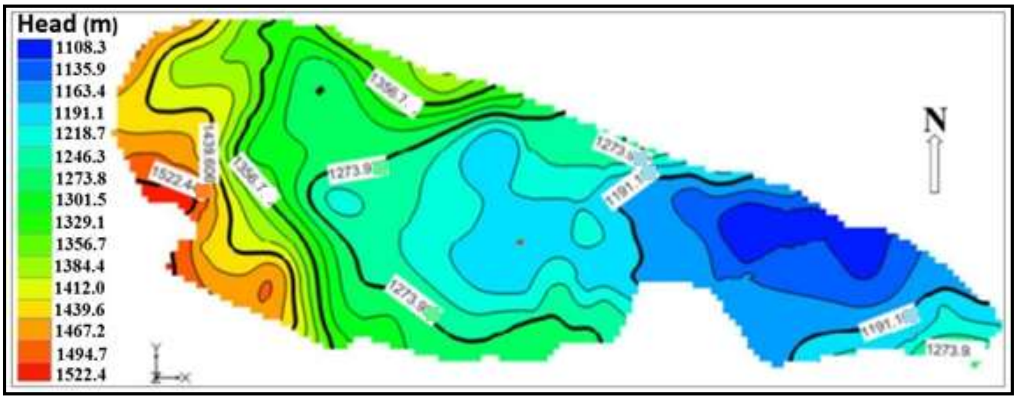

Figure2 Groundwater level map of the studied aquifer at the beginning of the forecast period (October 2017)

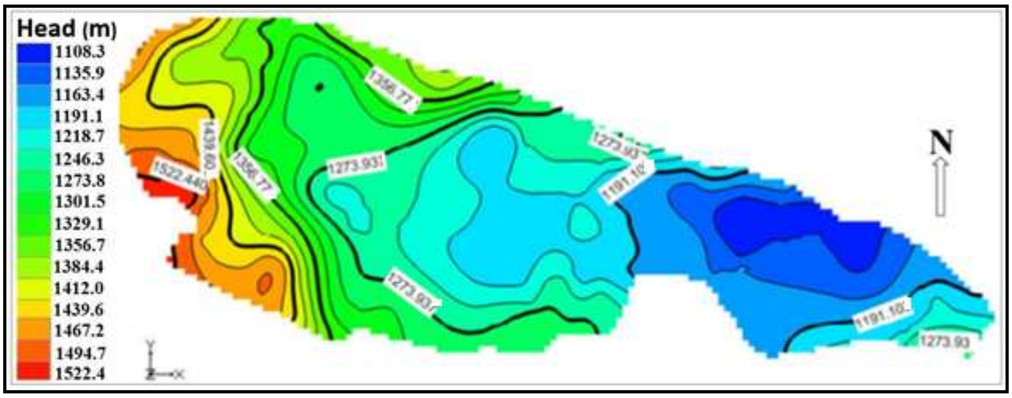

Figure3 Groundwater level map of the studied aquifer at the beginning of the forecast period (October 2022)

Results and discussion

The specific discharge values were optimized at the end of the model calibration (unstable state) and compared by statistical calculation method (using RMS criterion). Due to the amount of RMS error at the end of calibration, it has reached 2.145 meters and decreased. In this research, the sensitivity analysis of the model in both stable and unstable modes, towards parameters that have less certainty; was performed. At steady state, the parameters of hydraulic conductivity (K), boundary permeability coefficient (C) and pumping rate from exploitation wells (Q) were changed by 20, 10 and 30% in both decreasing and increasing modes; in the unstable state, in addition to the steady state parameters, the specific discharge parameter (Sy) was also changed to the similar steady state; And for all these cases, the model was implemented. In the steady state, the model is most sensitive to changes in hydraulic conductivity, and then to changes in the pumping rate of wells, the permeability coefficient of the boundaries, respectively, are in the next stages of sensitivity. The highest amount of RMS error recorded at this stage is related to the increase in hydraulic conductance values. Also, in the unstable state, the highest sensitivity of the model is to the specific discharge parameter, and the pumping rate from the exploitation wells, the hydraulic conductivity and the permeability of the boundaries are in the next stages of sensitivity, respectively. The results show that with the continuation of the current trend of groundwater abstraction in the study area from the beginning of the forecast period to the end of the forecast period, we will see a further decline in groundwater levels; This increase in decline is more and more evident in the central areas and near the west of the aquifer (which is an area with a high concentration of exploitation wells) and especially in the western and northwestern geographical area of Hosseinabad village.

Monitoring the Changes of Zaribar Lake in Kurdistan Using Spectral Indicators and Landsat Images in Google Earth Engine System

Document Type: Research Paper

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Abstract

Lakes are considered valuable national resources of any country and the study of changes in the level and volume of water of lakes in order to protect them and also for better decision-making and management of water resources is always of particular importance. The study of changes in recent years has found a special place among countries. In this study, the changes in the area of Zaribar Lake located in Kurdistan province in the long-term period of 36 years, from 1984-2020, have been monitored. It is noteworthy that in this study, the Google Earth Engine system, or GEE for short, was used, which is a new and very useful system in recent years. This system makes a large amount of information available with coding in the shortest time. In the present study, using Landsat 5 and 8 satellite images and GEE system and NDWI and MNDWI spectral algorithms in the shortest time and cost, water zone separation from other phenomena was done using thresholding and long-term changes in its area. Checked out. The mentioned changes are important for water resources management as well as crisis management in the region due to the importance of Zaribar Lake. Validation of the results and comparison between the indicators for Zaribar Lake showed that the MNDWI index with a kappa coefficient of 0.94 and an overall accuracy of 97% for the recent period is a very suitable index for this region and its results are much better than the NDWI index and The result is more efficient. Fluctuations in the surface of Lake Zaribar have been high over a long period of 36 years. For example, the average level of the lake in the period 1984-1995 with the index MNDWI of 852.960 hectares and in the period 2020-2015 with the same index, is 989.371 hectares. It is recommended that researchers, planners and executive users use the spectral indicators and the GEE system due to their high capabilities to identify the trend of changes in water areas in water resources management.

Keywords: Google Earth Engine, MNDWI, NDWI, Water Zone, Zaribar.

Introduction

Lakes are one of the most valuable national resources of any country and it is important to study the changes of water areas to improve decision-making and better management of water resources. The study of changes in water areas is very important due to the impact of these changes on the environment and due to the high threshold of environmental sensitivity of this phenomenon. Most water belts are created naturally, but some are man-made.

A water area is usually referred to as the accumulation of large volumes of water such as oceans, seas, and lakes, but can also be small accumulations of water such as reservoirs and lagoons, and so on. The water zone does not only include stagnant or enclosed water, but also rivers, streams, canals, and other areas where water flows from one place to another. Examining the trend of changes in the area of water areas is one of the important tools in planning and development. In recent decades, monitoring the changes in water areas at different time intervals has been considered as underlying research, because the area of water areas is dynamic in nature and the management of such ecological units is sensitive to obtaining accurate information at intervals. It needs a different time. Ecologically, water areas are of great importance and value due to their sensitive ecosystems, so there is a fundamental need to evaluate and monitor these areas.

Using the existing algorithms in remote sensing, a big step can be taken in water resources management. Google Earth Engine is one of the best and most powerful specialized remote sensing systems on the web, which in recent years has facilitated many processes of satellite image processing, especially time series data processing. With this system, all areas and coverages can be analyzed with high temporal resolution and also no need to download high-volume satellite images. Tools based on cloud computing operating systems are designed for large-scale processing of geographic data without the need for special technical expertise, such as the Google Earth Engine system, which can process the data in the database and provide the right results.

Slowly In the Google Earth Engine system, the possibility of extracting water resources information such as water area, rainfall, snow cover, snow depth, groundwater, runoff, flood, drought monitoring and many other issues can be examined. Researchers in recent years, with the introduction of this system, use it for remote sensing research, agriculture, natural disaster management, disease prediction and many other topics.

In this study, the changes in Zaribar Lake in Kurdistan in the period of 1984-1920 have been monitored. Examining the trend of changes in the water areas is one of the important tools for planning and development. In this study, Landsat images and NDWI and MNDWI indices have been used to identify the water zone (Zarivar Lake of Kurdistan). The Normalized Water Difference Index (NDWI) and the Normalized Water Difference Index (MNDWI) are universally recognized.

Materials & Methods

The study area is Zaribar Lake. This lake is one of the natural lakes in Kurdistan province and one of the largest freshwater lakes in Iran and is also one of the most famous and beautiful natural attractions in the west of the country. The height of the lake is 1285 meters above sea level and it is surrounded by oak forests. The length of this lake is 5 km and its width is 1.6 km and its depth is about 3 meters on average (between 2 to 5.5 meters).

One of the global indicators used to identify water areas is the NDWI index. This index is designed to maximize water reflection using green wavelength, minimize low NIR reflection with water properties and high NIR reflection by vegetation and soil properties. NIR and Green are the spectral reflectance values obtained in the near-infrared and green sections of the electromagnetic spectrum, respectively. NDWI values are between -1 to +1, which are negative or close to zero, which means non-water and values close to +1 indicate very high humidity. There are various spectral indicators based on which water zones can be identified on satellite images. One of these famous and practical indicators is MNDWI, which is an improved NDWI index. One of the most important indicators used in identifying water areas is the MNDWI index. This index is designed to highlight the water features in the images, which can well highlight mixed water areas with vegetation and urban areas.

The Overall accuracy method (OA) is a sum of the elements of the principal diameter of the error matrix divided by the total number of pixels. In recent years, using the Google Earth Engine, it is possible to analyze all areas, coverings and land uses with high temporal resolution as a time series. The system is an open-source database, and spatial analysis that allows users to touch and analyze the use of long-term satellite imagery. Google Earth Engine is the newest terrestrial processing platform that facilitates the scientific discovery process by allowing users free access to remote sensing data sets. In this system, users access GEE through an Internet-based programming interface and a web-based interactive development environment. An important source of information used in this study is the Google Earth Engine (GEE) system. With this system, areas can be analyzed with high time resolution and there is no need to download satellite images.

The GEE is a fledgling and very useful system in recent years. This system makes a large amount of information available with coding in the shortest time. In the present study, using Landsat 5 and 8 satellite images and GEE system and NDWI and MNDWI algorithms in the shortest time and cost, water zone separation from other phenomena was done using thresholding and long-term area changes. It is necessary to study these changes due to the importance of Zaribar Lake for water resources management in the region.

Results and Discussion

Validation of the results and comparison between the MNDWI and NDWI indices showed that the MNDWI index with a kappa coefficient of 0.94 and an overall accuracy of 97% for the recent period is a very suitable index for this region and its results are much better than the NDWI index. Based on the results, the average area of the lake during the study period based on MNDWI was 934.812 hectares and according to the NDWI index was 839.58 hectares. In order to study the trend of changes and fluctuations in the lake's surface, the results in 4 different time periods for both spectral indices were examined, which showed high fluctuations in recent years. Validation of results and comparison between indicators for Zaribar Lake showed that the MNDWI index with a kappa coefficient of 0.94 and overall accuracy of 97%, is a very suitable index for It is considered a region and its results are much better than the NDWI index.

Lakes are one of the most valuable national resources of any country. To better manage them, it is necessary to study the changes and fluctuations of lakes at different time intervals so that their various causes can be evaluated and as a result, researchers, users and executives to manage Water zones take advantage of them. Studies such as these can help planners and policymakers develop macro-policies in the management of natural resources and water resources. It is recommended that researchers, planners and executive users use the spectral indicators and the GEE system due to their high capabilities to identify the trend of changes in water areas in water resources management.

The important point is the trend of changes and in fact the amount of fluctuations in the lake surface in recent years, the most fluctuations have occurred in recent times. In the years with more rainfall, the lake level has also increased, as in 2018, when there was high rainfall and the lake level has also increased. In fact, high fluctuations in the lake in different seasons can be due to various factors such as floods and uncontrolled withdrawals from the lake, as well as changes and fluctuations in the rainfall regime and droughts, which in this study has referred to as the rainfall factor. And related graphs are also compared.

The results of Sarpa and Ozcelik (2017) study also emphasized on better performance of the MNDWI index and SVM method and Liang (2019) also introduced the MNDWI index as suitable for studying changes in the lake area. Sheikh Ghaderi and Mahdavifard (2020) also concluded that an engine system is a useful tool for detecting and monitoring the trend of changes in the level of lakes as well as working with bulk data.

Conclusions

The use of remote sensing technology and the use of medium and high spatial satellite imagery, which makes it possible to monitor changes in the past and present, is very effective and efficient. In this study, for the first time, long-term changes in the area of Zaribar Lake located in Kurdistan province were performed using the GEE system and Landsat images and NDWI and MNDWI spectral indices. In order to study the trend of changes and fluctuations in the lake surface, the results obtained in 4 different time periods of the past and recent years for both spectral indices were examined, which showed high fluctuations in recent years. Changes in the surface of the water zone can have various causes, the most important of which are changes in rainfall. In this study, the rainfall factor was also considered and a graph of rainfall changes and its comparison with changes in lake level was presented.

Validation of results and comparison between indicators for Zarivar Lake showed that the MNDWI index with a kappa coefficient of 0.92 and overall accuracy of 95% for the past period and also with a kappa coefficient of 0.94 and overall accuracy of 97%, a very suitable index for this It is considered a region and its results are much better than the NDWI index and therefore more efficient. Lakes are one of the most valuable national resources of any country. To better manage them, it is necessary to study the changes and fluctuations of lakes at different time intervals so that their various causes can be evaluated, and as a result, researchers, users and executives to manage the area. Bluebirds take advantage of them. Studies such as these can help planners and policymakers develop macro-policies in the management of natural resources and water resources.

Detecting saline water plume in a heterogeneous synthetic aquifer through a combination of POD and geoelectrical surveys

Document Type: Research Paper

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Abstract

In recent decades, geoelectrical surveys have been progressively used to capture the geometry and evolution of contaminant plumes in groundwater systems. In this study, we examine a procedure of a combination of proper orthogonal decomposition (POD) and geoelectrical forward and inversion models to map the salinity plume inside a heterogeneous synthetic aquifer through the surface resistivity data. Here, we improve the framework presented by Oware et al. (2013) in which they used POD as part of the geoelectric inversion stage needing a higher memory and time to run as well as using a finite difference approach. More importantly, the center of mass of the final modeled plume obtained from their methodology required to be shifted to the mass center of the original plume, resulting in the inapplicability of the method for the real cases in which the mass center of the plume is still unknown before modeling. Since the POD method is separately performed prior to the geoelectrical models and also solved through the finite-element rather than the finite-difference approach, the presented procedure, in addition to decrease the required RAM capacity, can correctly capture the spatial distribution and geometry of the salinity plume without the need for shifting the mass center of the modeled plume, so that, it can be reasonably used for real cases. Moreover, the findings from the three different scenarios of salinity injection (single injection point on the border, single injection point somewhere inside the aquifer, and two injection points somewhere inside the aquifer) show that the border effect may cause a horizontal shift in the modeled plume compared to the reference case. Additionally, the results indicate that the strength of the method for detecting the geometry of the plume decreases with depth.

Keywords: Contaminant plume, Geoelectric surveys, Heterogeneous aquifer, POD.

Introduction

In modern hydrogeophysics, one of the primary goals is to capture the maximum petrophysical information from the underground systems through a combination of hydrogeological and geophysical data (Binley et al., 2015; Linde and Doetsch, 2016). In practice, geoelectrical methods are less expensive compared to well drilling and direct measurements in hydrogeological approaches. Moreover, the well data are mostly representative of either a single point or a small region around the well (Rezaei et al., 2020) while the two- and three-dimensional tomography images from the geoelectric surveys are on the basin scale (Hermans et al., 2018).

This paper attempts to apply a combination of proper orthogonal decomposition (POD) and geoelectrical forward and inversion models to map the salinity plume inside a heterogeneous synthetic aquifer. Here, we try to improve the framework presented by Oware et al. (2013) in which they used POD as part of the geoelectric inversion model. More importantly, the center of mass of the modeled plume obtained from their methodology required to be shifted to the mass center of the original plume, so that, this step makes the method inapplicability for the real cases with an unknown mass center of the plume. They further used the finite difference method for modeling.

Materials and Methods

The steps of the methodology used here are as follows:

Generating of 100 series of heterogenous hydraulic conductivity (K) for an aquifer with 25m*25m through sequential Gaussian simulation, (2) Flow and transport modeling of a salt contaminant (NaCl), separately for each of the 100 K-series in Python (Fig. 1), (3) Use proper orthogonal decomposition (POD) to extract the main modes explaining the highest variance of the data and obtaining the best contaminant plume accordingly, (4) Transforming the salt concentration values obtained from the previous step to conductance according to the Archi equation, (5) Performing forward geoelectric model to obtain the apparent resistivity values through a dipole-dipole array, and (6) Finally, obtaining the resistivity value from inverse geoelectric modeling and back transform the resistivity to salt concentration by Archi equation.

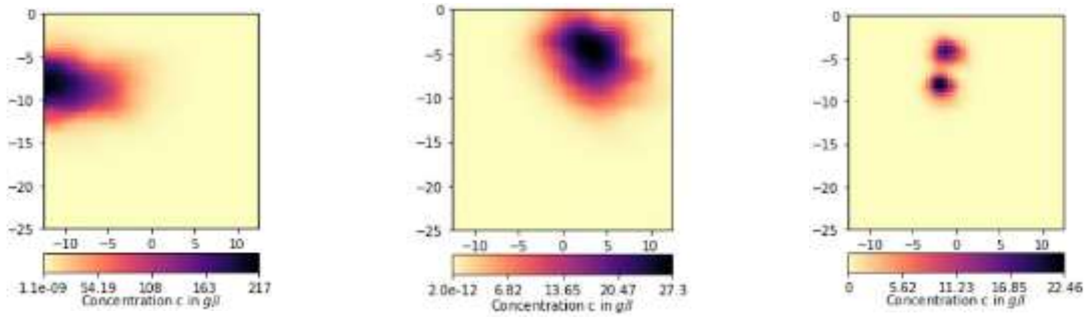

Fig. 1. One sample for each of the salinity plume simulated under the first (left), second (middle), and third (right) scenarios.

Results and Discussion

Fig. 1 shows the three scenarios for the injection: a single injection point on the left border, a single injection point somewhere in the middle of the aquifer, and two injection points somewhere in the middle of the aquifer at the same x position but at different depths. The first and third scenarios are respectively designed to explore the border effect and depth effect on geoelectrical models. The salt injection at each point for the first and second scenarios is 2000 mg/l per second while for the third one is 1000 mg/l per second.

As the mean, standard deviation, and plume retrieved from the first 10 dominant modes of POD are shown in Fig. 2, the modeled plume is asymmetric for all three scenarios owing to the heterogeneity of the aquifer. The salt is concentrated in the center of mass of the plumes that the injection rate is high while the hydraulic gradient is low. This high concentration helps capture the model with a greater resolution by geoelectric surveys. The standard deviation values, on the whole, are small compared to the salinity values, particularly in the second scenario. Similar to Hermans et al. (2016), the highest value of standard values from all scenarios are observed at those locations with an abrupt increase in salinity upstream.

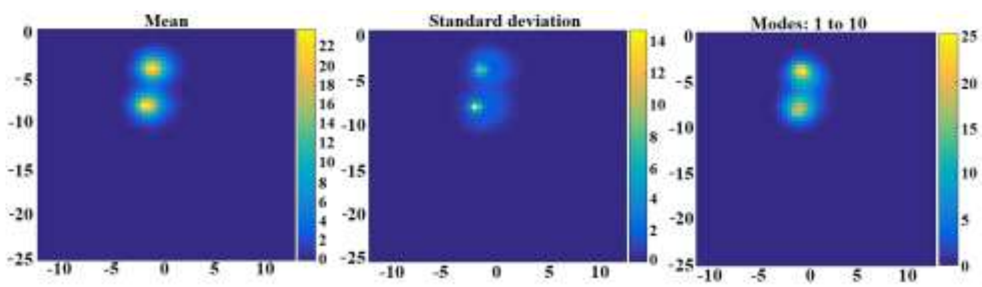

Fig. 2. The mean, standard deviation, and plume retrieved from the first 10 dominant modes of POD.

The computed variances of the different modes of POD for each of the scenarios demonstrate that the linear combination of the 10 dominant modes explains more than 99.5% of the total variance of the solute values. Notably, the first dominant mode itself comprises more than 97% of the variance. As an example, Fig. 3 presents the concentrations from the first 10 dominant modes for the second scenario, showing that the plume obtained by the first dominant mode is highly consistent with the reference plume (mean in Fig. 2). Although modes 2 to 10 are of a very small variance compared to the first mode, we here consider the linear combinations of all modes from 1 to 10 in order to guarantee to take into account more than 99.5% percent of total variance for modeling. Comparing the mean plume with that obtained from the first 10 dominant modes for the three scenarios demonstrates that the POD is able to correctly capture the geometry and the location of the contaminant plumes, particularly in the second scenario which is not affected by the border effect. Oware et al. (2013) to obtain the plume location correctly performed an excess step of shifting the mass center of the modeled plume to the mass center location of the reference plume. Although this work increases the model accuracy, it is practically not possible in real cases in which the plume mass center is not yet known. Here, the proposed framework enables the correct plume modeling by separating the POD step from the inverse geoelectric and using a finite element without the need for mass center shifting of the modeled plume. In a conclusion, the proposed method is practical and can be used for read cases with unknown plume center locations before geoelectric modeling.

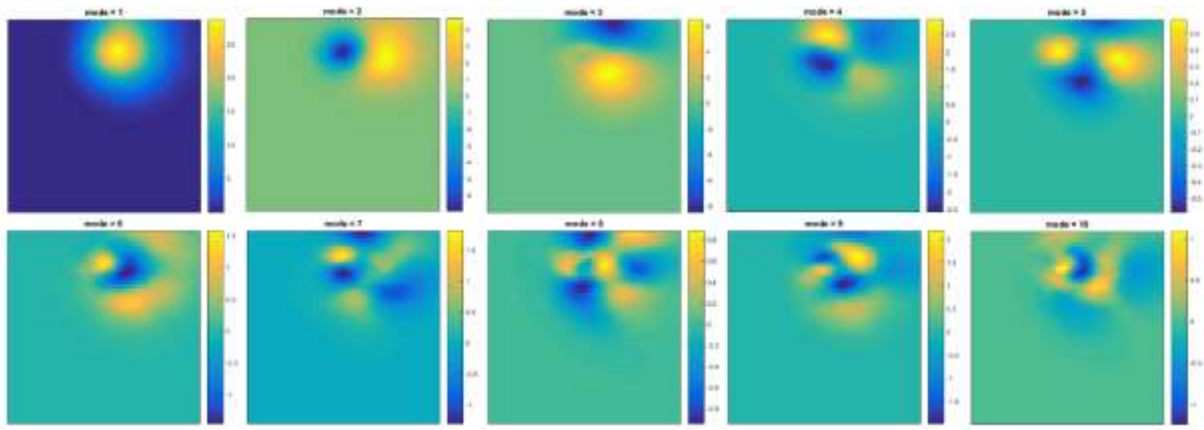

Fig. 3. Concentration plumes from the first 10 dominant modes for the second scenario.

Unlike the work by Oware et al. (2013), both the forward and inverse geoelectric models are run in the finite element framework. The finite element leads to a better resolution than the finite difference, particularly in cases with curvature borders such as the contaminant plume in aquifers. Notably, in Fig. 4, the geometry and location of the three plumes are well captured by the model. However, in the first scenario with the injection point on the left border, the center of mass is not well modeled due to the border effect (Oware et al., 2013; Hermans et al., 2016). In the second and third scenarios where there is no border effect, the mass center of the plumes is correctly captured and the lowest values of resistivity correspond to the higher salinity locations.

The other notable point is the covering effect of shallower anomalies with lower resistivity. In the third scenario (lower row in Fig. 4), our model can relatively separate the two plumes from each other where the mass center for the shallow one is at -4m depth and for the deeper plume at -6m. Otherwise, the deeper plume in Oware et al. (2013) is captured with a highly lower amplitude compared to the shallower one; this may be due to that we used a more accurate method of finite elements rather than finite-difference.

Although the proposed framework has relatively improved the geoelectrical surveys for capturing the contaminant plume in groundwater systems, there still exist some limitations that would be focused on in future works. In the three scenarios, Fig. 4 shows that the maximum concentration values in the model plumes are smaller than the mean of observed plumes, particularly in scenarios two and three. This underestimation has also been observed in other methods such as Tikhonov and coupled inversion (Oware et al., 2013). The main causes of this underestimation are (1) the over-smoothing of the geophysical image (Vanderborght et al., 2005; Caterina et al., 2014; Nguyen et al., 2016) and (2) the petrophysical relationship of Archi (Hermans et al., 2016). Another worth noting point is that the deeper plume in the third scenario is estimated about 2m shallower than its reference plume, in part, due to that it is located under a high conductance plume (Reynolds, 2011; Telford, 1990).

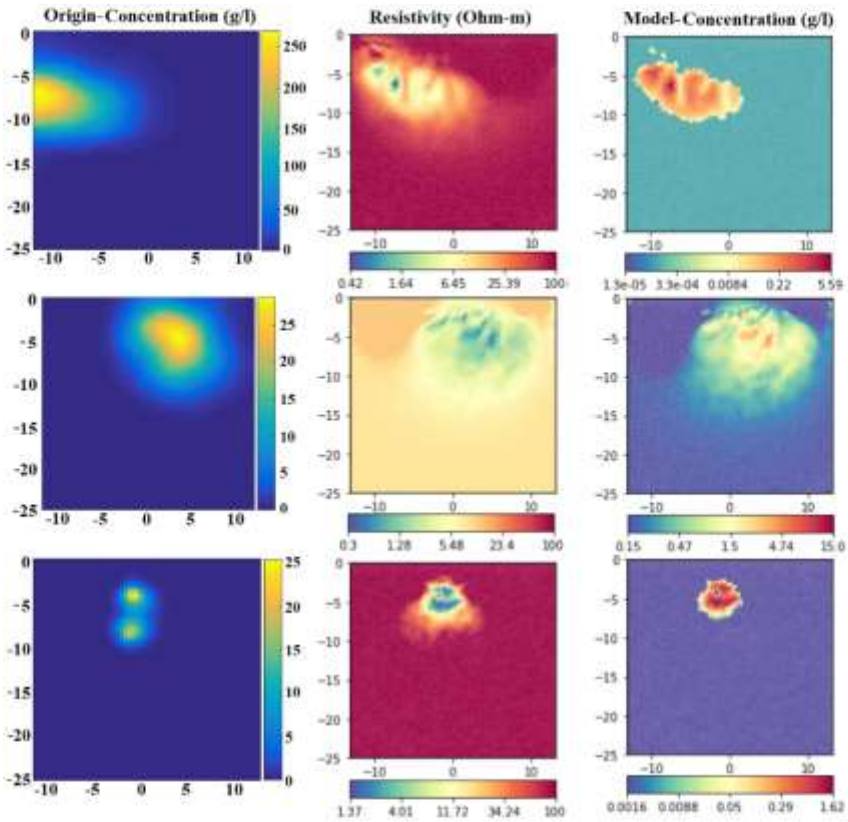

Fig. 4. Comparison of the model results with the original cases.

Conclusions

A combination of hydrogeological and geoelectrical models with POD enables us to successfully model the geometry and location of the salinity plume in a heterogeneous synthetic aquifer through surface resistivity data. In this paper, we used a finite element approach and performed the POD analysis separately before geoelectrical models. The proposed method by Oware et al. (2013) is not practicable in real cases with an unknown plume’s mass center while our approach can model the plumes correctly without the need for shifting the center of mass of the modeled plume.

Hydrogeochemistry of Bonab and Malekan Water Wells with the aim of Geoenvironmental Quality Assessment

Document Type: Research Paper

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Abstract

Bonab-Malekan area is located in the northwest of Iran and in the southwest of East Azarbaijan province. 12 water samples were collected from the water wells of Bonab and Malekan in order to investigate the hydrochemistry of groundwater. Water quality data of selected wells including pH, EC, TDS and eight other parameters were analyzed by Chemistry, AQQA and SPSS software for processing and interpretation which were evaluated to determine the quality of samples for drinking, agricultural and industrial use. Scholer diagram was used to assess water quality in drinking water. For the determination of water quality for irrigation and industry purposes, the Wilcox diagram and Lange index are used, respectively. According to the Schuler diagram, the water samples of the area indicate a range between good and acceptable waters, indicating the favorable water quality of the area for drinking purposes. Also, according to the Wilcox diagram, the samples in the area indicate two categories including good and average water quality. Among the selected samples, W12 was of good quality and the others were of medium quality. Furthermore, collected samples from W8, W9, W10 and W12 wells could be used for industrial purposes, however, the sample of W6 was scaly. Samples taken from the area are mainly classified as very hard in the total hardness (TH) category which causes consumer dissatisfaction. The samples of the Bonab area were all corrosive due to the low thickness of the Bonab aquifer compared to the Malekan aquifer. Thus, the corrosive properties of the Bonab samples cause water pert and health problems.

Keywords: Bonab and Malekan, Groundwater, Hydrochemistry, Total Hardness, Water quality.

Introduction

physical and chemical parameters that are strongly influenced by the geological structures and formations of the region and human activities. Safe water must have good quality characteristics so that it can be used in various applications of drinking, agriculture and industry. Groundwater is more difficult to control than surface water. Groundwater quality is the result of all the processes and reactions that have acted on it from the time of formation and condensation of water in the atmosphere until it is released from the ground by wells, springs or aqueducts. The geochemical nature of the formations in the path of water movement has a significant effect on the type and facies of water; On the other hand, water quality assessment is done with the aim of its suitability for various uses using special indicators. One way to determine the quality of water for drinking is to use the Schuler semi-logarithmic diagram. In addition to showing the nature of the sample graphically, the Piper diagram also shows its dependence on other samples. The chemical composition of groundwater resources is a complex function of many variables such as hydrogeological conditions, hydrochemical evolution of water to move from it in the reservoir, geological conditions and structures of the region, evaporation from the water table and human activity in the region; Therefore, groundwater quality is mainly affected by both natural and anthropogenic factors.

Materials and Methods

In this research, in line with the above objectives, the chemical and hydrogeochemical quality of groundwater in the Bonab and Malekan region for drinking and agricultural uses was investigated using the Piper diagram and Willcox and Schuller quality indicators and various factors affecting water quality in the study area, including Soluble solutes, chemical facies of water, capabilities and water consumption limitations have been investigated.

Sampling was performed according to water standards (Iranian Institute of Standards and Industrial Research) and analysis methods based on (APHA). The collected water samples were chemically analyzed after field studies in the laboratory of the province water and sewage company. pH and electrical conductivity were measured by pH meter and EC meter, the concentration of sodium and potassium ions by flame photometry, the concentration of calcium, magnesium, bicarbonate and chlorine ions by titration method and sulphate ion by spectrophotometry. The ionic balance calculation method was used to determine the quality control and measurement error of the decomposition data. The analysis error of chemical analyses in the study area was less than 5%.

Results and Discussion

The EC values range from 735 µS/cm in the Malekan area to 1250 µS/cm in Bonab. All data have a TDS content of less than 1000 mg/l, indicating that water resources are of good quality and freshwater. Also, except for one sample with acidic pH, the rest of the samples in the study area have alkaline pH. According to the WHO standard, the allowable limit of calcium in water is 250 mg/l and the amount of calcium in all of the samples is less than 150 mg/l, which is the reason why water is desirable. That is, the samples of the study area have a normal distribution in terms of calcium content. The amount of magnesium in the water according to the WHO standard should not be more than 50 (mg/l) and the graph of the values of the samples shows the optimal quality of water in terms of magnesium content. According to the WHO standard, the amount of sodium in water is 200 mg/l. The sodium content of the samples in the study area is less than 100 mg/l. Only the maximum sample amount is 148 mg/l, which is less than the allowable limit. Due to the low sodium content of the samples, water quality is desirable and the presence of excess sodium salts causes damage to the soil and reduces the permeability of water in the soil. According to the WHO standard, the permissible limit of potassium in groundwater is set at 12 mg/l. The potassium content in most samples of the study area is less than 8 mg/l and is desirable. Bicarbonate content in water samples of the Bonab and Malekan regions is also desirable. According to the WHO standard, the allowable limit of chloride (mg/l) is 400, and except for one sample that has a lot of chlorides, the rest have less chlorine, and due to the low amount of chloride, water quality is desirable. The permissible limit of sulphate in water according to the WHO standard is 400 mg/l and the sulphate content in all samples of the study area has a normal distribution. Groundwater hydrochemical facies reflect water types with different geochemical natures. Using the Piper diagram is one of the common methods in determining the type and facies of groundwater. According to the Piper diagram, the predominant hydrochemical facies of groundwater in Bonab-Malekan region is of the bicarbonate type, except for W_1 and W_3 Bonab samples which are sulphate and chloride types, respectively. Especially in the case of W_1, the effect of marl rocks and salt flats along Lake Urmia on the groundwater type can be observed. The water sample of W_3 has a type and groundwater facies that are compatible with hydrogeological conditions and is a facies of calcium chloride type.

In order to determine groundwater consumption for drinking and health, agriculture, and industry purposes as well as calculations related to water lightness or softness, it is very important to study water hardness. To evaluation the samples of the study area in terms of water hardness was used by Todd and Miz's classification. It was found that all (except one of the samples) belongs to the hard class. The lowest hardness value is related to the W_{12} sample in the Malekan area. Drinking water must have desirable physical properties in terms of color, turbidity, taste and smell. One of the criteria for classifying water in terms of drinking is the Schuler diagram. Chemistry software was used to draw this diagram. Most of the samples are in a good and acceptable area, so there are no restrictions for drinking consumption in these waters. Evaluation of irrigation water quality is one of the important parameters in agriculture. The Wilcox diagram is able to classify water into different classes based on the electrical conductivity (EC) of water-soluble solutes and the sodium adsorption ratio (SAR). In the study, the sodium adsorption ratio (SAR) and electrical conductivity (EC) in the Wilcox diagram were used to determine groundwater quality for agriculture use. According to the relevant diagram, it was found that only one sample of groundwater in the region is suitable for agriculture and the rest of the samples are moderate. In this study, in order to evaluation of water quality for industrial consumption in the study area, the Langelier index was used from Water Stability Analyzer software. The Langelier index indicates the state of water in terms of corrosion and scaling. Decreasing the pH and the presence of chlorine and sulphate ions intensifies corrosion and increases the pH and the presence of calcium, magnesium, bicarbonate and carbonate ions reduces corrosion. In order to investigate the limitations of using groundwater samples for industrial use and to determine whether it is corrosive or scaly water, the calcite saturation index (Langelier index) was calculated for groundwater samples in the Bonab-Malekan region. One of the main reasons for water corrosion in some samples is the presence of sulphates. Also, one of the main factors in the scaling of water samples is the high amount of calcium and calcium carbonate in terms of geological formations. Among the total samples, water wells W_8, W_9,

W_{10}, and W_{12} can be used in industrial consumption. Of all the analyzed samples, one is scaly water (W_6) and the rest of the examined samples are corrosive. Examination of the sediment thickness maps showed that the thickness of alluvial sediments in the Bonab plain was less than in Malekan and it has affected the depth of wells. The reason for the corrosivity nature of Bonab wells can be related to the lower thickness and fine-grained sediments, the shallow depth of wells and their impact from surface drains with high acidity.

Conclusions

According to the results of this study, the groundwater of the study area was very hard and only the W_{12} water sample has hard water. Schuler's diagram of groundwater showed that most of the samples are in a good and acceptable area for drinking. Therefore, there are no restrictions for drinking water in these waters and the water has a good quality in terms of drinking. To evaluate the water quality in terms of agricultural use, the Wilcox diagram was used which showed that most of the samples fall in the field of C3S1 and the groundwater samples of the region are in two categories of good and medium and only one of the samples (W_{12}) is in the appropriate category. In the study of water quality in the region for industrial use, it was found that one of the main causes of water corrosion in some samples is the presence of sulphates. Also, the main cause of the scaling of water samples is the high levels of calcium and calcium carbonate in terms of geological formations in the region. Of all the samples, water from wells W_8, W_9, W_{10} and W_{12} are suitable for industrial use. The water sample from well W_6 is scaly and water samples from other wells are industrially corrosive. Bonab city is very important in terms of industrial development and Malekan city in terms of agricultural development in the northwestern region of the country, and in general, not paying attention to environmental issues will pose serious risks to the region in the future. Although the quality of the samples is suitable for drinking purposes in some parameters, at the same time the hardness of most samples is very high and needs to be improved according to health standards. On the other hand, due to the corrosive nature of water samples in the Bonab region, the problem of corrosion of water transmission lines will increase water loss in the urban drinking network and will cause a lot of financial and health losses.

Effects of evaporation rate on groundwater level and drainage coefficient by means of HYDRUS-2D software (Case study: Interception drain of Qazvin plain)

Document Type: Research Paper

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Abstract

Fresh groundwater overexploitation causes many problems the most important of which are saline water expansion to upstream lands and enhancing salt concentration in shallow groundwater conditions. Interceptor drains can control salinity expansion and decrease saline water hydraulic gradient to freshwater resources. Also, in arid and semi-arid regions evaporation plays an important role in decreasing hydraulic head. In this research, HYDRUS-2D has been used in order to assess the effect of evaporation on groundwater depth and drainage coefficient in Abyek interception drain. This salt marsh has located in the southeast of Qazvin and the purpose of installing an interceptor drain in this area is to lower the saline groundwater level and control the salinity expansion till upstream lands gradually improve by soil leaching due to rainfall and groundwater flow and drainage outflow. Simulation has been done in 90 days for three soil texture: clay, loam and sand and four evaporation rate including: low, medium, high (0.2, 1, 2.5 $mm\,day^{-1}$) and without evaporation. Results showed that clay evaporation has a significant role in causing a decrease in water table level and drainage coefficient. As the evaporation rate increased from 0 to 0.2 $mm\,day^{-1}$ groundwater level drop increased by 16.5% and the drainage coefficient decreased by 20.6%. in loamy soil, these values were 1.9% and 1.7%, respectively. As a result, the effect of evaporation is less in loamy soil and a low evaporation rate can be ignored. Also, low and medium evaporation rates in sandy soils are ineffective in causing groundwater level decrease and reducing drainage coefficient. While high evaporation rate with a 6.9% increase in water level fall and a 15.7% decrease in drainage coefficient is effective and should be measured accurately and considered in the simulation. The results of this study are consistent with the work of researchers who have worked in related fields and it is suggested that special attention should be paid to the effect of evaporation in drainage studies especially in clay soils.

Keywords: Clay, Evaporation ratio, Groundwater Depletion, Loam, Sand.

Introduction

Overexploitation of fresh groundwater (GW) causes vital issues, among them are the advance of saline GW toward upstream and enhancing of salinity concentration at salt marsh in shallow water table conditions. Large areas of Iran suffer from salinity. Furthermore, increased population and demand for food cause surplus pressure on freshwater resources. More GW withdrawal lead to more water table depletion. This loss causes lots of problems as among them are, drying semi-deep wells, digging deeper wells to find more water, soil compaction, decreasing effective porosity, soil subsidence and at last decreasing groundwater flow, plain's discharge and increasing hydraulic gradient of saline groundwater toward fresh groundwater. This condition confines saline water and it could not leave the plain that leads to extra salinity and waterlogging. In these circumstances, an interception drain would send the saline water out of the plain and decrease the saline groundwater depth. So, it could control salinity and waterlogging. Constructing an interception drain for this condition not only could avoid moving saline water to upstream but also, protects upstream lands from salinity.

In addition to key role of interception drain to improvement, evaporation is intensifying the process. In this study HYDRUS-2D software was used to determine the effects of evaporation on GW level and drainage coefficient in three different soil textures included: Clay, Loam and Sand with four evaporation rate levels included: No-evaporation, low evaporation rate, medium and high rates.

Balugani et al (2017), separated the portion of evaporation and transpiration and assessed each one's effect on groundwater loss in semi-arid areas. Final results showed that in semi-arid regions with low vegetation, evaporation has a significant role in groundwater loss.

Furthermore, in another research evaporation effect on water table level has been assessed in six different soil textures including: gravel, fine sand, sandy loam, light loam, medium loam and heavy loam. Results showed that the evaporation rate from the aquifer in addition to the evaporation potential depends on the evaporation surface roughness, soil heat capacity, soil thermal conductivity, soil color and soil albedo coefficient. These characteristics are different in different soil textures. Experimental results have shown that as the size of soil particles decreases, the amount of evaporation decreases too. Also, soil thermal capacity and thermal conductivity are completely related to the mechanical composition of soil particles, and with decreasing soil particle size, the amount of saturated moisture in the soil and consequently the soil heat capacity increases, which means that due to surface heating, temperature increases lower, water molecules move more slowly and less evaporation occurs. Moreover, soil color is effective in surface albedo coefficient and solar radiation received by the earth. The darker the soil, the more heat is absorbed by the soil, the sooner the soil temperature rises and the more evaporation occurs.

Materials and Methods

Study area

The study area covers 64400 ha that is located at the south east of Qazvin, which is a flat region between longitudes 380-420 km E and latitudes 3920-3980 km N. At last, the core of the saline area was about 10000 ha but gradually increased to 20000 ha over time as a result of water table loss and decreasing hydraulic gradient out of the plain. An interception drain was built in this area to decrease the saline water table's depth and control salinity movement to upstream lands. But to make a loss in groundwater depth in addition to the interception drain, evaporation is effective too. To investigate this, a simulation was done in three soil textures: Clay, Loam and Sand. 99 wells were drilled in 9 sections (A to I) in Drain's path for monitoring the water table's depth and salinity. Section B was chosen to simulate because of the region's situation (section B is located at the first parts of the drain's path and upstream fluxes have less effect on this section).

HYDRUS Software

One of the most important software for simulating water, heat and solute movement through saturated and unsaturated porous media is HYDRUS. This software was developed by Simunak et al at USSL (U. S. soil salinity laboratory) in 2006. HYDRUS can do a simulation in three ways: 1D, 2D and 3D. This package contains Computational and Graphical user interface. Also, the HYDRUS program numerically solves Richards's equation for variably saturated water flow and advection-dispersion equations for both heat and solute transport.

Research procedure

The soil texture of the study area is clay but the three textures mentioned above were simulated in section B. Observation nodes were determined exactly on observation wells that are located in 10, 25, 50 and 100 m from the drain both on the upperside and downside. The simulation's duration was 90 days, and four evaporation rate levels for each texture were investigated. Without evaporation, low, medium and high evaporation rate (0.2, 1 and 2.5 mm day^{-1}). Also, for calculating input fluxes, equation 1 was used. In this equation h is the piezometric head of observation wells (m), s is the storage coefficient, N_r^* is the net sink and source term ($\mathrm{m\ day^{-1}}$), k is saturated hydraulic conductivity ($\mathrm{m\ day^{-1}}$), x is the distance to drain (m) and $\mathrm{C_1}$ and $\mathrm{C_2}$ are integral's constants.

$$q = \frac{-N_r^*}{h}x + \frac{c_1 k}{2h} \quad (1)$$

Results and Discussion

The results of the simulation showed that the effect of evaporation on groundwater level and drainage coefficient is significant but it is different in varied soil textures.

Clay

Evaporation is very effective in groundwater loss in clay soils. There is a big difference in water table depth when there is no evaporation in comparison to 0.2 mm day^{-1} evaporation rate. In no evaporation state just, the drain is decreasing water table depth. But in other states, evaporation intensifies the effect of drain and causes more drawdown. In well BD3 (third well downstream), on the last day of simulation for no-evaporation treatment, groundwater is located at 2.31 m from ground surface, for 0.2 mm day^{-1} evaporation rate, this depth reaches 2.55 m. In other words, by increasing evaporation to 0.2 mm day^{-}, groundwater loss would increase up to 16.5%. In same way 1 and 2.5 mm day^{-1} evaporation rates can reach water table depths of 3.61 m and 4.53 m which is increasing groundwater loss by 41% and 53% respectively.

For the drainage coefficient, the results were the same. For no evaporation, 0.2, 1and 2.5 mm day^{-1} evaporation rate drainage coefficient would be 0.034, 0.027, 0.014 and 0.010 mm day^{-1}. So evaporation has the ability to decrease drainage coefficient by 20.6%, 58.8% and 71% more than no evaporation state respectively.

Loam

In loamy soils, results are similar to clay soil but the evaporation effect is smaller. In well BD3 after 90 days for no evaporation, 0.2, 1 and 2.5 mm day^{-1} evaporation rate states water table depth is located at 2.04, 2.08, 2.27 and 2.72 meters which means low, medium and high evaporation rates can increase groundwater loss 1.9%, 10% and 25% respectively.

Also, low, medium and high rates of evaporation can reach drainage coefficients of 0.229, 0.210 and 0.163 mm day^{-1} in comparison with 0.233 mm day^{-1} for no evaporation state. So different evaporation rates can increase drainage coefficient loss by 1.7%, 10% and 30%, respectively.

Sand

In sandy soils, evaporation doesn't have an important role in increasing groundwater loss. Results show that in no evaporation state water table depth is 2.27 m from the soil surface and when the evaporation rate is 0.2, 1 or 2.5 mm day^{-1} water table depth would be 2.28, 2.33 and 2.44 m. thus groundwater loss increases 0.4%, 2.5% and 6.9%.

Also at no evaporation rate, the drainage coefficient is 1.938 mm day^{-1} and low, medium and high rates of evaporation can reach 1.912, 1.822, 1.633 mm day^{-1} which means this rate of evaporation can decrease drainage coefficient 1.3%, 5.9% and 15.7% more than no evaporation state.

This different behavior in different soil textures is due to different pore sizes and changes in capillary effect. As decreasing in capillary fringe in coarse-textured soils, evaporation's effect would be low and even ineffective. In fine-textured soils, the large number of capillary tubes make a big capillary fringe so evaporation in these soils would be effective and meaningful.

This research's results are coincident with Arvin et al (2016) study, they assessed the effect of climate fluctuation and extracting groundwater on groundwater levels in Damane plain in Isfahan. They claimed that in addition to extracting irregular amount of groundwater, air temperature and evaporation have a meaningful relation to groundwater level change. Furthermore, the results of Yue et al (2016) study, assessing the effects of water saving on groundwater balance in northwest china showed that 92% of groundwater's charge and 92% of its discharge are related to infiltration and evaporation. This result is coincident with the simulation results in the present study. Also, Hu et al (2018) research, comparing phreatic evaporation at zero water table depth with water surface evaporation on 6 different soil textures, showed that the evaporation rate depends on evaporation potential and soil texture. This result is completely coincident with the present research's results too.

Conclusions

In clay soils, the evaporation rate is very effective in causing a drop in groundwater level, thus, even the smallest amounts of evaporation can not be ignored in research and simulations. In loamy soils, the effect of evaporation is less and the low evaporation rate in these soils can be ignored. In sandy soils, this effect is less and only high evaporation rate is effective in increasing groundwater loss.

The difference in the behavior of different soil textures is due to the difference in the size of soil pores and as a result changes in the capillary affect them. By reducing the depth of capillary area in coarse-textured soils, the effect of evaporation in this soil is low and ineffective. However, in fine-textured soils, due to the accumulation of capillary tubes and large capillary areas, the effect of evaporation is significant.

Also, the effect of evaporation in reducing the drainage coefficient in clay soils is more than in loamy soils and in loamy soils more than in sandy soils. In addition, the difference in drainage coefficient values in these soils is due to differences in their hydraulic conductivity.

Investigation of geochemical interactions of groundwater resources of Kamarderaz anticline plunge using statistical methods, Southwest of Izeh city

Document Type: Research Paper

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Abstract

Karstic aquifers are one of the most important freshwater resources, and in some areas, they are the only available water resources. These resources have significant challenges, including reduced quality and increased pollution. Izeh city in the southwest of Iran intensively depends on karstic water resources due to the lack of access to surface water streams. Accordingly, five water wells were drilled to supply part of the city's and surrounding villages' drinking water in the Kamarderaz anticline plunge. During the drilling in the Atabaki area, two wells encountered H2S gas penetration and increased Ec during drilling, making the wells cumbering. The chemical parameters of water resources were measured to investigate the causes of qualitative changes in 4 states during two seasons in spring and summer over 2017-2018. Na /Cl, Br /Cl, I /Cl ion ratios, and Total Organic Carbon Index (TOC) was used to differentiate salinity sources, water sources mixing with brine, and the infiltration of hydrocarbons into water. In this study, statistical analysis, including PCA and AHC, was used to more accurately investigate the factors affecting the qualitative changes in the region. According to the statistical analysis in the area, two factors of carbonate mineral dissolution, evaporation and brine infiltration, have simultaneously affected the water quality, especially in the western part of the plunge anticline. TOC analysis and Na /Cl, Br /Cl, and I /Cl ratios illustrated the mixing of water and oil brines and the infiltration of hydrocarbons.

Keywords: Hierarchical Cluster Analysis, Hydrochemical parameters, Karstic aquifer, Principal Component Analysis.

Introduction

Water resources in karstic aquifers are one of the most important freshwater resources in the world, and in some areas, they are the only available water resources. Karst water resources have significant challenges, including reduced quality and pollution of such water resources. Various causes have been identified for the salinity of karstic aquifers, including the dissolution of evaporate minerals, oil brines, deep water, and seawater penetration into these reservoirs. Hydrochemical evaluations generally use Na/Cl, Br/Cl and, I/Cl ion ratios and other significant Ca^{2+}, Mg^{2+}, Na^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{2-} ions to distinguish salinity and mixing of saline and freshwater. In addition to ion ratios and salinity indices, the Total Organic Carbon (TOC) index can investigate groundwater's relationship to organic matter and hydrocarbons. Due to the lack of access to surface water flows, Izeh city in southwestern Iran heavily depends on karstic water supplies. Accordingly, five water wells were drilled to supply part of the city's and surrounding villages' drinking water in the Kamarderaz anticline plunge. During the drilling in the Atabaki area in 2016, two wells encountered H_2S gas penetration and increased Ec during drilling, making the wells cumbering. Due to the high capacity of the aquifer in the anticline depression, such qualitative changes occurred in this part of the aquifer, and the drinking water supply of the city faced significant challenges. Given the necessity of water supply for the region, analyses of hydrochemical parameters, geochemical processes, reference ion ratios, graphs of salinity source, TOC and, statistical analyses such as PCA and AHC were performed to investigate the causes of quality changes and also the origin of salinity.

Materials and methods

Geology and Hydrogeology

Kamarderaz anticline is located northeast of Khuzestan province (southwest of Iran) and southwest of Izeh city. The Kamarderaz anticline is an asymmetrical, one-sided fold whose southwest edge is severely crushed and destroyed by tectonic activity in the area, except in small sections. The anticline area is very tectonically active and, the outcrop formation in this anticline is mainly of Asmari carbonate formation of the Oligocene-Miocene age. The Asmari formation is, in turn, composed mainly of lime, dolomite and, its lower part includes the marl and anhydrite layers. In the lower part of the Asmari Formation, the Pabdeh formation composed of shale, marl and, lime sediments with different percentages belongs to the Paleocene-Eocene time. The Pabdeh formation on both sides restricts the eastern and western edges of the anticline. Gachsaran evaporates formation consists mainly of evaporate minerals such as gypsum, halite, lower Miocene, and lower marl in the west of the anticline. The outcrops of the study area formations are shown in Fig. 1. The karstic forms in the middle part of the Asmari formation are abundant in this anticline. The climate of the study area is semi-arid, with 480 average rainfall and 21 C average temperature.

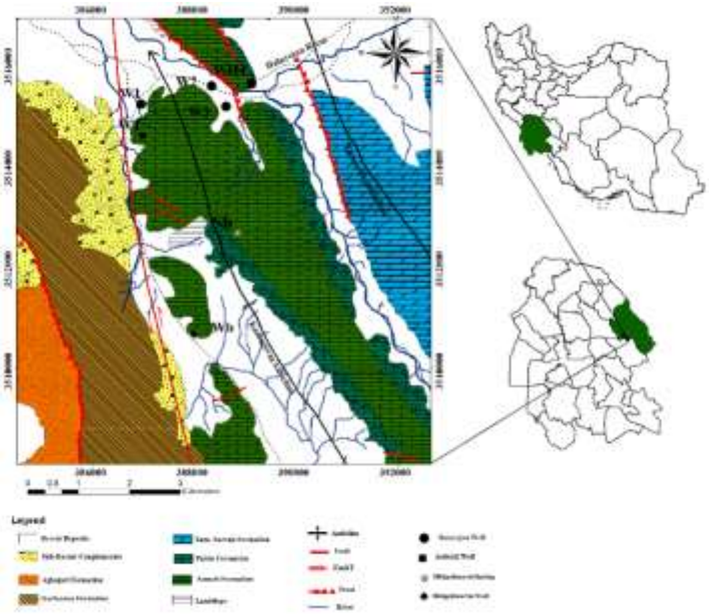

Fig1- Location of Kamarderaz anticline, sampling resources, and formation outcrops in the area

Sampling and Analysis

To perform hydrochemical studies in a wet and dry period, 16 samples of water resources in the study area during four stages, including Halayejan wells 1, 2, 3, 4 and, two samples of Bibigolmorde spring, were taken. Besides, water samples collected during drilling at depths of 69, 97 and, 100 m of Atabaki Well were used. For statistical analysis and the results of samples, Bibigolmorde data are used. Hydrochemical parameters are interpreted using Principal Component Analysis and Hierarchical Cluster Analysis and Graphics methods.

Discussion and results

PCA results show a high correlation of Ca, and Mg with HCO_3, which may be due to the dissolution of carbonate minerals such as calcite and dolomite in the Asmari Formation. The relatively strong correlation of Na, Cl and, Ca, SO_4 can result from the dissolution of evaporative minerals of Asmari marl layers. A high correlation of Ca with Cl can result from mixing the studied aquifer with water containing the values of these two ions. Based on the biplot of PCA Ca, Mg, and HCO_3 effect on Wb, WT1 (depth of 69m), they are affected by the dissolution of Dolomite and Calcite. Na, Cl, EC affect WH1 more than other water resources. The result of HCA is illustrated by a dendrogram. HCA selected three groups. Group 1 contains W2, W3, W4, Wb and, Sb. The Piper displayed, the dominant type of water in these resources is Ca-HCO3. The samples of this group have a better quality than other wells and are located in the eastern part of the anticline plunge. Group 2 exists W1, WT2, and WT3 (depth of 97 and 100 meters). These wells are located west of the Kamarderaz Anticline, and their dominant type of water is Ca-Cl. Group 3 includes samples of two wells, W4 and W2, in July. The reason for classifying these two samples in one group was the pattern of the sudden increase of SO4 anion in them compared to other wells in July 2017(Fig. 2). Based on the Na/Cl diagram versus the vertical axis Ec graph, most of the groundwater samples in the study area are in the reverse ion exchange range. Investigation of sodium to chlorine ion ratio in the study area showed that in most of the samples, the weight ratio was less than 0.6. Analysis of the Na/Cl weight ratio in the Atabaki well revealed that at 69 m depth, atabaki water had been affected by the dissolution of small amounts of halite in marl layers. It was also found that with increasing depth (depths of 97 and 100 meters), the difference in concentration of two ions increased due to increasing the concentration of Cl-ion, which could result from possible mixing of water wells with oil-brine at lower depths of this aquifer. The data distribution in the Na/Cl ratio versus Cl graph is in the range of mixing freshwater with oil brine (Fig. 3).

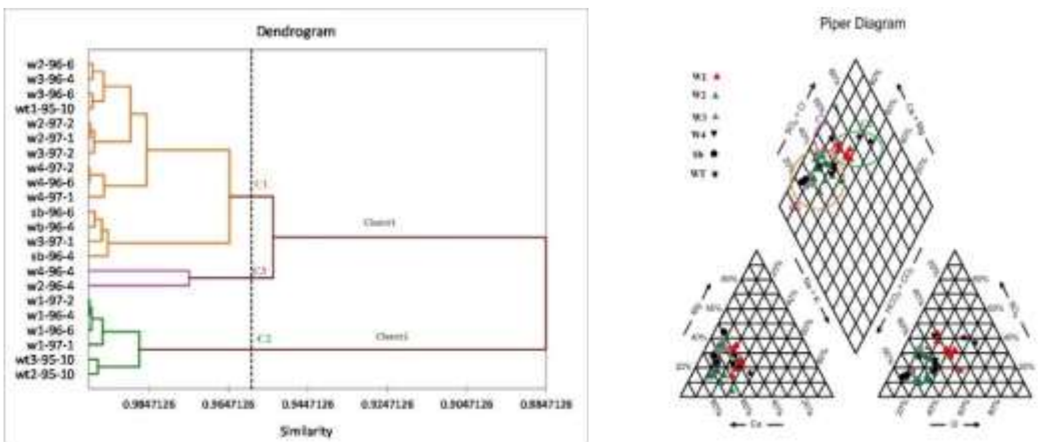

Fig 2- Dendrogram and **Piper diagrams of the water resources samples of the Kamarderaz anticline**

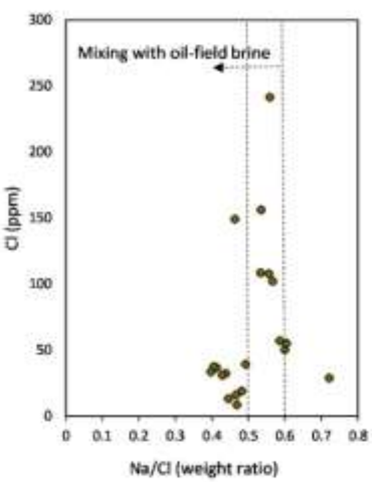

Fig 3- Cl inverse Na/Cl diagram of Kamarderaz anticline plunge water samples

Examination of the ratio of Br/Cl and I/Cl in the studied water samples showed that samples located on the plunge were affected by the influence of oil brine. The TOC analysis in the WT sample showed that the concentration of this parameter is 23.2 mg/L, indicating the penetration of hydrocarbon materials into this source.

Conclusions

The results of different hydrochemical studies in this study showed that the decrease in the quality of water resources, especially in wells located in the western part of the anticline, is due to the dissolution of marl layers and the mixing of water with oil brines.

Evaluation of the Aghili aquifer hydrochemical status with emphasis on multivariable statistics method

Document Type: Research Paper

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Abstract

Groundwater is one of the most important sources of drinking agricultural and industrial water supply in the world and its importance is increasing due to population growth and climate change. therefore Improper management of water resources, lack of rainfall and recent droughts have adversely affected the quantity and quality of groundwater resources in most parts of Iran. Due to the importance of Aghili alluvial aquifer located in Khuzestan province in the agricultural sector and also the supply of drinking water to cities and villages in the study area, the groundwater quality status of this aquifer has been studied. In order to study the parameters affecting the groundwater quality of the Aghili aquifer, the results of the chemical analysis of 13 exploitation wells in March of the wet year (2014-2015) were used. In this study, in order to identify the factors affecting the groundwater quality of the Aghili aquifer, saturation index, ion exchange diagrams, drawing methods and multivariate statistical methods (principal component analysis (PCA) and hierarchical clustering analysis (HCA)) were employed. The predominant type of groundwater in this aquifer is sodium chloride. The PCA showed that two factors with a total of 82.2% of the total changes (the first factor of 61.4% including the parameters Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-} and SO_4^{2-} and the second factor of 20.8 in Including pH and HCO_3 parameters control the quality of Aghili aquifer water resources. Based on the results of HCA of hydrochemical data, two clusters were observed. In general, dissolution of minerals, sedimentation, reverse ion exchange, and agricultural wastewater are among the most critical factors affecting the groundwater quality of the Aghili aquifer.

Keywords: Aghili aquifer, Hydrogeochemistry, Ion exchange, Multivariate statistical methods.

Introduction

Different factors are influencing groundwater quality and concerning this, valuable researches have been conducted. The most important controlling elements deteriorating water quality include; lithology, water-rock interaction, weathering and salt leaching, water residence time, reduction in rainfall (drought), low recharge, evaporation, low-quality recharge water from nearby water bodies, irrigation return water, topography, basin sedimentation conditions and industrial and domestic wastewater.

The drought and heavy exploitation in recent years resulted in to impact on the quality of the Aghili aquifer, which counts as an important water-bearing layer for irrigation and industry in the area. The available literature indicated that multivariate statistical analysis was useful to determine influential parameters impacting groundwater quality. The aim of this investigation was to ascertain geochemical processes governing the quality of the Aghili plain groundwater. In order to reach the goal, conventional methods such as composite diagrams, saturation index, ion exchange and multivariate statistical analysis (PCA and HCA) were undertaken.

Materials and Methods

The study area

The Aghili aquifer occupies about 142 km^2 and is located in the north of Shushtar City, Khuzestan province and is placed within longitude 48 49 to 48 58 and latitude 32 6 to 32 16. Elevation ranges from 37 to 140 masl, experiences dry climate and mean annual temperature, rainfall and evaporation are 27.6 C, 339 mm and 2860 mm respectively. The geological formations surrounding the Aghili aquifer comprise of the Ghachsaran gypsum, the Mishan marly limestone, the Aghajari inter-bedded marly sandstone, the Lahbari marly member of the Aghajari and the Bakhtiari conglomerate formations belonging to the Miocene period and the Quaternary alluvial deposits. The Bakhtiari conglomerate formation recharges the aquifer from the north and the northeast while the Ghachsaran evaporative formation feeds the area from the east and the southeast. The groundwater flow direction follows the land surface relief and flows from the east to the west and southwest.

In order to evaluate the quality of the Aghili aquifer 13 groundwater samples in February 2016 were collected and analyzed for major ions (HCO_3^-, SO_4^{2-}, Cl^-, Ca^{2+}, Mg^{2+}, Na^+ and K^+). Temperature, pH and EC were measured in the field. For standardization of the data in statistical methods, the Kaiser method was used, where on this bases KMO value for all hydrochemical parameters was above 0.5. To ascertain influential factors impacting on groundwater quality of the area, graphical methods, saturation index of the minerals, ion exchange and multivariate statistical analysis, including, principle component analysis (PCA) and hierarchical cluster analysis (HCA) were applied. During this investigation PHREEQC ،Excell ، Aq.QA ،XLSTAT, and Arc GIS10.3 were used.

Results and Discussion

Saturation index

As the equilibrium condition of the minerals is a good clue to indicate water-rock interaction, the saturation index of the main minerals, including calcite, dolomite, gypsum and halite was computed. In the majority of the samples, the values for calcite and dolomite were beyond zero displaying supersaturation of groundwater samples with respect to these minerals. Apart from the low solubility of these minerals to reach equilibrium, the alkaline pH of the groundwater system enhances the saturation process and precipitation. The gypsum and halite were under saturation states and the dissolving of these minerals is occurring in the groundwater regime.

Ion exchange

Ion exchange and reverse ion exchange are commonly used to recognize the governing geochemical processes. In order to appraise the effect of the ion exchanges on groundwater quality the mole ratio of (Na^+/Cl^-) via EC and $Ca^{2+}+Mg^{2+}$ via $SO_4^{2-}+HCO_3^-$ were plotted. The samples placed above the line of $Na^+/Cl^-=1$ depict ion exchange while the samples located below the line confirm the reverse ion exchange. Based on the plot of $Ca^{+2}+Mg^{2+}$ and $SO_4^{2-}+HCO_3^-$, it was realized that samples which are following the line of 1:1 disclose dissolution of calcite, dolomite and gypsum while the samples situated below and above the line denoting ion exchange and reverse ion exchange respectively. The Aghili alluvial aquifer is fed from the limestone Bakhtiari and the evaporated Ghachsaran formations and in addition to these formations, the alluvial aquifer contributes Ca and Mg ions to the groundwater system and these elements is sharing in the reverse ion exchange process with Na ions of halite and clay minerals. Based on the two graphs, the reverse ion exchange is observed in samples (AG8, AG10, AG27, AG5, AG6, AG17, AG7, AG29 and AG9) located away from the recharge zones.

Multivariate statistical analysis

A- Principle component analysis (PCA)

According to the PCA results, two factors altogether comprise 82.2% of the total changes, controlling groundwater quality of the aquifer. The first agent with 61.4%, which is the most affecting element responsible for groundwater deterioration, embraces Ca^{2+}, Mg^{2+}, Na^+, K^+, SO_4^{2-}, Cl^- and EC and the second aspect which covers 20.8% of the quality changes incorporates pH and HCO_3^-. Based on the scatter graph plot of the total factor of pc1 over pc2, the sample number AG29, samples AG11 and AG20, the samples AG8 and AG10 placed in first, second and third quarter respectively and all the remaining samples consolidated on a location in the graph. To explain the distribution of the samples on the scatter plot graph

Piper diagram was used. The sample AG29 was collected from a semi- depth well in the northwest of the area. The salt leaching(NaCl) due to irrigation activities and relatively low depth of the well promoted reverse ion exchange and resulted in the water type being SO_4-Ca. The samples AG11 and AG20 are located in the northeast and due to recharge from the Bakhtiari formation water type is HCO_3-Ca and their quality is better with respect to other samples. Though, the AG8 and AG10 samples are located in the middle part of the aquifer and unlike the geochemical evolution, the water type is Na-Cl. The reason for this is recharge from the Gachsaran evaporative, the Aghajari formations and the Lahbari member of the Aghajari formation(fine grain sediments containing NaCl) and residence time. With exception of AG6 which acquired its water Ca-Cl type from inverse ion exchange, the rest of the samples (AG36, AG27, AG5, AG6 ،AG17, AG7, AG26 and AG9), which are located in the center and towards discharge zone exhibiting Na-Cl water type and designate geochemical evolution trend.

B- The hierarchical cluster analysis (HCA)

The hierarchical cluster analysis (HCA) indicated two clusters for the hydrochemical data and the sample numbers AG8 and Ag10 which are more similar to each other placed in the first cluster. The sample numbers AG11 and AG20 are lying in the first sub-group of the second cluster, sample number Ag29 belongs to the second sub-group of the second cluster and the other samples (AG36, AG27, AG5, AG6, AG17, AG7, AG26 and AG9) form a separate sub-cluster. The results of both the Principle component analysis (PCA) and the hierarchical cluster analysis (HCA) confirms each other. In addition to the similarities of the PCA and HCA results, a resemblance is also observed among multivariate statistical analysis outcomes and the saturation index and ion exchange data.

Conclusions

The groundwater quality of the study area is under the influence of climatic conditions, lithology, water-rock interaction. The saturation index depicted that the majority of the samples were supersaturated with respect to dolomite and calcite and in regard to gypsum and halite was under saturation. Therefore, the precipitation of calcite and dolomite minerals and the dissolution of gypsum and halite is occurring. The samples which are away from the recharge zone experience reverse ion exchange. Although, a few samples displayed HCO3-Ca water type, the majority of the samples revealed a Cl-Na nature. The considerable correlation between Cl and Na ions and also between SO4 and Ca^{2+} and SO_4^{2-} and Mg are reflecting the dissolution of halite, gypsum and magnesium sulfate minerals respectively. The principle component analysis (PCA) showed that two factors comprised about 82.2% of the total changes, controlling the groundwater quality of the aquifer. The first factor with 61.4%, which is the most affecting element responsible for groundwater deterioration, is related to Ca^{2+}, Mg^{2+}, Na^+, K^+, $SO4^{2-}$, Cl and EC and the second component which covers 20.8% of the quality changes includes pH and HCO3. The first and second factors which affect the groundwater quality of the Aghili aquifer is due to human activities involving irrigation, suburban and urban swages. The results of the hierarchical cluster analysis (HCA) with regard to the groundwater quality of the area are absolutely in accordance with the principle component analysis (PCA). Overall, the outcome of the multivariate statistical analysis disclosed the usage efficiency of the PCA and HCA for hydrochemical assessment.

Vulnerability of Lahijan-Chaboksar aquifer using comparative assessment of three indices of GALDIT, SINTACS, and AVI

Document Type: Research Paper

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Abstract

Many countries throughout the world have a large population in coastal areas. Therefore, appropriate water supply in these areas is an important task. The increasing development of human societies has been a major contributor to environmental pollution, especially in the water sector. Groundwater vulnerability mapping is used to conserve the quality of groundwater resources. In this study, a comparative evaluation of the vulnerability was performed using three GALDIT, SINTACS and AVI indices to determine vulnerable areas in the Lahijan - Chaboksar coastal aquifer. The GALDIT index offers better results than groundwater vulnerability to the intrusion of seawater in the coastal aquifer, especially in the flat areas, which cannot be identified by SINTACS and AVI. The results of AVI indicate a larger area that is highly vulnerable compared to the SINTACS index, but both methods show the high vulnerability of groundwater in Lahijan - Chaboksar aquifer due to pollution from ground surface sources. In general, this aquifer has a higher vulnerability to pollution on the coasts and the near zones to the Caspian Sea, particularly in the northern parts of the study area. It is needed to special attention considered for aquifer control and protection. The AVI and SINTACS indices can be applied to assess the vulnerability of no coastal aquifers and, in combination with GALDIT, is a useful tool for assessing the vulnerability of groundwater against any pollution at ground surface sources and the intrusion of seawater into the groundwater of coastal aquifers.

Keywords: AVI, GALDIT, Lahijan-Chaboksar coastal aquifer, Seawater intrusion, SINTACS, Vulnerability.

Introduction

In many countries, there is a large population in coastal areas which have become major commercial, economic and tourist centers. Groundwater contamination in coastal aquifers is much more complex and crucial compared to other aquifers. Inappropriate application of these aquifers will lead to seawater intrusion from the sea into the coastal groundwater reservoirs. Seawater intrusion in coastal aquifers is one of the most serious issues regarding sustainable water management that threatens the quality of coastal groundwater, particularly, in case the water over-exploitation due to population growth and industrial and agricultural demands (Ataie Ashtiani et al., 2013). It is evident that preventing groundwater resources from pollution is more convenient than water pollution removal. This matter has led to the advent of several conservation methods and operational management procedures that can be applied to identify areas susceptible to aquifer pollution. Vulnerability investigation of aquifers to pollution is one of these methods for protecting and conserving groundwater aquifers (Ketabchi and Ataie-Ashtiani, 2015).

There are many techniques to assess the vulnerability of water resources, which can be categorized into three groups of index methods, statistical methods, and process methods. Statistical methods comprise a wide range of practices from simple or descriptive statistics to complex analyses of pollutant concentrations. The process approaches refer to methods that either simulate or take into account the physical processes of water movements and also contaminant transport in the environment. These approaches typically involve the use of process simulation models that compute the distribution of vulnerabilities based on water motions and solutions. Index methods directly assign digits for quantifying physical processes, which can be put into several vulnerability groups (Ribeiro et al., 2017).

The possibility of pollutant movement underground reaching groundwater resources is conducted through an examination of groundwater vulnerability. Several studies have been conducted to assess the vulnerability of groundwater using GIS and these methods so far. Groundwater vulnerability models incorporate similar parameters that are utilized with various data. There are several methods to assess the vulnerability of groundwater resources including GALDIT, SINTACS, GOD, and AVI.

In recent years, the increase in human activities, such as agriculture and the use of chemical and animal fertilizers, as well as the development of various industries has caused groundwater resources to be endangered by contaminants produced by these activities. In this research, GALDIT, SINTACS, and AVI methods are employed in GIS software to investigate the vulnerability of the Lahijan-Chaboksar aquifer. Considering that the aforementioned aquifer has not been investigated for potential pollution yet, the identification of areas with a high potential for pollution in the region can be useful in water resources management and also in producing vulnerability maps. The main objective of this research is to identify areas with high pollution potential in order to manage groundwater resources effectively in the case study under a comparative study scheme. The aquifer is recharged by many rivers in this area.

Materials and Methods

The study area

The study area of Lahijan-Chaboksar is located in the east of Guilan province Iran as illustrated in Figure 1. This region with 854.77 square kilometres is restricted to a plain area. The highest altitude is 183 meters above sea level whereas the lowest altitude is -26 meters at the outlet of the basin. It is worth noting that the study area of Lahijan-Chaboksar extends from the north to the Caspian Sea, from the south to Taleghan-Alamut, from the east to Ramsar-Chalus and from the west to Astaneh-Kuchesfahan. In the Plain of Lahijan-Chaboksar, an alluvial aquifer with an area of 847.34 km^2 has occupied 99.13% of the plain. The average temperature during the 45-year period is 11.5 °C at high altitudes and in the plain is 16.4 °C. Moreover, the annual precipitation is 774.6 mm at high altitudes whereas 1329.8 mm in the plain.

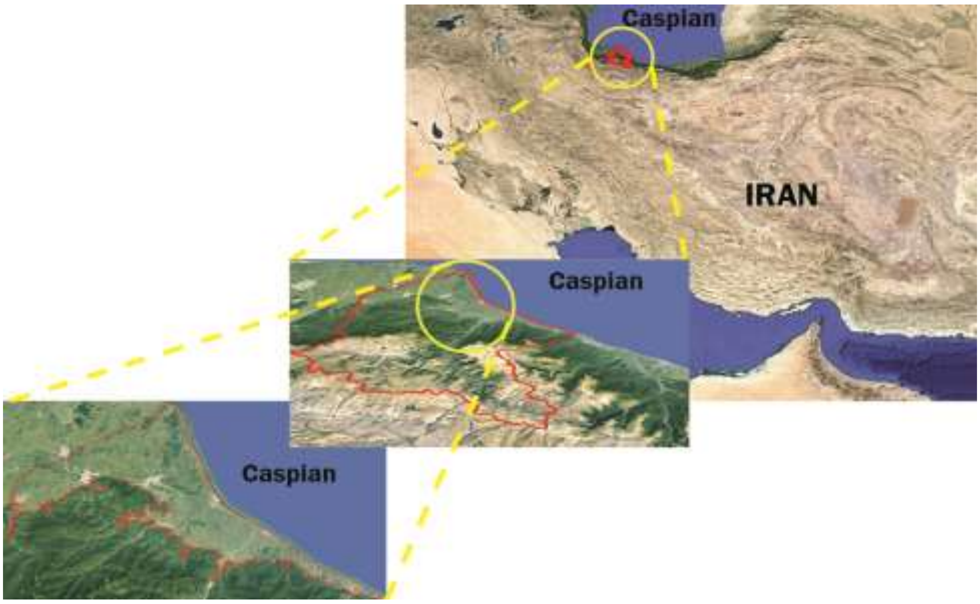

Figure 1: The study area of Lahijan-Chaboksar, Guilan province, Iran

Vulnerability assessment methods

GALDIT, SINTACS, and AVI methods are employed in GIS software to cover the vulnerability assessment objectives in this study. SINTACS has more options for the weight string based on the different environmental settings of the aquifer. SINTACS provides weight strings including those factors associated with human activities. The AVI is simpler than SINTACS, with only two parameters required for the analysis, and it was selected in order to compare with SINTACS to evaluate the effect of the number of parameters inputted on the vulnerability indices. However, neither SINTACS nor the

AVI has parameters to determine contamination from seawater intrusion while GALDIT is suitable for vulnerability assessment of seawater intrusion into the coastal aquifer and compared with SINTACS and the AVI. The SINTACS and GALDIT methods are based on the index weight rating and overlay analytical function using the Arc GIS program, while the AVI method is based on the type and thickness of the aquifer media above the groundwater level.

Results and Discussion

All the parameter layers were superposed in the GIS environment and weights are assigned to each layer to produce the GALDIT, SINTACS, and AVI vulnerability maps. Once indices have been computed, it is possible to identify areas more likely to be susceptible to seawater intrusion. The higher the index, the greater the vulnerability to seawater intrusion. Figure 2 illustrates the spatial distribution of the mentioned indices in the study area

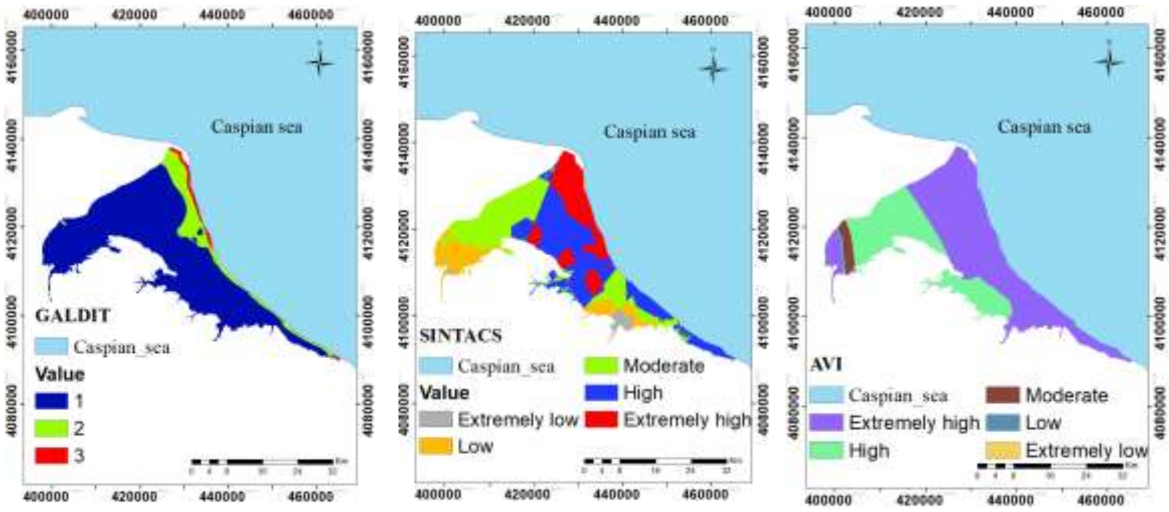

Figure 2: GALDIT vulnerability indices maps of Lahijan-Chaboksar aquifer based on GALDIT, SINTACS, and AVI methods.

Conclusions

The main objective of this study is to use the GIS in implementing the GALDIT, SINTACS, and AVI methods in the Lahijan-Chaboksar coastal aquifer. In this regard, these indices were applied to determine the vulnerability of the study area. After achieving the needed layers in the GIS software environment, the maps were provided. The results reveal that the parts of the aquifer having a high vulnerability index are located in the low-lying areas consisting of permeable sediments, where the groundwater level is close to the soil surface and rapidly responds to changes in groundwater recharge. The results from the GALDIT method provide a better insight into groundwater vulnerability to seawater intrusion of the coastal aquifer, particularly in areas having a low hydraulic gradient, which cannot be identified by the AVI or SINTACS from anthropogenic sources on the ground surface. In summary, vulnerability maps can be useful and effective in decision-making, planning, management and conservation of groundwater quality in coastal aquifers. According to the results obtained from the Lahijan-Chaboksar coastal aquifer, appropriate management measures seem to be required in order to minimize the seawater intrusion effect.

Removal of cyanide from aqueous solutions using natural zeolite modified with cationic surfactant

Document Type: Research Paper

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Abstract

Cyanide is one of the most important and harmful pollutants released to the environment and as a result of industrial activities, aquatic environments are the most important route for exposure of living organisms to this pollutant. This research aimed to study the adsorption of cyanide by raw zeolite and modified zeolite with surfactant. Using the cationic surfactant of hexadecyltrimethylammonium bromide, the raw zeolite was modified. After the determination of prepared adsorbent properties and isothermal experiments, kinetics, the effect of pH, and the ionic strength of the stock solution was measured by batch tests. The XRD results confirmed the presence of clinoptilolite mineral in the structure of the raw zeolite and the surface coating of raw zeolite by surfactant after modification was observed by SEM images. The Langmuir, Freundlich and, Tamkin adsorption models showed an excellent ability to describe the cyanide adsorption isotherm using the studied adsorbent. The adsorption capacity of cyanide by modified zeolite was 3.97 mg /g, which is significantly increasing compared to the maximum adsorption capacity of raw zeolite cyanide (0.54 mg /g). Modelling of kinetic data showed that pseudo first-order and pseudo second-order models have an excellent ability to describe the adsorption kinetics of cyanide contaminants using natural and modified zeolites. Cyanide removal by surfactant-modified zeolite decreased with increasing pH and ionic strength of the stock solution. The results of this study showed that the modification of zeolite with surfactant could be used as a non-toxic and efficient adsorbent to remove cyanide from aqueous solutions in the bed of the tailings dams of the Zareshoran mine processing plant in Takab city of West Azerbaijan province of Iran.

Keywords: Adsorption, Cyanide, Gold mine, Isotherm and kinetics of adsorption, Modified natural zeolite, Surfactant.

Introduction

Cyanide is a toxic pollutant is widely released into the environment from industrial wastewater such as metal plating, drugs, food industry (Ghasemi and Rouhani, 2019). Cyanide has adverse effects on the health of humans and other living organisms, so exposure to small amounts of cyanide can be fatal. Water-soluble cyanide exists in two forms, free cyanide and cyanide complex (Han, 2005). Hydrogen cyanide is the most toxic type of cyanide, which is very important from an environmental perspective (Logsdon et al., 1999).

Among the methods of removing cyanide from aqueous media are oxidation, adsorption, ion exchange, and reverse osmosis, which in the oxidation method using an oxidant ion convert cyanide into low-risk compounds such as cyanate (Jaskak et al., 2017). Economic and environmental considerations such as low cost and non-production of toxic residues are the most essential factors in choosing a method to remove cyanide from the solution. While most of these methods are costly, the adsorption method is considered an efficient method in terms of economy, low waste production, ease to use, and usable for aqueous solutions containing medium or low concentrations of pollutants and must be removed quickly. Low price, high abundance, and high absorption capacity are the characteristics of a suitable adsorbent. Various adsorbents such as activated carbon, activated carbon modified with iron, copper, nickel and silver, snail shell, titanium dioxide, and pyrolite have been used to adsorb cyanide from aqueous solutions (Ghasemi and Rouhani, 2019).

Zeolites are crystalline compounds with a porous structure with very fine, orderly, and open pores consisting of a tetrahedral network of SiO_4 and AlO_4 (Norouzi et al., 2018). Zeolites are generally divided into natural and synthetic (synthesizable in the laboratory), which today almost all of the natural species can be prepared in synthetic form (Burke, 1964). Applications of zeolite include adsorbent and catalyst in industry and research (Torabian et al., 2010). Clinoptilolite zeolite is a natural species of zeolite whose natural mines exist in Iran (Ashrafizadeh et al., 2008). Zeolites as an adsorbent usually contain a negative charge and are therefore less inclined to adsorb anionic species and are usually cation exchangers. Most adsorbents used to remove pollution from aqueous media have an acceptable capacity for cationic contaminants, and the anionic property of cyanide in solution is the most critical barrier to the use of various materials with high adsorption capacity to eliminate cyanide toxicity.

In general, zeolites contain a negative surface charge and, unlike cations, do not show much tendency to adsorb anions. One way to increase the adsorption capacity of anions by zeolite is to change their surface chemistry using different materials. Cationic surfactants are positively charged and have an excellent ability to absorb anionic contaminants. One of the common types of surfactants to modify the surface of various materials is hexadecyltrimethylammonium bromide (Norouzi et al., 2018).

Because zeolites do not have the same adsorption behaviour due to different origins and impurities in different places and due to the abundance of enormous zeolite mines in our country and the high capacity of clinoptilolite ion exchange, and also because not many studies have been reported to study cyanide adsorption by zeolite, Therefore, in this study, the efficiency of natural zeolite in West Azerbaijan province and natural zeolite modified with hexadecyltrimethylammonium bromide to absorb cyanide from aqueous solutions from the tailings of Zarshoran Takab gold mine processing plant were investigated.

Materials and Methods

Preparation of Adsorbents

In this study, natural zeolite was prepared from the Pozolan mine of Qizkorpi Shahindej, and after crushing, it was passed through a 0.5-millimetre sieve. To prepare the modified zeolite, 4 g of crude zeolite was mixed with 0.7289 g of hexadecyl trimethyl ammonium bromide and stirred for 24 hours at 21 ° C at 100 rpm. The prepared mixture was dried in an oven at 70 ° C for 24 hours in the last step. The adsorbents were passed through a 0.5 mm sieve and stored in plastic containers for testing modular.

Determination of adsorbent properties

Determination of the mineralogical composition of zeolite prepared by X-ray diffraction (XRD) and X-ray fluorescence (XRF) was used to determine the constituent elements of natural zeolite. to study the surface morphology of natural and modified zeolites, scanning electron microscopy (SEM) and Energy Dispersive Atomic X-ray(EDAX) were used.

adsorption isotherm

to prepare all the cyanide-containing solutions required for the experiment from the 1000 mg / L cyanide solution prepared from sodium cyanide salt. For isothermal experiments, 40 ml of solutions with an initial cyanide concentration of 1 to 35 mg/L, initial pH of 7, and ionic strength of 0.01 mol/L were added to 30 mg of natural and modified zeolite adsorbents in 50 ml test tubes. The ionic strength of the solution used was generated by the sodium chloride salt. The samples were stirred for 24 hours at room temperature (21 ° C) at 100 rpm, and after 5 minutes, the supernatant was centrifuged and separated by filter paper.

The data obtained from the adsorption isotherm experiment were fitted to three absorption models of Langmuir, Freundlich, and Tamkin.

Adsorption kinetics

For adsorption kinetics experiments, 40 ml of cyanide solution at a concentration of 20 mg / l sodium 0.01 M sodium chloride base solution and pH 7 to 0.03 g of modified zeolite was added to 50 ml test tubes. The test tubes were quenched at 5, 15, 30, 60, 120, 180, 240, 480, and 960 minutes at room temperature (21 ° C), and after 5 minutes, the supernatant was centrifuged and separated by filter paper.

Kinetic data were fitted to pseudo first-order and pseudo second-order kinetic models.

Effect of pH on cyanide adsorption

To investigate the effect of pH on the studied adsorbents, 40 ml of cyanide solution with a concentration of 20 mg / l of 0.01 M sodium chloride base solution with pHs of 7, 8, 9, and 10 to 30 mg of modified zeolite 50 ml was added to the test tubes. Adjustment pH was performed using NaOH and HCl as normal. The test tubes were shaken at room temperature (21 ° C) for 24 h, and after 5 minutes, the supernatant was centrifuged and separated by filter paper.

Effect of ionic strength on cyanide adsorption

To investigate the effect of ionic strength on cyanide adsorption, 40 ml of cyanide solution at a concentration of 20 mg/l with a pH of 7 at 0.01, 0.05, 0.1, and 0.15 M ion of the base solution created with sodium chloride to 30 mg of modified zeolite was added to 50 ml test tubes. The test tubes were shaken at room temperature (21 ° C) for 24 h, and after 5 minutes, the supernatant was centrifuged and separated by filter paper. The concentration of cyanide in the solution was determined by titration method using silver nitrate solution in the presence of a potassium iodide detector. Graphs were drawn using the software Excel. Nonlinear fitting of isothermal and kinetic models was performed using the software Solver, and the coefficient of determination (R^2) and standard error (SE) were calculated for each of the models.

Results and discussion

morphology and adsorbent properties

to identify the adsorbent properties used, XRF and XRD experiments were performed. The pattern obtained from the natural zeolite sample is following the zeolite pattern of the clinoptilolite type.

The type and percentage of oxides in the natural zeolite sample were determined by XRF analysis, which showed SiO_2 with 70.46 and Al2O3 with 13.74 %, containing more than 83% of the components of zeolite.

Cyanide adsorption isotherm

Based on the results of Freundlich, Langmuir and, Tamkin adsorption isotherms in both natural and modified zeolite samples intensity of the absorption process decreased with increasing equilibrium cyanide concentration, this may be due to the reduction of adsorption sites for cyanide on the adsorbent surface. The intensity of the cyanide adsorption process on modified zeolite is higher than on natural zeolite (3.97 mg/g and 0.54 mg/g, respectively). Because in the modified sample, there is a possibility of a cyanide reaction with active surfactant groups adsorbed on zeolite, but in the natural sample, cyanide is more in the pores. The parameters of the adsorption equations, which describe the adsorption behaviour of cyanide on the adsorbents, were significantly increased in the modified zeolite, which indicates an increase in the intensity and capacity of the adsorption.

Adsorption kinetics

The cyanide adsorption kinetics on natural and modified zeolites did not differ much between the pseudo first- and second-order models, and the values are obtained from the experiment and calculated were slightly different. Modified zeolite had a higher adsorption capacity and reaction rate than natural zeolite. In this regard, it can be said that in natural zeolite, perhaps only the outer surface of the adsorbent is used as adsorption site. However, about the modified zeolite, in addition to the outer surface, the internal parts of the adsorbent also participated in the adsorption, so the adsorption capacity of cyanide increased with the modified zeolite. On the other hand, due to the physical nature of absorption, the absorption rate also increases.

The effect of pH

The pH of the solution is one of the most important factors controlling the ion adsorption process on the adsorbent surface, which affects the properties of the contaminant, adsorption mechanism, and polarity of the adsorbent surface charge. At low pHs, cyanide ions are released as HCN gaseous, so experiments were performed at high pHs. With increasing pH, the absorption of cyanide decreased and at pH equal to 10 reached its lowest amount (2.43 mg/g).

The effect of ionic strength

Increasing the ionic strength of the stock solution reduces the thickness of the electrical double layer and consequently reduces the formation of extracorporeal complexes. The change in ionic strength has little effect on the formation of intracorporeal complexes or ions that are specifically adsorbed. By increasing the ionic strength of the solution from 0.01 to 0.15 mol / L sodium chloride, the adsorption of cyanide by modified zeolite decreases from 3.57 mg/g to 1.7 mg/g.

Conclusion

Based on the results of this study, surfactant-modified zeolite can be used as an adsorbent to adsorb cyanide. Cyanide removal decreased with increasing pH due to the negative charge of the modified zeolite surface. The Langmuir, Freundlich, and Tamkin adsorption models showed an acceptable ability to characterize the cyanide adsorption isotherm using raw and surfactant-modified zeolite (the Freundlich model was most consistent with experimental data). The adsorption capacity of cyanide by modified zeolite was 3.97 mg/g, which is significantly increasing compared to the maximum adsorption capacity of crude zeolite cyanide (0.54 mg/g). The adsorption kinetics results showed that pseudo first-order and pseudo second-order models have an excellent ability to describe the adsorption kinetics of cyanide contaminants using natural and modified zeolites. Increasing the concentration of electrolytes in the field has a negative effect on the adsorption of cyanide by modified zeolite. In general, the results showed that surfactant-modified zeolite could be used as a non-toxic and effective adsorbent on a laboratory scale and in the bed of Zareshoran gold mine tailings dams due to economic and environmental considerations in removing cyanide from aqueous media.

Investigation of uncertainty due to model complexity in groundwater modeling

Document Type: Research Paper

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Abstract

One of the factors that lead to uncertainty in the mathematical model of groundwater flow is the uncertainty due to the complexity of the conceptual model that results from the increase of model parameters. Considering the complexity of groundwater modeling can aid in selecting an optimal model, and can avoid model uncertainty and misleading conclusions. The purpose of this study is to investigate the uncertainty of the complexity of the mathematical model of the Najafabad aquifer. In this regard, six conceptual models with five different degrees of complexity with the number of calibrated model parameters (4, 16, 20, 22, 26, and 26 parameters) with the same observational data in Najafabad aquifer located in Isfahan province in a steady-state and for the year 2018-2019 were developed and model selection criteria (AIC, AIC_C, BIC, and KIC) were used to evaluate the probability of models. The results showed that model #1 with four parameters, which is the simplest model, was selected as the best model and has the least uncertainty. But models 5 and 6, which are the most complex models, have the most uncertainty and the least level of confidence. Therefore, it can be said that in defining the conceptual model of an aquifer, determining the optimal number of parameters will decrease the uncertainty of the mathematical model.

Keywords: Model selection criteria, Najafabad aquifer, Probability of Model, Uncertainty of complexity.

Introduction

Increasing the model parameters is one of the factors of model complexity that leads to uncertainty in the model (Hill and Tiedman, 2007). In preparing alternative conceptual models, it is better to prepare a simple model at first and then create complex models. The advantage of this practice is a better understanding of the available data and finally the creation of a complex model (Schwartz et al., 2017). Kullback-Leibler (K-L) information is the basis of model selection theory. When the information criterion is used to select models, any conceptual model can represent the actual groundwater system (Refsgaard et al, 2006). There are a number of model selection criteria for estimating the K-L value. These include the Akaike Information Criteria (Akaike 1974), the Akaike Information Corrected criterion (Hurvich and Tsai 1989), the Bayesian Information Criteria (Rissanen 1978; Schwarz 1978), and the Kashyap Information Criteria (Kashyap, 1982). The purpose of this study is to investigate the uncertainties due to the complexity of the groundwater flow model using the root mean square error methods and model selection criteria. To determine the uncertainty resulting from the complexity of the model in the aquifer of Najafabad, alternative models with different parameters have been created. Six alternative conceptual models with different degrees of complexity are considered. In preparing these conceptual models, first, the simplest model or model number 1 with four parameters is defined. The rest of the models have gradually increased in degree of complexity with an increasing number of parameters.

Materials and Methods

Case Study

The Najafabad study area is located in the central part of the Gavkhouni catchment and in Isfahan province. Catching water from the river is done through the network. Also, the average annual rainfall in the highlands and in the plains is 195 and 153.7 mm, respectively (Malmir et al, 2021).

Development of alternative conceptual models with different complexities

To determine the uncertainty resulting from the complexity of the model in the Najafabad aquifer, alternative models with different numbers of parameters were created. There are several ways to find a model with a good fit and a number of optimal parameters (Hill and Tiedemen, 2007). In creating these conceptual models, first, the simplest model or model number 1 with four parameters was prepared. The rest of the models gradually increased in degree of complexity with the increasing number of parameters. So model #2 with sixteen parameters, model #3 with twenty parameters, model #4 with twenty-two parameters, and models #5 and #6 each with twenty-six parameters were prepared. In this research, the model selection criteria method has been used to determine the best model to avoid model complexity. Table 1 shows the specifications of the six models.

Table 1- Characteristics of six alternative concept models

Model number	1	2	3	4	5	6
Hydraulic conductivity	Interpolation (1Parameter)	Interpolation (1Parameter)	Interpolation (1Parameter)	Zoning out (7 Parameters)	Zoning out (7 Parameters)	Zoning out (7 Parameters)
Recharge	Zoning out (3 Parameters)	Zoning out (15 Parameters)	Zoning out (1Parameters)	Zoning out (15Parameters)	Zoning out (15Parameters)	Zoning out (15Parameters)
River	Well	Well	Recharge Package (4 Parameters)	Well	Recharge Package (4 Parameters)	Zoning out (4 Parameters)
General Head Boundaries	GHB	GHB	GHB	GHB	GHB	The Well Package is defined as the output boundary

Results and Discussion

Implement alternative conceptual models

Model calibration

Using steady-state calibration, water level conditions were created for the year 2018-2019 (Table 2).

Table 2- Results of calibration and validation of conceptual models

Models	1	2	3	4	5	6
RMSE	0.718	0.757	0.777	0.815	0.943	0.83
Model Ranking	1	2	3	4	6	5

Model balance results

After preparing and correcting the hydrogeological parameters by the model and implementing the model, the final balance of Najafabad plain for the year 2018-2019 in a steady-state has been calculated and the results are presented in Table 3.

Table 3 - Computational balance results for conceptual models in stable conditions

	Parameters	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Input	WELLS	99560	102900	0	98400	0	0
	GHB	365990.4	365924.5	363391.4	368816.5	366080.4	389064.7
	RECHARGE	1119976	1123745	1223934	1126500	1220181	1220519
	Total IN	1585526.4	1592569.5	1587325	1593717	1586261	1609584
Output	WELLS	1430242	1436711	1429561	1430643	1429561	1453243
	GHB	155507.2	156088.6	157995.6	163323.9	157010.5	156710.5
	Total OUT	1585749.2	1592799.6	1587557	1593967	1586572	1609954
	IN-OUT	-222.8	-230.1	-231.2	-250.4	-310.1	-369.8

Investigate model complexity using selection criteria

The posterior probability of alternative conceptual models has been examined through selection criteria and the results are shown in Tables 4-6.

Table 4 - Ranking of conceptual models using the AIC method

Models	P-Model 1	P-Model 2	P-Model 3	P-Model 4	P-Model 5	P-Model 6
AIC	41.21	58.48	0.2951	0.0064	6.20E-07	7.35E-05
Ranking	2	1	3	4	5	6

Table 5 - Ranking of conceptual models based on AICC and BIC

Models	P-Model 1	P-Model 2	P-Model 3	P-Model 4	P-Model 5	P-Model 6
AICC	99.99	2.1E-06	1.2E-15	6.07E-23	5.04E-48	5.98E-46
Ranking	1	2	3	4	6	5
BIC	99.99	3.8E-06	8.2E-10	3.6E-12	1.4E-17	1.7E-15
Ranking	1	2	3	4	6	5

Table 6 - Ranking of conceptual models based on KIC

Models	P-Model 1	P-Model 2	P-Model 3	P-Model 4	P-Model 5	P-Model 6
KIC	100	1.7E-23	7.3E-26	5.9E-26	2.7E-28	9.3E-29
Ranking	1	2	3	4	5	6

Conclusions

Comparing the results of four criteria (BIC, AICC, AIC and KIC), it can be said that a simple model with fewer parameters is suitable for investigating the groundwater flow behavior of the Najafabad aquifer. However, models 5 and 6, which have the highest number of parameters, lead to high uncertainty. Therefore, if the process of model complexity is not considered and the number of parameters is increased, uncertainty due to the resulting complexity leads to incorrect management results and decisions. According to the different probabilities calculated between alternative conceptual models, trusting a conceptual model in the groundwater modeling process leads to inaccurate results. Therefore, it is suggested that in modeling studies in different aquifers, the uncertainty of the conceptual model be considered by defining alternative models and calculating the probabilities related to it.

Groundwater Recharge Estimating in Mashhad-Chenaran Aquifer using water table fluctuations method (MRC algorithm)

Document Type: Research Paper

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Abstract

Mashhad-Chenaran Aquifer with an area of about 2527 km2, as the most sustainable resource supplying the drinking water of Mashhad city, is the most important alluvial aquifer in Khorasan Razavi Province. In this study, groundwater recharge has been estimated using the water table fluctuations method and MRC algorithm in a period of 15 years (Sep. 2001 to Sep. 2016) measured in 31 observation wells. Results suggested that recharge in Mashhad-Chenaran Aquifer follows a certain pattern depending on rainfall fluctuations. Seasonal rainfall starts at the end of October and reaches its maximum in April. The trend of increasing groundwater recharge continues until the end of March, and then, with the beginning of the spring season, the amount of recharge is significantly reduced. The most important reason for the decrease in recharge rate during this period is the lag time between the beginning of rainfall and its impact on the groundwater. The highest amount of recharge takes place in January, February and March and the lowest in August and September. During the 15-year period, the lowest and the highest amounts of recharge were 87.2 MCM (12.4% of rainfall) and 221.7 MCM (29% of rainfall) respectively in the 2002-2003 and 2011-2012 water years. During this period, the average annual recharge is about 122 MCM (19% of rainfall). Recharge events less than 5 MCM have the highest frequency and high amounts also have the lowest frequency. Assessing the ratio of recharge to precipitation indicates the correct estimation of recharge by the water level fluctuations method and MRC algorithm.

Keywords: Groundwater Recharge, Mashhad-Chenaran aquifer, Water Table Fluctuation (WTF), MRC Algorithm.

Introduction

Estimation of groundwater recharge and discharge and changes in groundwater storage in an aquifer is the first step in water resource management. Unlike discharge parameters, which are more directly measurable, estimating groundwater recharge is faced with certain problems and complications. In unconfined aquifers, various factors such as infiltration and percolation, runoff and agricultural return flow, infiltration from disposal wells and groundwater exploitation through production wells, springs and qanats cause the fluctuation in the water table. Among the factors mentioned, recharge through runoff flow is of special importance due to its natural form and also its huge impact on annual changes in aquifer storage.

The water table fluctuations method, which is a physical method in the saturation zone is the most common method for estimating groundwater recharge in unconfined aquifers (Crosbie et al. 2005; Healey And Cook, 2002; Sophocleous, 1991). According to Scanlon et al. (2002) although there are several methods that can be used to estimate recharge, choosing the appropriate method for this prupose is a difficult and a rather composition process. They believe that the temporal and spatial scales; the range and certainty of recharge; easy estimation and availability of computer codes are the most important points in choosing a proper method for estimating recharge.

Despite the numerous studies and implementation of many development projects in the Mashhad-Chenaran Aquifer, due to complex geological and hydrogeological conditions and the different and sometimes incompatible hydraulic patterns, no acceptable estimate of aquifer flux parameters has been provided yet. In this research, taking into account the above-mentioned conditions, an attempt has been made to estimate the vertical recharge into the aquifer, which is mostly due to rainfall on the plain, using the water level fluctuations method.

Materials and methods

Geography and Geology

Mashhad-Chenaran watershed, which is part of a Quaraqum basin with an area of about 9957 km2, lies between 58° 22´ E and 60° 7´ E longitudes and 37° 2´ N and 59° 35´ N latitudes. Mashhad – Chenaran Aquifer, the most important alluvial aquifer in terms of extent and utilization, is located in this area.

From the geological point of view, Mashhad – Chenaran plain is a pull-apart basin stretching northwest-southeast, which lies between the Binalood mountains in the west and southwest and the Hezar Masjed mountain range in the north and northeast. Most of the study area's surface is covered by sediments and formations of the second geological Era (Jurassic and Cretaceous). Alluvial fans and young alluvial sediments cover almost the entire central part of the plain. These sediments are of the coarse size and of high permeability at the margins of the heights and form the main reservoir of the Mashhad-Chenaran aquifer.

Hydrogeology

Mashhad alluvial aquifer covering an area of 81,000 km2 is an unconfined aquifer. The bedrock is mainly made of Neogene sediments in the southeast and southwest parts of the aquifer up to Cheneran city, limestone (Shoorijeh and Tirgan formations) in the North and igneous-metamorphic rocks in the southern band of the plain. The average specific yield is 6% and the transferability varies from 200 to 3000 m2/day in the alluviums in the vicinity of the southwestern highlands to 3000 m2/day in the center of the plain. The groundwater depth decreases from the southern highlands to the northern highlands. This main trend follows the changes in the depth of the bedrock. In addition to the topographic slope, the groundwater flow direction is controlled by the geology and morphology of the bedrock.

Methodology

In the water table fluctuations method, the rise in groundwater level is used to estimate recharge (Hepner and Nimo, 2005). In this method, the amount of recharge is estimated by multiplying the rise or fall in the water table by the specific yield. In order to estimate the recharge by water table fluctuations method a number of assumptions are used. The most important of these assumptions are: 1) the observed water table fluctuations are due to natural recharge and discharge; 2) The specific yield is constant during the recharge period; 3) The falling limb of the hydrograph, which indicates the pre-recharge period can be calculated by extrapolation method as long as the ΔH (tj) is estimated; 4) There is no recharge from the adjacent aquifers. According to these assumptions, the water table rise (ΔH (tj)) should be measured relative to the level at which no recharge has taken place. Thus, ΔH (tj) is calculated by subtracting the minimum and the maximum water table amounts during the recharge period. The lowest groundwater table level during the recharge is estimated by extrapolating the hydrograph falling limb and plotting the surface at which no recharge has taken place. Various methods such as the graphical method, master recession curve method (MRC) and computer code RISE are used for extrapolation. In this study, the MRC method presented by Hepner and Nimo (2005) was used. In this algorithm, the rate of groundwater depletion relative to the groundwater table is plotted on the hydrograph falling limb.

Results and discussion

Groundwater level in the observation wells

Currently, there are 74 active piezometric wells at which the groundwater level is measured monthly. According to the annual mean values of groundwater depletion and considering the well depth, aquifer type and behavior, those wells with less than 0.5 meters decline per year and those showing water level rise, are not suitable for estimating annual recharge in the aquifer. Accordingly, 31 wells were selected in order to estimate the recharge.

Aquifer specific yield

In this research, the specific yield has been used from previous studies. Based on the water balance and consumption studies and the mathematical model of the Mashhad-Chenaran plain, the average specific yield is 6%.

Estimation of rainfall at the observation wells.

To estimate rainfall at the location of observation wells, the daily rainfall data from rain and evaporation stations in the Mashhad - Chenaran and surrounding study areas (25 rainfall stations and 9 Evaporation stations) has been used.

Estimation of the recharge

To estimate the recharge in the Mashhad-Chenaran aquifer, groundwater level data and aquifer storage coefficient at the location of each well have been used. After drawing the monthly hydrograph for the index observation wells, the master recession curves were extracted based on the hydrographs' falling limbs data during a 15-year statistical period. Then, the recharge elevation values were estimated by multiplying the monthly ΔH values by the specific yield. The aquifer recharge value was estimated using a weighted average of monthly recharge and Theisen area.

Based on the monthly changes in the recharge volume and rainfall in the Mashhad-Chenaran aquifer in a 15-year period (2001-2005), seasonal rainfall in the Mashhad-Chenaran plain begins in late October and reaches its maximum in April. At the end of the wet season, the seasonal rainfall gradually decreases and reaches its minimum in August and September. The recharge also follows the rainfall pattern and is a function of the rainfall amount and intensity and the amount of aquifer utilization as well. As the seasonal rainfall increases, the aquifer recharge rate is higher. This increasing trend continues until the end of March and then, with the beginning of spring, the amount of recharge decreases significantly. The most important reasons for the recharge decrease in spring, despite the occurrence of good rainfall, are the beginning of extraction from the aquifer, showery rainfall and the existence of a lag time between the occurrence of rainfall and groundwater response. In the spring, when most of the rainfall is in the form of showers, there is a higher percentage of runoff and so, less water infiltrates into the ground. In addition, there is always a lag time between the beginning of rainfall and its impact on the groundwater. With regard to the cross-correlation between rainfall as the independent variable and the groundwater level as the dependent variable and depending on the rainfall amount, this time interval is about 3 to 5 months on average. The highest amount of recharge during the statistical period occurs in January, February and March and the lowest in August and September.

According to the spatial distribution of recharge, the changes are a function of the hydraulic and hydrogeological characteristics of the unsaturated zone, the groundwater depth, the amount and intensity of rainfall and other unknown factors. Most of the recharge occurs in alluvial fans and aquifer inlets, which contain coarse-grained, high-permeability materials. The depth to the water table is also another parameter affecting the spatial changes in the recharge. In the areas where the unsaturated zone is composed of uniform sediments and the depth of groundwater is shallow, there is a greater rate of recharge. The other factors that play a very limiting role in the groundwater recharge process are the soil surface cover and the geological column of the region. In the presence of clay and silty layers in the unsaturated zone, the recharge rate is controlled by these factors and drastically reduced.

In order to validate the estimations, the recharge to precipitation ratio has been used. In the 2007-2008 water year, despite the dramatic decrease in rainfall, the amount of recharge seems to be estimated as very high. This anomaly is due to the extraction control applied by the installation of counters for the first time on agricultural wells in Mashhad plain and, as a result, the reduction in groundwater depletion. Eliminating this anomaly, the minimum and maximum amounts of recharge are 87.2 (12.4% of rainfall) in the 2002-2003 water year and 227.7 (29% of rainfall) in the 2012-2013 water year, respectively. The annual average recharge in the Mashhad-Chenaran aquifer is about 126 MCM.

Conclusion

Since there is always a relationship between the groundwater table drop and the amount of recharge, and MRC is a function of the physical, hydraulic and hydrogeological characteristics of the aquifer, it can be used to predict the groundwater table behavior in non-recharge periods. In this method, the recharge details can be depicted on a local scale. The accuracy of this method depends on the accuracy of the required data, including specific yield and water table data. The most important disadvantage of this method is the high correlation between the input parameters of the model and their non-uniqueness. This challenge will be significantly complicated when the recharge caused by rainfall and the irrigation return flow are intertwined and their separation is temporally and spatially impossible. The only possible solution is to correctly identify the rise of the groundwater table and its relation to the occurrence of precipitation. Generally, the groundwater recharge is mostly controlled by the unsaturated zone conditions (thickness, material, etc.) and a number of other factors such as land use and aquifer utilization. Therefore, it can be said that the changes in the groundwater depth are somehow the main factor causing a lag time between the occurrence of rainfall and the beginning of recharge in the aquifer. In this study, the amount of recharge in the Mashhad-Chenaran aquifer for a 15-year period was estimated using the water table fluctuations method and MRC algorithm. In this period, the lowest and the highest amounts of recharge occurred in the 2001-2002 (87.2 MCM (12.4% of rainfall)) and 2011-2012 (221.7 MCM (29% of rainfall)) water years, respectively. The average annual recharge is also 122 MCM (19% of rainfall). In the 2001-2002 water year, despite the occurrence of good rainfall, the recharge is the lowest value during the statistical period. This can be due to the effect of other parameters such as aquifer exploitation and the occurrence of showery rainfalls in the area, which can directly affect the water table fluctuations. In this condition, despite the good rainfall, the positive fluctuations of the water table, which are the basis of estimates in the MRC algorithm are neutralized by the negative fluctuations, which are due to the groundwater extraction, and in practice, the recharge is estimated less than its actual value.