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Simulation of mulch effect on soil moisture and salinity distribution using HYDRUS-2D and AquaCrop

Document Type: Research Paper

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Abstract

One of the main objectives of the agricultural sector in arid and semi-arid regions is to improve soil moisture conservation and water productivity. Evaporation from the soil surface is non-beneficial loss in irrigation. Mulching is one of the most important agricultural managements in maintaining soil moisture and improving the physical environment of the soil. The use of mulch outside the growing season prevents the salinity of the topsoil. The purpose of this study was to investigate the effect of plant mulch on solute transfer, soil moisture, temperature and salinity outside the growing season, using two laboratory lysimeters with a length of (1 m), a width of (0.5 m) and a height of (1 m) was investigated. During the 122-day simulation period, moisture and salinity values from 5 depths of soil profiles (50-40-30-20-10 cm) were measured. To compare the means of each treatment with each other, a t-test was used in two software models, HYDRUS-2D and AquaCrop. RMSE, MBE, MAE and R^2 statistical indexes were used to evaluate each model. The results show that the HYDRUS-2D model has a good ability to model moisture at depths of 10 to 40 cm, but for depths of 0 to 10 and 40 to 50 cm has not performed well in the simulation. Also, the results of the AquaCrop model show that this model does not have a good ability to model moisture at depths and the HYDRUS-2D model compared to the AquaCrop model has the ability to better estimate and more acceptable relative accuracy of moisture at depths of 10 to 40 cm for simulation of solute transportation.

Keywords: Control treatment, Groundwater, Modeling, Mulch, Salinity.

Introduction

Many arid and semi-arid regions of the world face severe water shortages due to the lack of rainfall and high evaporation rates. Lee et al. (2000). According to the Deputy Minister of Water Affairs, the average rainfall in Iran is about 400 billion cubic meters per year, of which 270 billion cubic meters are evapotranspiration and 130 billion cubic meters per year are used as renewable water (groundwater). To be placed. When at least part of the soil surface is uncovered, evaporation takes place directly from this surface. In the absence of vegetation, the soil surface is exposed to radiation and wind, and evaporation takes place completely from the soil surface. Evaporation of soil moisture, in addition to wasting water, will also increase the risk of soil salinization. This risk is more pronounced in arid areas with low annual rainfall, saline irrigation water, and high groundwater aquifers. Covering the surface with mulch or reflective material can reduce the intensity of the impact of external factors such as radiation and wind on the soil surface. Due to the fact that mulch has been of great importance in maintaining soil moisture and reducing evaporation from the soil surface. The aim of this study was to investigate the effect of plant mulch on solute transport, moisture and temperature in the soil in conditions where the water is saline and the water table is constant.

Materials and Methods

This research was performed in the hydraulic laboratory of the Department of Water Engineering, Faculty of Agriculture and Natural Resources, Imam Khomeini International University, Qazvin.

In this study, a laboratory lysimeter with a length of 2 m, a width of 0.5 m and a height of 1 m was used to simulate field conditions. The lysimeter was divided into two separate parts by walls from the middle. In one part, control treatment was applied and in the other part, wheat straw mulch and straw to a thickness of 1 to 2 cm were applied. In the treatment with mulch at five depths and in each depth at three points (15 holes in total) and in the control treatment in the same way (five depths at three points) and a total of 30 holes per lysimeter were created. These holes were made by drills with a diameter of 9 mm to pass the sensor of the moisture and salinity measuring device. Drainages were placed at a depth of 15 cm from the lysimeter floor and at a distance of 25 cm from each other. After installing the drains at a depth of 15 cm from the lysimeter floor, the area around them was covered with wind sand. The soil used was determined to determine the soil particle grain distribution curve, moisture content curve, soil texture and soil salinity. The water used for the experiment was a combination of municipal drinking water and regional drained water in Qazvin, which was used to feed the box after reaching a salinity of 10 ds / m. Water tanks were filled with salt water. After a few days, the desired static level was formed and humidity, salinity and temperature were measured by a delta sensor on specific days. The movement of water by the capillary force caused the static level to drop during the test period, so to place the static surface at the desired point, water was injected into the box manually on specific days to the power supply. During the 121-day period, samples were taken from all points where the sensor was located and extracted using a vacuum pump, and the amount of salinity was measured with an EC meter. The process was then simulated using two models HYDRUS-2D and AquaCrop.

HYDRUS-2D software

A popular Windows model for analyzing water flow, solute transfer and heat in two-dimensional conditions, and is able to estimate hydraulic properties and solute transfer by inverse modeling. This model is able to simulate saturated and unsaturated conditions in horizontal, vertical and radial modes. This model has been used in many field and laboratory studies to simulate the movement of water and salts in the soil, optimize and reverse estimate the hydraulic properties of the soil and the results have been somewhat satisfactory.

AquaCrop software

Using the AquaCrop software, it tries to balance three factors: accuracy, simplicity and power. Including the capabilities of the model, water shortage assessment and achievable crop in case of water shortage, comparison of the expected crop with actual crop in the field, evaluation of crop production in Faryab conditions, development of irrigation program to achieve more production under different climatic scenarios, low evaluation Excessive irrigation and irrigation, analysis of future climate scenarios, optimization of available water scarcity, evaluation of actual water efficiency on the farm and on a larger scale, support for water allocation decisions and other decisions Government is related to water.

Results and Discussion

According to the values of statistical indicators, the AquaCrop model did not have a good ability to model soil moisture. Considering that the Darcy equation is needed to study the upward motion of water by considering the soil moisture characteristic curve and the relationships between the matrix potential and the hydraulic conductivity of the soil, since these relationships are not available in the AquaCrop model and are exponential. And experimentally used for capillary ascent, Therefore, the cause of low accuracy in simulation can be considered as empirical relationship. according to the experimental equations of solute transfer in AquaCrop software, which are based on the equation of water and salt balance in the soil, the salinity model simulated low soil depths much more than experimental measurements and equal to the salinity of groundwater. Considering that the upward movement of solutes is due to the capillary ascent of saline groundwater in response to evaporation from the soil surface, and given that the simulation results of water movement in the model soil were not satisfactory, it cannot be expected to perform the model of simulation of solute transfer with high accuracy. The results showed that the salinity model estimates the soil surface as less than the actual value. Therefore, it should be noted that the simulation of solute transfer at the soil surface is related to how to simulate moisture in the software because the moisture values close to the soil surface are less than the actual values and show a constant value, so if the surface layer moisture Soil contains a low percentage during the model simulation period, the solute transfer does not take place properly. Finally, it can be concluded that AquaCrop software for simulating the movement of water and salts through the capillary force in the unsaturated region is not relatively accurate. In the continuation of moisture distribution data, control and control simulations were shown using the model.

The results showed that HYDRUS-2D had a good ability to model moisture at depths of 10 to 20, 20 to 30 and 30 to 40 cm but for depths of 0 to 10 cm and 40 to 50 cm there was a good agreement between the values of simulated moisture and There was no measure.

Table 1. Statistical indices of humidity of HYDRUS-2D model (control treatment)

Depth	R^2	RMSE	MAE
0-10	0.49	0.10	0.08
10-20	0.73	0.02	0.01
20-30	0.72	0.05	0.04
30-40	0.56	0.001	0.03
40-50	0.19	0.03	0.03

Table 2. Humidity statistical indices of 2D-HYDRUS model (mulch treatment)

Depth	R^2	RMSE	MAE
0-10	0.36	0.01	0.09
10-20	0.52	0.02	0.01
20-30	0.74	0.05	0.04
30-40	0.66	0.03	0.03
40-50	0.44	0.03	0.03

Conclusions

The results obtained in this study showed that the presence of mulch over a longer period of time clearly shows its major effect on soil surface moisture storage and reduced evaporation, and the longer the measurement period, the clearer the positive effect of mulch will be.

Simulations performed with software showed that the HYDRUS-2D model has a better ability to estimate soil moisture depths of 10 to 40 cm compared to the AquaCrop model. And did not have acceptable estimates for other depths. In contrast, the AquaCrop model was not a suitable model with a groundwater boundary condition and conditions similar to this experiment. Due to the AquaCrop model moisture estimation and the relationship between solute mobility and moisture, the software estimated the salinity of the soil surface to be much lower than the actual value. Compared to the AquaCrop model, the HYDRUS-2D model had acceptable relative accuracy for simulating solute transport. Comparison of the salinity values of the depths of both mulch and control treatments, both by measurements and by simulation with both software, showed that more accumulation of salts occurs on the surface without coating. In general, the results of this study showed that the use of organic mulch has increased water productivity in the region by maintaining and storing moisture and also modulating the temperature in the soil profile.

Assessment of quality and quantity of Baghmalek aquifer using Statistical analysis hydrochemical method and GIS

Document Type: Case study paper

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Abstract

A large number of aquifers in different parts of the country are suffering from the deduction of storage. This occurrence is due to the proliferation demand for water, the exploitation of wells' increase, the reduction in precipitation and inappropriate spatial and temporal rainfall distribution. The alluvial Baghmalek aquifer with 49.93 km^2 is one of the promising groundwater storages in Khuzestan, which supplies water for agriculture as well as other activities in the area. In this study quantity and quality aspects of the Baghmalek aquifer were assessed for a period of ten years (1386 – 1396), using statistics and geostatistics methods. To assess rainfall amount changes and their effect on groundwater within the statistical period, Standard Precipitation Index (SPI) was taken into account. The unit hydrograph, groundwater table map and water table rising and descending map was prepared. The results indicated that on average the water table drop was -13.79 m in ten years period, but the outstanding fall (19 m) was observed in the east and central parts of the area around piezometers. The Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) for qualitative data in the 2007-2017 period showed that the wells in the region are divided into three groups and electrical conductivity has the highest correlation with sulfate and calcium. Also, the principal component analysis states that there are two main factors in the region, that the first factor includes 60.12% of the changes, and in order of importance are: EC, SO4, Ca, K, Cl, Mg, Na, and the second factor that causes 15.15% of the changes, just includes HCO3.

Keywords: Baghmalek plain, GIS, Hydrograph, Statistical Analysis, Water table drop.

Introduction

Groundwater is considered an important source of water resources due to its lower pollution possibility and high storage capacity compared to surface water (Ghazavi, 1395). Population growth and expansion of human activities reduce increasing water demands, which leads to people turning to groundwater resources, especially in arid and semi-arid regions. Iran is one of the arid and semi-arid regions of the world. Iran's share of the world's total renewable water resources is solely 36%. This is if the countries of the world have utilized only 45% of their optimal resource capacity and our country has used 66% of its freshwater supply (Khajeh, 1393). Overexploitation of groundwater resources and improper distribution of precipitation in terms of spatial and temporal due to global warming, the decline in groundwater level and the effect of inappropriate quality parameters on the quality of groundwater resources.

Materials and methods

Baghmalek plain (Figure 1) is located in Khuzestan province in the geographical position of "17 '49 ° 49 to" 11 '56 ° 49 east longitude and "38 '30 ° 31 to" 19 '38 ° 31 north latitude. The study area is located in the folded Zagros zone and among the most important outcrops in the study area are Gachsaran, Bakhtiari, Lahbri, Mishan and Aghajari, where most of the Baghmalek alluvial aquifer is fed by Bakhtiari and Gachsaran formations. In this study, the SPI index was used to study changes in rainfall and drought in the region. Also, in order to study the changes in the water level of the plain hydrograph, the map of water level, flow direction and fluctuation were drawn during the ten-year statistical period of 2007-2017 using the data of 7 observation wells. In order to study the chemical parameters and their maximum impact on different wells and recognize the chemical conditions prevailing in the aquifer, the principal component statistical methods and cluster analysis were used

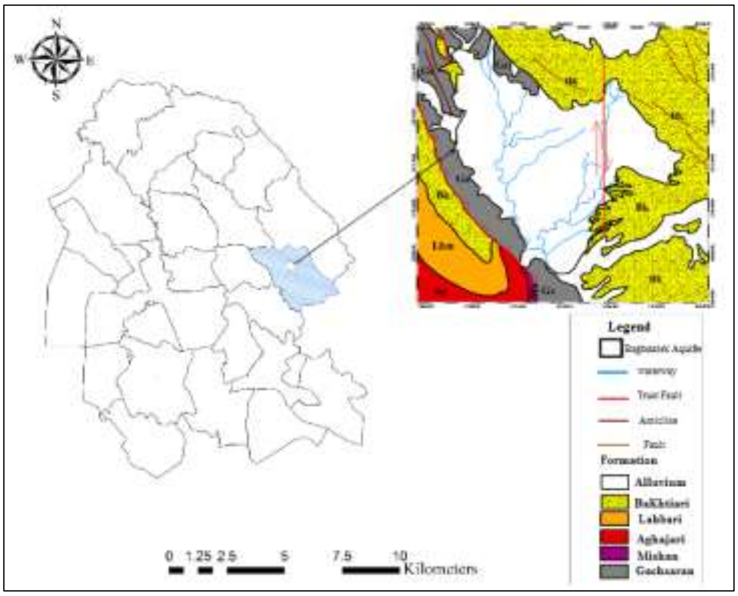

Figure. 1. Map Of studied area

Discussion and results

The results showed that in the years 1996-1986, the decrease in rainfall in dry years result in a negative effect on the volume of the reservoir over time. According to the groundwater level map, the highest level is in the northeastern, eastern and northwestern parts and the lowest level is in the southern part of the plain. The hydrograph diagram of the plain shows a drop rate of 13.79 m. The highest drop occurred in Bm4 and Bm2 Bm6 observation wells, with changes of about 12 to 19 meters in the east and center of the plain. The Bm7 observation well is in an almost sensitive condition (Figure 2).

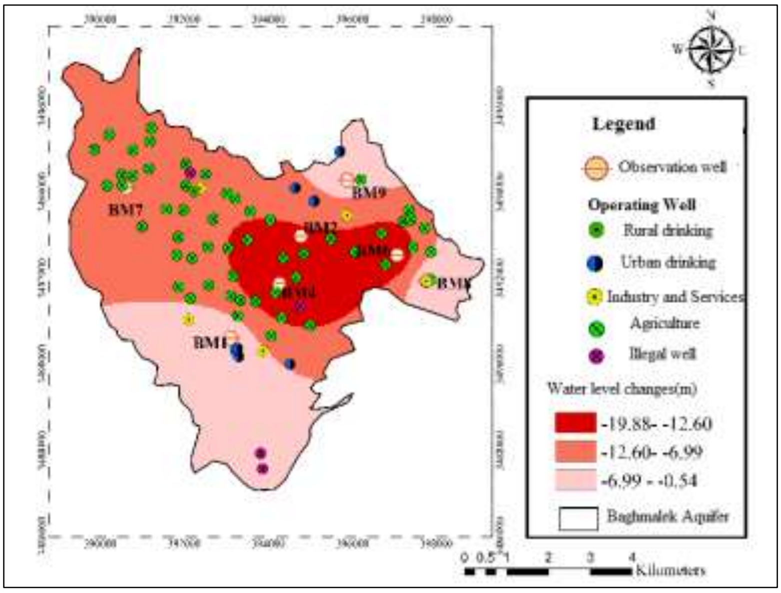

Figure.2. Map of drop and dispersion of wells in the study area

PCA showed that factors F1 and F2 account for 75.27% of the changes, the first factor with 60.12% and the second factor with 15.15%. The percentage of changes in the first factor relates to sulfate, calcium, Chlorine, sodium, potassium, EC and the second factor relates to HCO_3. The biplot also shows the appropriate correlation between Ca, SO_4, Mg and EC ions (Figure 3). Considering the location of

Wbm5 and Wbm6 wells in the lower left quarter and the correlation with the mentioned ions, it indicates the effect of the Gachsaran Formation on the water quality of these wells. The location of wells on the F2 line in this diagram illustrates the mixing of water resources in the center of the plain.

Examination of the HCA diagram depicts that the wells in the area were divided into three clusters (Figure 4). the first group comprises the wells that recharge from Bakhtiari Formation, the second group includes wells that are located in the mixing zone and the third group is related to wells that recharge from Gachsaran Formation. EC level according to the map of EC spatial changes from the northwest to the east and southeast of the region shows a decreasing trend. In fact, proximity to the Gachsaran Formation has increased the amount of solutes and electrical conductivity in groundwater. Exploitation wells located in the eastern and central part of the plain due to feeding from the Bakhtiari Formation and mixing zone (recharged from Gachsaran and Bakhtiari sand) have less salts than wells located in the western and northwestern part of the plain that feeds from Gachsaran Formation. There are more. Of course, the decrease in rainfall in the study area and the subsequent droughts that occurred during the statistical period along with uncontrolled exploitation wells are the main factors reducing the volume of groundwater reservoir in the Baghmalek plain and the existence of Gachsaran Formation in the north, northwest Reduces the quality of groundwater resources, especially in mixed wells and wells in the west of the plain. The decrease in groundwater level also affects the increase in EC.

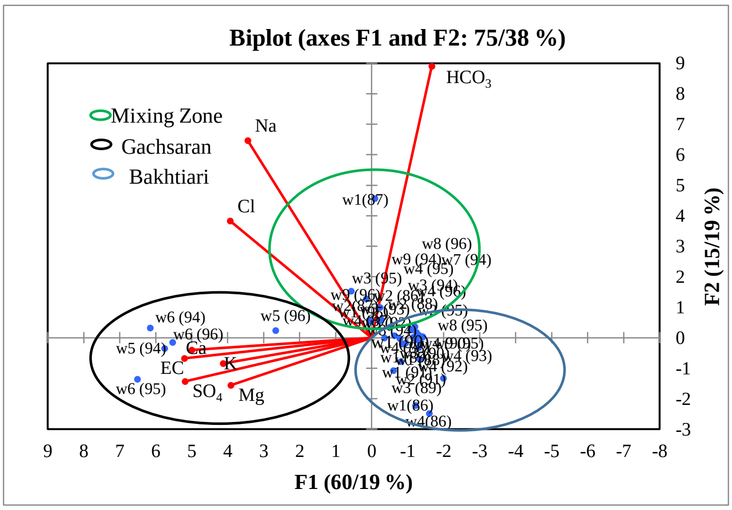

Figure.3. Two-variable diagram of main components and distribution of wells in Baghmalek plain

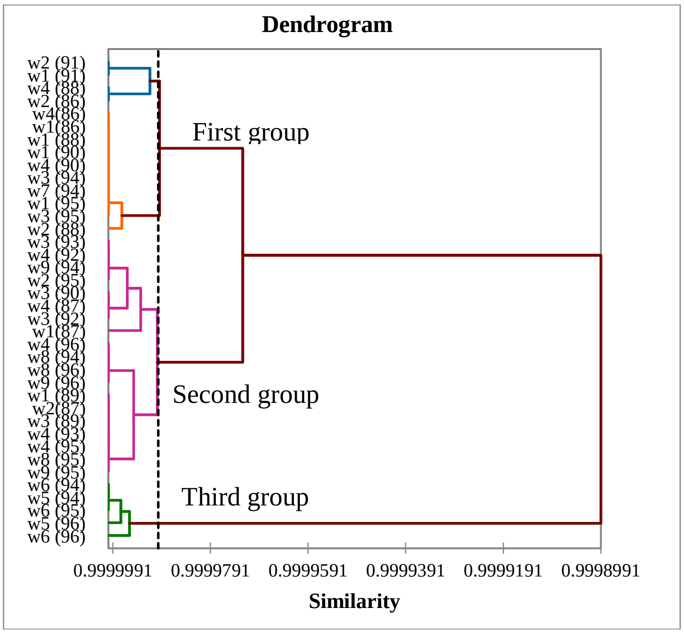

Figure.4. HCA diagram

Conclusion

According to SPI results, in some years during the study occurred a period of drought, which dropped the water level by 13.79 meters. Also, based on the results obtained from PCA in the central part of the plain, water mixing is due to Bakhtiari Formation and Gachsaran Formation. Feeding from Gachsaran Formation in the northwestern part has reduced the water quality of wells in the region.

Clustering of observation wells of Khoy Plain aquifer from the view of water quality using the K-Means

Document Type: Research Paper

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Abstract

The aim of the present study is the regionalization of groundwater observation wells of Khoy plain into distinct clusters based on the quality of water using the K-Means method. The recorded data of fourteen groundwater quality parameters including the Total Cations, Total Anions, Electrical Conductivity (EC), pH, Total Dissolved Solids (TDS), Sodium Absorption Ratio (SAR), Total Hardness (TH), Sodium percent (%Na), Magnesium (Mg^{2+}), Calcium (Ca^{2+}), Sodium(Na), Sulfate (SO_4^{2-}), Chloride (Cl^-), Bicarbonate HCO_3^-) were used. These data were gathered for the 26 observation wells in the time period of 2001-2003. The optimum number of clusters was found by optimization method in the K-means clustering algorithm assumed to be between two and five. In order to determine the groundwater quality to use for agricultural and drinking purposes the Wilcox diagram was used. The results showed that the groundwater of Khoy plain can be classified into four distinct classes. The first class covers an area equal to 214.3 km² (51.14 % of the total area of the plains), which has very favorable to use in agriculture and drinking use. The second region covers an area of 50.1 square kilometres (11.95 %) and the third region's area was 52.7 km² (12.57 %), respectively. The third region has poor water quality and the area of this region is equal to 9.101 km² (24.31%). The high values of EC and SAR were found in the third cluster, which led to groundwater quality being poor. In general, it can be concluded that more than 50 percent of the Khoy plain's groundwater had desirable chemical quality. It is recommended to protect groundwater in Khoy plain from pollution risk and overexploitation. For sustainable use of groundwater, it is recommended to protect groundwater by prohibiting agriculturalists and other users from overexploitation.

Keywords: Cluster Analysis, Groundwater, Water Quality, Wilcox diagram.

Introduction

Water is an essential element of the hydrologic cycle. In general, available water can be categorized into two distinct classes namely surface water and groundwater. This study focused on the latter class i.e. groundwater, which is a very important source of freshwater in arid and semiarid countries. In Iran, amazing water conveyance structures namely Qanats which are horizontal tunnels with vertical wells dug under the ground provided water for agriculture and drinking thousands of year ago. In some cases, the length of these Qanats reaches several hundred kilometres, which convey groundwater from far away to the farms, cities and/or villages, where water is consumed. After the invention of diesel motors, in the industrial revolution, many deep wells were dug by farmers which led to pumping more water which in turn led to declining of groundwater level day to day. This abuse of innovative technology in Iran first decreased the Qanat discharges and then led to the complete drying of them. As the number of groundwater wells increased in many plains the pressure on the extraction of groundwater increased. This led to disturbing the water balance of groundwater in many plains of Iran. Soil crust encountered deep and lengthy cracks, deep openings and land subsidence in some places due to over-exploitation of groundwater (Dinpashoh et al. 1996).

It is obvious that for sustained use of groundwater, some important facts should be considered especially in arid and semi-arid countries such as Iran. The first is how much groundwater is allowed to be pumped and used in a certain time scale. The second is related to water quality. This study focuses on water quality in the Khoy plain located in the north west of Iran. Understanding groundwater quality at different points of a plain is so crucial for the optimal use of fresh water. All of the drinking, sanitation, industrial, and agricultural sections need water, however, each of them may use different levels of water quality. Furthermore, monitoring the water quality in different wells and springs across the plain is needed to find the pollution source(s). Routine tests for water quality were done by the water authority continuously and the recorded values are available for investigators in different plains of Iran. Mainly recorded values for different anions, cations, electrical conductivity (EC), total dissolved solutes (TDS) and so on facilitate these studies nowadays. The recorded values are now available from Regional Water Organizations in different provinces of Iran. The present study used the past records of water quality in some observed wells in Khoy plain.

There are many available published literature on groundwater from the view of quantity and quality. Trends in groundwater level in Ardebil plain located in the north west of Iran investigated by Daneshvar Vosoughi et al. (2011). A similar study was carried out in Tabriz plain by Negahban Khajeh and Dinpashoh (2019). Trends in groundwater geochemical constitutes studied by many investigators such as Daneshvar Vosoughi and Dinpashoh (2013), Dinpashoh et al. (2015), Kolahdouzan et al. (2015) and many others. Some of the researchers used multivariate linear regression to delineate the plain into a few distinct homogeneous regions. Among them, it can be referred to the works of Kimet al. (2004), Chapagain et al. 2010, and Srivastava and Ramanathan (2008). Cluster analysis has been used for the regionalization of the aquifer in the works of Carvalho et al. (2016), Jani (2020), Ay and Kisi (2014), and Everitt et al. (2011). The pollution risk of groundwater in the Varzegan aquifer was studied in detail using the DRASTIC, SINTACS model by Nadiri and Sedgi (2020). The other method which has been used for the delineation of observation wells is factor analysis. This method has been used by several researchers such as Celestino et al. (2016). Fig. 1 shows the geographic location of Khoy plain in the northwest of Iran. Also, the location of observation wells and the Thiessen polygon at Khoy plain was shown in Fig. 2. The main aim of this study is to delineate the observation wells of Khoy plain based on hydro-geochemical elements of extracted groundwater samples obtained from different wells across the aquifer.

Materials and Methods

The area under study is called Khoy plain located in the north west of Iran. This plain is positioned in the north of Urmia Lake and discharged surface waters into the Aras River, a border river between Iran-Azerbaiejan and Iran-Armenia. The area of Khoy plain is equal to 3802 square kilometres. The selected plain is approximately lay between 44 15 E and 45 15 E in longitudes and between 38 28 N and 38 50 N in latitudes. The main rivers in this area are called Alland, Gotoor, Hinduwan and Ghazan-Chai. The mean annual precipitation in this area is about 280 mm. The climate of this plain is arid and semi-arid with cold winters and dry summers. The mean height of this plain is about 1233 m above sea level. The mean annual air temperature is about 11.8 degrees Celsius. In winter the absolute value of minimum air temperature in the synoptic station namely Khoy falls to -27 degrees Celsius experienced on January 9, 1974. However, the maximum absolute value of air temperature which is recorded on August 3, 2003, is about 43 degrees Celsius. The mean number of snow days in a year is about 113 days in a year.

The fifteen hydrogeochemical elements were recorded in each of the 26 observation wells of Khoy used in the present study. These elements are Total Cations, Total Anions, Electrical Conductivity (EC), pH, Total Dissolved Solids (TDS), Sodium Absorption Ratio (SAR), Total Hardness (TH), Sodium percent (%Na), Magnesium (Mg^{2+}), Calcium (Ca^{2+}), Sodium(Na), Sulfate (SO_4^{2-}), Chloride (Cl^-), and Bicarbonate HCO_3^-). These data were gathered from the Khoy water office. Only a single recorded value (in summer) was selected from each element in a year. Following the standardization of each time series the regionalization was carried out using the cluster analysis via Xlstat software. The K-means algorithm was used for the clustering of wells. By trial and error approach, an objective function denoted by F is defined in equation (1) and then minimized to find the best number of clusters using the K-means. The number of clusters examined to were 2-5 here. Among them, the one that yields a minimum value for F is selected as a solution. The squared value of Euclidean distance was selected as a measure of similarity between the groundwater quality of wells. The most important index for the evaluation of groundwater quality is the Sodium Absorbed Ration (SAR), that employed in this research as well. This index indicates the degrees of alkalinity of groundwater. Based on SAR and EC the position of stations marked on Wilcox's diagram in this study.

Results and Discussion

Fig. 3 shows the within-group variance vs the number of clusters obtained using the cluster analysis of observation wells in Khoy plain. As can be seen from Fig. 3 that among the different numbers of clusters used for clustering of observation wells, the optimum number of clusters was equal to four. It was found that as the number of clusters increases from 2 to 4, the between-group variances increased. At the same time, the within-group variances decreased when the number of clusters increased from two to four. However, when the number of clusters considered to be five the between-group variance decreased slightly and within-group variance increased too. Therefore, using the K-means method the optimum number of clusters was found to be four in the Khoy aquifer. The first cluster constitutes the wells located in small portions of the area as well as the west and eastern parts of Khoy plain. The mean value of TDS and EC of this cluster was less than others. Particularly, the mean TDS of wells in the first cluster was equal to 879 mg/l and the mean value of EC for this group was about 571. The second cluster had three wells located in the north-west of Khoy plain. The mean values of TDS and EC of the 2nd cluster were found to be 936 (mg/l) and 1440, respectively. The third cluster defined the northeast and southwest parts of Khoy plain. This cluster was the worst groundwater quality among the other clusters. The mean values of TDS and EC of the 3rd cluster were found to be 2236 (mg/l) and 4440, respectively. The fourth cluster constitutes wells located in the central and southeast parts of the Khoy plain. The mean values of TDS and EC of the 4th cluster were equal to 1241 (mg/l) and 1527, respectively. This cluster had the third rank considering the groundwater quality following the first and second clusters. It is worthy to note that the Fig, 4 shows the locations of the four resulting clusters on Khoy plain. Figure 5 shows the mean values of EC and TDS parameters in groundwater of the four distinct clusters at Khoy plain. This diagram indicates the fact that the two first clusters had the good-quality groundwater according to EC and TDs. Figure 6 shows the mean values of Ca and Mg ions of the four resulting clusters in Khoy plain. As can be seen from this figure the first cluster had low values of Ca and Mg ions, whereas the fourth cluster had high values of them among the four clusters. Figure 7 shows the mean values of SAR of the four clusters obtained in Khoy plain. As can be seen from the mentioned figure, the two first clusters had good water quality according to the SAR, however, the third cluster showed the highest value of SAR among the four obtained clusters. In 2014, the positions of the chosen wells were mapped on the Wilcox diagram according to the EC and SAR values. This diagram was shown in Fig. 8. As can be seen from this figure unless the three wells on the right-hand side of the diagram, all the other wells had groundwater with low alkalinity. However, according to solute concentrations of the samples, the selected stations had a different level of salinity. The first cluster had low alkalinity and medium salinity denoted by S1C2. Most of the wells grouped in clusters 1, 2 and 4 had low alkalinity and high salinity i.e. S1C3 according to the Wilcox diagram (Fig. 8). Three wells belonging to cluster 3, had high and very high alkalinity and very high electrical conductivity.

Conclusions

This study used the chemical information of groundwater samples obtained from 24 stations to group the observation wells into different classes. The number of chemical elements was 15. After standardization of parameters, the stations clustered by the K-means method. Among the four predefined numbers as the cluster numbers (i.e. 1-5) the most suitable classification obtained for clustering the sites into the four groups. Results indicated that more than half of the stations had good water quality. Among the four clusters, the first cluster had better groundwater quality. The position of the first cluster is some small portions of plain as well as the west and east part of Khoy plain. The third cluster located in the northeast and south of the region showed bad groundwater quality.

Estimation of hydraulic conductivity and specific storage of Shabestar Plain Aquifer using numerical model

Document Type: Research Paper

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Abstract

Hydraulic conductivity and Specific storage are known as the most important hydraulic characteristics of aquifers. Recently, due to software advances, the use of numerical models in the operation of groundwater aquifers has expanded. Modeling is one of the best tools for studying and simulating the state of water resources. One of the advantages of modeling is the simultaneous determination of several parameters such as hydraulic head, flow path and etc. Likewise, via modeling, it is possible to simulate the reaction of the basin against changes such as natural or artificial recharge and the amount of pumping, and by applying appropriate solutions, determine the best performance of the system and then use it to manage the basin. In the present study, MODFLOW numerical model and GMS user interface were utilized to simulate and calibrate the model. Accordingly, the hydrodynamic properties of the Shabestar plain aquifer were evaluated regionally. As a result, the RMSE values of the hydraulic head for the steady-state and non-steady-state models were 0.59 and 0.95 m, respectively. The obtained results demonstrated that the more heterogeneous the aquifer, the more diverse the hydrodynamic coefficients will be, and this variation does not follow a specific trend due to the existence of geological formations, the density and the porosity of the formations.

Keywords: Aquifer, Hydrodynamic coefficients, Modeling, Transmissivity.

Introduction

Introduction

Groundwater is one of the most important resources in the world and has a special significance in industry and human life in arid and semi-arid regions. Today with the advancement of technology and the development of cities, utilizing these underground resources is becoming more common than in the past. Due to the many challenges of the groundwater resources such as the fact that some parts of the world are generally in drought conditions or severe water shortages, optimal utilization and allocation of groundwater resources taking into account the needs of users alongside concerning environmental aspects and social criteria such as justice, turn to one of the most important issues in the exploitation of water resources.

The cognition of aquifers is one of the most important steps to consider and the management of groundwater. This important step requires obtaining the hydraulic and geophysical properties of aquifers. Hydraulic conductivity (K) and specific yield (Sy) are the most important hydrodynamic characteristics of aquifers. The specific yield refers to the volume of water that is extracted from a unit of the aquifer's surface as a result of lower or higher water levels. The specific yield obtained from pumping tests is inadequate due to inaccuracies in these tests. Another approach used to estimate the specific yield is the use of geological log information for different regions, which also due to severe heterogeneity in the aquifer structure still cannot be reliably quantified. Hydraulic conductivity indicates the ability of a porous medium to pass water. One of the important features of porous media in terms of groundwater flow and generation of hydrous layers is their hydraulic conductivity coefficient. The amount of this factor in porous media depends on the size and number of porosity and their arrangement. However, finding a way to estimate and quantify these parameters seems necessary. Groundwater modeling in this case with its good background can be a perfect tool for estimating these coefficients. In this study, these coefficients are estimated and presented by groundwater modeling for the Shabestar aquifer located in Iran.

Materials and Methods

Study area

Shabestar plain is one of the critical groundwater sources in the Urmia Lake basin. By recognizing the hydrodynamic properties of this aquifer, it will be possible to sustainably manage the aquifer with existing tools such as modeling. Shabestar plain is located in the west of East Azarbaijan province and it is one of the 25 sub-basins of the Urmia Lake catchment and is located 60 km west of Tabriz city. In this study, the extent of discontinuous sediments is 781 km2 and the area of hard formations is 474 km^2.

Unfortunately, groundwater harvesting due to insufficient information on aquifers does not comply with the aquifer recharge and discharge and will cause irreparable damage to the groundwater status and future livelihoods of farmers and beneficiaries. Numerical models are used to simulate the flow and diffusion of pollutants based on the laws of flow and diffusion of pollutants in these environments. With the advancement of computer capabilities, the application of numerical models to groundwater utilization has expanded significantly. One of the advantages of numerical models is the simultaneous determination of several parameters such as hydraulic head, flow path, and so on. It can also represent the basin response to changing variables such as recharge or artificial recharge, pumping rates, and so on. In this way, by applying appropriate solutions, the best system performance can be determined and used to manage a basin.

Model development

Groundwater numerical models that show the temporal and spatial conditions of groundwater flow are the best way to manage and achieve sustainable groundwater balance. Building a conceptual model is an essential step of groundwater modeling. The conceptual model is a simplification of the physical and hydrological conditions in the real world and the existing situation. This simplification is very helpful in understanding the changes and their locations. But it should not be done in such a way as to get the issue to go further from reality. The conceptual model of an aquifer consists of its physical and hydrogeological framework. The aquifer range used to model the Shabestar aquifer was provided by the Regional Water Authority. It has also been accurate by drilling logs and geo-electric cross sections and discrete in the 250 m to 250 m grid. The parameters needed to run the model were imported to the model in separate layers.

It should be noted that if the initial parameters and data are precision, the modeling will accelerate and the results will be closer to reality. The inlet and outlet boundaries are also generated based on the piezometers data in the start year on which the model is based. And other required parameters such as surface recharge and river infiltration, etc. were imported with the relevant packages to the model.

Results and Discussion

The results of steady-state and unsteady-state modeling in 36 steps, which include 3 years, indicate the superior quality of modeling under both conditions. The model was calibrated manually for precision operation in different sections due to different aquifer formations and different conditions of this aquifer. Finally, the sensitivity analysis of the model has been extracted by the PEST computational engine in the final step. The high correlation and low RMSE obtained from the calibrated model indicates the high quality of the modeling and briefed that the model is reliable in terms of aquifer hydrological parameters. As a result, the RMSE values for the steady-state and non-steady-state model were 0.59 and 0.95 m, respectively. The values of RMSE indicate that the model calibration precision is good as the RMSE values are under 1 m. Also the high correlation achieved between the observational and calculative groundwater levels is indicative of the sufficient precision of this model, and it can be used for the reliability of calculations. A summary of information about the statistics of modeling is provided in Table 1 to show the model calibration precision for steady and non-steady state conditions.

Table 1: The statistical summary of the comparison between the observational and calculative values of groundwater level.

	Calibration	
	Steady-State	**Non-steady**
RMSE (m)	0.59	0.95
MAE (m)	0.45	0.65
R^2	0.9998	-
MR (m)	-0.07	-0.04

According to reliable modeling with acceptable statistical values, the drilling log provides the hydraulic conductivity values and the specific yield based on the structure and gender of the drilled area structure by comparing the values of the output parameters from the modeling and hydraulic conductivity and the specific yield obtained from the drilling log, it can be concluded that the output values are in high agreement with the values presented by the geological Formations. In addition to the method used in this study, specific yield through aquifer water balance can be obtained, however, provide a good amount for the entire aquifer, but this value is not separable for different regions and it is merely a number for the entire aquifer.

Due to the hydraulic conductivity and specific yield obtained from the modeling, it can be stated that since the model considers the parameters affecting these coefficients, it has provided reliable values. The outputs of the model are presented as the values of hydraulic conductivity and storage coefficient in each zone. The zoning of the Shabestar Plain aquifer in the modeling of the aquifer is shown in Figure 1. The range of changes in hydraulic conductivity and specific yield is from 0.4 to 28 m/day and from 5 to 16 percent, respectively. Table 2 shows hydraulic conductivity and specific storage of the Shabestar plain aquifer in each zone.

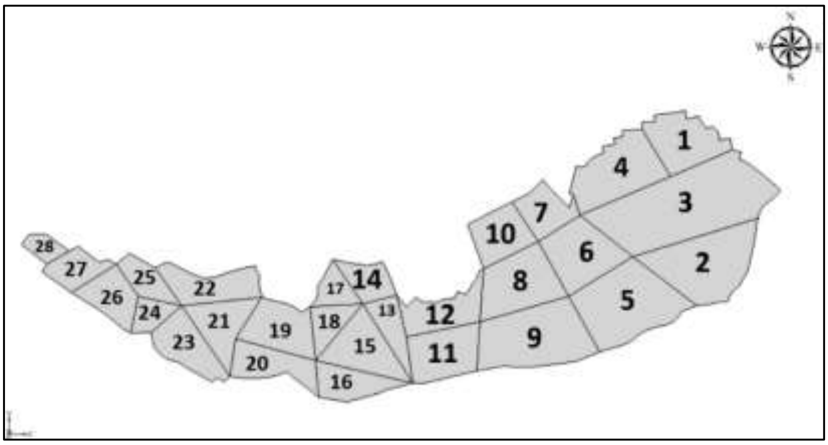

Figure 1: Zoning of Shabestar Plain aquifer

Table 2: Hydraulic conductivity and Specific storage of Shabestar plain aquifer

Zone	Sy (%)	K (m/day)	Zone	Sy (%)	K (m/day)
1	5.5	2.5	15	14.8	0.4
2	5.5	1.2	16	10	5.0
3	12	14.1	17	7	2.0
4	7	2	18	12	1.1
5	15	0.8	19	5.5	1.5
6	16	1.8	20	7	0.9
7	8	28	21	11	5.3
8	12	16	22	15	4.1
9	11	5.8	23	10	2.4
10	10	3.8	24	12	1.7
11	8	11	25	14.8	2.8
12	10.7	1.0	26	11	3.9
13	10	0.4	27	10.7	5.5
14	5	4.0	28	13.8	4.2

Conclusions

The results obtained from the Shabestar aquifer modeling can be very important in future studies in terms of investigating and applying management scenarios on this aquifer. According to the results of this study, the more heterogeneously in the aquifer, according to the geological formations, compaction and porosity of the formations, etc. Cause the more variety in hydrodynamic coefficients and we will have significant differences in these coefficients in each other zones. Therefore, reliable and accurate hydrodynamic coefficients should be used for analyzing and planning aquifers and their management. Due to the cost of field measurement methods and physical models, as numerical models have proven accuracy in aquifer simulation, it is suggested that the hydrodynamic data of these valuable water resources be calculated or quantified using this method.

Dynamic analysis of concrete gravity dam considering Dam-Reservoir Interaction: A case study of Koyna Dam

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Abstract

Today, the construction of dams to collect and store river water for different consumption purposes including drinking, agriculture, and industry is inevitable. Nevertheless, dams are colossal structures that pose potential dangers to their downstream community and their failure can be catastrophic. Dynamic analysis of concrete dams is more complex than that of conventional structures due to the presence of a reservoir. This complexity mainly results from the dam-reservoir interactions in seismic conditions. In this study, the seismic response of concrete gravity dams was investigated using Abaqus finite element software in different conditions of the full, half-full, and empty reservoirs. To this end, Koyna concrete gravity dam with specific geometric and physical characteristics was analyzed by applying Kobe earthquake records. The results from finite element analysis showed that the values of the main stresses in different modes of analysis were considered significant. Most of these stresses occurred at the site of the downstream slope change (level of 66.5 m), thus causing stress concentration in this area. Furthermore, according to the results, upon increasing the reservoir level, the amount and intensity of displacement fluctuations would increase, mainly due to the dam-reservoir interactions and the effect of fluctuations in the hydrodynamic pressure of the reservoir in the time curve of the displacement in the crown of the dam. In general, in case the reservoir is full, the levels of stress and displacement would be higher than those in other modes.

Keywords: ABAQUS, Concrete gravity dam, dam-reservoir interaction, dynamic analysis, finite element method.

Introduction

Once the whole endeavour of constructing dams began, humanity has always created assumptions based on available data and equipment and thus, established models to define the behavior of dams, construction materials, and applied forces. Given the advances in science and technology, most of such assumptions have been discredited. Moreover, following the development of relevant software, it is now possible to conduct a 3D nonlinear analysis of dam behaviors with higher precision via scrutinizing the model behavior of materials based on lab results, studying the current dam responses during the earthquake, and perceiving the nature of earthquakes. For the first time, Westergaard (1993) provided an analytical answer for the hydrodynamic pressure exerted on the rigid gravity dam subjected to harmonic load. Next, Chopra (1967) presented the dam response under the impact of horizontal and vertical velocity with desired magnitudes. Bustamante (1963) examined the impact of reservoir length for the range of stimulation periods wider than the ranges investigated earlier and found that the aforementioned impact would be negligible for stimulation periods longer than the natural reservoir period, while it would play a major role in the harmonic motion in the case of smaller periods. The above author studied the impact of surface waves on harmonic stimulation and estimated the error in overlooking the surface waves. Zanger (1953) determined the value of hydrodynamic pressure for different forms of the upstream dam. The author assumed the water to be incompressible and thus, used an electrical analog approach. with the latest advances in the ability to process heavy computations using computers, numerical approaches to modeling concrete gravity dams have been developed. Zhong et al. (2013) studied the anti-seismic reinforcement FRP materials in concrete dams. They demonstrated that FRP as a reinforcing factor can postpone crack occurrence and prevent the joining of upper- and lower-bound cracks. In other words, reinforced dams can exhibit better performance under earthquakes. Mazaheri et al. (2020) conducted static and dynamic analyses of pore water pressure in earth-fill dams using Abaqus. The use of the Interval Fuzzy Multi-Stage Stochastic Model in the allocation of Latyan water was studied (Rastegari pour, 2020). Moghimi et al. (2020) investigated using water pressure test results to calculate seepage through the grouting curtain of the Seymareh Dam in the Ilam Province of Iran. Mozafari (2019) the issue of leakage in Shah Ghasem Dam through hydrogeological analysis.

Materials and Methods

Region of study: Koyna Dam

Koyna Dam is located in Maharashtra, India and is characterized by 853 and 103 meters in length and height, respectively. In the design of this dam, the earthquake coefficient of 0.05 was uniformly used in the height, and due to the low-quality materials and unusual shape associated with this dam, it is quite vulnerable to earthquakes, hence much damage seen so far. The dam length compared to other dimensions is larger and it appears that the impact of the earthquake on the width of the dam is more damaging (Ghazi Marashi & Hossein, 2014).

Computational methods

Abaqus software represents a set of engineering simulation programs functioning based on the finite element method and it facilitates resolving a range of engineering problems including simple linear to complex non-linear simulations. Abaqus possesses an extensive library of different elements as well as a comprehensive set of various material models for modeling most the engineering materials. The software can handle construction and thermal analyses. In addition, such analyses as soil mechanics with mass transfer and fluid–structure interaction are also possible to be performed. In non-linear analyses, the mentioned software automatically selects a proper load increment and convergence tolerance and it consecutively makes adjustments so as to efficiently achieve an accurate response.

Modeling via Abaqus

The first stage in any finite-element analyses is real geometric discretization using a limited set of elements. Every finite element describes a discrete part of a genuine physical model. Finite elements join one another via shared nodes. A set of nodes and finite elements is called a mesh. The number of elements in length, surface, or volume units is called mesh velocity. In every analysis, in each of the nodes, a basic variable is considered in computations. For instance, in stress analyses, nodal displacement is the basic variable. Upon determining the displacements, the values of stresses and strains in every finite element are easily computable.

Results and Discussion

Based on the results, tension stresses at times 5.32 and 6.15 occur at the downstream slope position of the dam while the location where the change to the downstream slope occurs at the level of 66.5 meters. Therefore, an increase in the level of the reservoir compared to its half-full causes a change in the location of maximum stress. In the case of compressive stress at time 6.15 (second), the maximum stress occurs at the upstream location and at a level of 65 meters. This location varies in similar conditions in the case of the half-full reservoir. The values of maximum tension and compressed stresses occur at times 5.42 and 5.61 (seconds), respectively. In a similar situation with the half-full reservoir, these tresses occur at the location of downstream slope change.

Based on the results, in a dynamic state of the full reservoir (D3), the displacement of the crown occurs at a greater extent than that in other states. As mentioned earlier, maximum horizontal displacement at the peak acceleration of an earthquake does not take place. Given that this issue is quite clear in the empty state, one can point to the complexity of the dynamic behavior of the dam as the main reason for the above problem and thus, disregard the roles of the aforementioned dam-reservoir interaction. In the empty (D1) and half-empty (D2) states of the reservoir, the displacement is almost the same in value, while significant changes in maximum displacements occur upon an increase in the level of the reservoir from 45 to 91.75 meters. As can be seen in Fig. 19, in the D1 state, the displacement curve for the crown is smoother than that under other states. Following an increase in the reservoir level, displacement fluctuations and their values increase. This problem results from the dam-reservoir interaction and the impact of hydrodynamic pressure fluctuations in the time history curve of the crown displacement. The maximum hydrodynamic pressure applied by the reservoir to the dam body in D2 is 0.296 mpa. This value in D3 increases by 117% to 0.641 mpa. Of note, the maximum pressure in D2 occurs at time 6.15 s and at seismic peak acceleration time. However, in D3 and given the increased reservoir level, the occurrence of maximum pressure is slightly delayed and it takes place at time 6.22 s, because with an increase in the reservoir level, the reservoir complexities resulting from the mutual dam and reservoir vibration increase.

Conclusions

Finite-element results for the Koyna dam subjected to the defined seismic accelerations were obtained. The analyses included static analysis (S), dynamic in the empty reservoir level (D1), dynamic in the half-full reservoir level (D2), and dynamic in the full reservoir level (D3). The values of tension and compressed stresses in different states were significant. The major portion of maximum stresses at the location of downstream slope change (level of 66.5 meters) occurred and led to stress concentration here. Stress value in this part would be reduced significantly if the width of the dam had been designed such that failure or change in the downstream slope at higher levels and in proximity to the dam crown were predicted.

By and large, in the D3 state, the stress level and displacements are greater than those in other states. In the D3 state, maximum tension stress was 74% greater than that in D2. In the case of compressed stress, the mentioned value increased by 112%. However, in D2, maximum compressed and tension stresses were 8 and 4% greater than those in D1. This finding holds in the case of displacements. Considering the reservoir level changes, it can be generally stated that the pattern of stress distribution does not experience significant changes. Although the maximum stress at different times varied in different states, maximum compressed and tension stresses occurred in the downstream slope position. Maximum horizontal displacement at seismic peak acceleration time did not occur. One can point to the complexity of the dynamic behavior of the dam as the main reason for the above problem and thus, disregard the roles of the aforementioned dam-reservoir interaction. The obtained data and findings hold in the case of compressed and tension stresses.

Prediction of hydraulic conductivity from the soil grain size data using SICM intelligent model

Document Type: Research Paper

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Abstract

Permeability is one of the parameters affecting water flow in porous environments such as rock and soil mass and is of special importance in geotechnical studies, e.g., the location of important structures such as urban trains. Accordingly, the determination of permeability is one of the main goals in geotechnical studies. Also, it is an important parameter in solving geotechnical problems such as seepage, settlement measurement, stability analysis, etc. Due to the fact that direct methods (field and laboratory) of measuring permeability are expensive, highly specialized, time-consuming and unreliable, and due to the nonlinear behavior and heterogeneous and anisotropic conditions in hydrogeological environments which cause inherent uncertainty in the methods of direct measurement of this parameter, various artificial intelligence methods which work more accurately than the above methods have recently been proposed to compensate for some of these shortcomings. In this study, two individual artificial intelligence methods including Least-Squares Support Vector Machine (LSSVM) and Wavelet-Artificial Neural Network (WANN) were used on lines 1 and 2 of Tabriz Urban Train to predict hydraulic conductivity based on grain size data; then the results of these two individual models were combined by an Artificial Neural Network (ANN) and improved the results under the name of Supervised Intelligent Committee Machine (SICM). Comparison of test step results of the three models presented in this study showed that all three models had a relatively good performance in predicting hydraulic conductivity, but the SICM model with Root Mean Squared Error (RMSE)= 0.000161 cm/sec and Determination Coefficient (R^2)= 0.83 provided better results than the individual models.

Keywords: Hydraulic conductivity, Support Vector Machine, Supervised Intelligent Committee Machine, Tabriz Urban Train, Wavelet-Artificial Neural Network.

Introduction

Hydraulic conductivity is an important physical concept and it means the ability of fluid to pass through porous materials such as rock and soil. With the increasing development of large cities, the need to build massive engineering projects such as the Urban Train increases. Proper management and control of groundwater at the site of such large structures are essential. Therefore, the evaluation of parameters such as hydraulic conductivity that affect the flow of water in porous media is important for the optimal and reliable design of such structures. Many parameters affect the hydraulic conductivity, such as soil texture properties including pore size, grain size distribution, grain shape, grain density, etc. Accordingly, this research focuses on grain size distribution.

Different methods have been proposed for determining the hydraulic conductivity including field (Pumping test, slug test and packer test) and laboratorial methods as well as calculations based on experimental formulas. Although these methods have various advantages such as recognizing subsurface conditions by drilling, they are time consuming and costly and require more manpower. Various artificial intelligence methods which work more accurately than the above methods have recently been proposed to compensate for some of these shortcomings.

Also, review studies conducted on the estimation of hydrological and hydrogeological variables such as runoff, stream flow, surface water and groundwater quality, suspended sediment load, etc. have confirmed the success of AI methods. Considering the inherent, unique and different abilities of each of the individual AI models, multiple models have been considered.

In this study, the SICM method was used to predict hydraulic conductivity in Tabriz Urban Train. Considering that the SICM model used in this study applies the output of individual AI models, LSSVM and WANN, the advantages of each of these methods are used to estimate the desired variable, which is hydraulic conductivity. ANN method is applied to combine the output of the AI model as a nonlinear combiner method. Because each of the individual models has a unique strength, the estimated values of the individual models are combined in the SICM model.

Materials and Methods

Study Area

The city of Tabriz is located in East Azerbaijan province in northwestern Iran. Tabriz Urban Train consists of 5 lines. In this study, lines 1 and 2 were studied.

Data Analysis

After studying the borehole data, from among 20 boreholes, we used the data from 15 boreholes on line 1 for this study. Geotechnical studies of line 2 included 133 boreholes, from among which the data of 34 boreholes were used in this study after a complete review of the information of all boreholes. A total of 94 soil samples were selected from 49 boreholes and used. The soil samples were selected from depths at 3m intervals.

Hydraulic conductivity determination tests were carried out by the LEFRANC test. D30, D60 and D80 were determined according to the grain size distribution curves.

In this study, 70% of the data was allocated for the training step and the remaining 30% for the testing step (trial and error).

Artificial Intelligence Methods

Support Vector Machine (SVM)

SVM is an algorithm that finds a specific type of linear model that produces the maximum hyperplane margin. Maximizing the hyperplane margin leads to maximizing the decomposition between the clusters. The nearest training points to the maximum hyperplane margin are called support vectors, and only these vectors are used to define the boundary between the clusters.

Wavelet-ANN Model (WANN)

In general, the WANN method is used in the simulation and prediction of signals. That is, the signal is converted into several sub-series using wavelet decomposition, one of which is the estimate or background of the main series, and the rest of the sub-series are the details. Then, by considering these sub-series as the input of the neural network, the signals are predicted and analyzed.

Supervised Intelligent Committee Machine (SICM)

Individual LSSVM and WANN models were used to implement this model. Each of these models was implemented individually; then their output was optimized using an artificial neural network. The output of individual models, was used as the input of the Artificial Neural Network. Thus, the Supervised Intelligent Committee Machine (SICM), has been presented.

Results and Discussion

LSSVM

For SVM implementation, first, the SVM type was determined. The SVM type was LSSVM. The regulator value (γ) and the kernel variable (σ) were determined by coding in MATLAB software and then optimized using the trial and error method. The best values for γ and σ variables were 2.8 and 7.9, respectively. From among the types of Kernel Functions, the RBF kernel was selected. R^2 and RMSE values in the training and testing steps were 0.88 and 0.000129 cm/sec and 0.64 and 0.000238 cm/sec, respectively.

WANN

The efficiency of the WANN model depends on the variables such as the type of Wavelet Function, the decomposition level, and the number of hidden neurons. The db4 Wavelet Function as the mother wavelet was more accurate than the other functions. Better outcomes can be achieved at decomposition level 2. The decomposed data are entered into the Multilayer Perceptron Neural Network. The number of hidden neurons was selected as 3 (using a trial and error). R^2 and RMSE values in the training and testing steps were 0.88 and 0.000128 cm/sec and 0.69 and 0.000222 cm/sec, respectively.

SICM

After implementing the SICM model, it was observed that the results of estimating the hydraulic conductivity became more desirable than those of the individual models and this model had much higher efficiency. R^2 and RMSE values in the training and testing steps were 0.91 and 0.000109 cm/sec and 0.83 and 0.000161 cm/sec, respectively.

A comparison of test step results of the three models showed that the SICM model with R^2= 0.83 and RMSE= 0.000161 cm/sec provided better results than the individual models and had a more accurate prediction of hydraulic conductivity, also WANN model with R^2= 0.69 and RMSE= 0.000222 cm/sec had a better prediction related to LSSVM with R^2= 0.64 and RMSE= 0.000238 cm/sec.

For visual comparison, the proximity of the computational values of all three models to the observational values of the testing step was plotted in a chart (Fig 1). After drawing the chart, it was found that the SICM model has been able to significantly increase the proximity of computational and observational values. This proximity is quite evident in 13 of the 28 points (for example points 2, 7 and 15), also, in points 12, 14 and 27, the SICM model has been able to perform better than an individual artificial intelligence model.

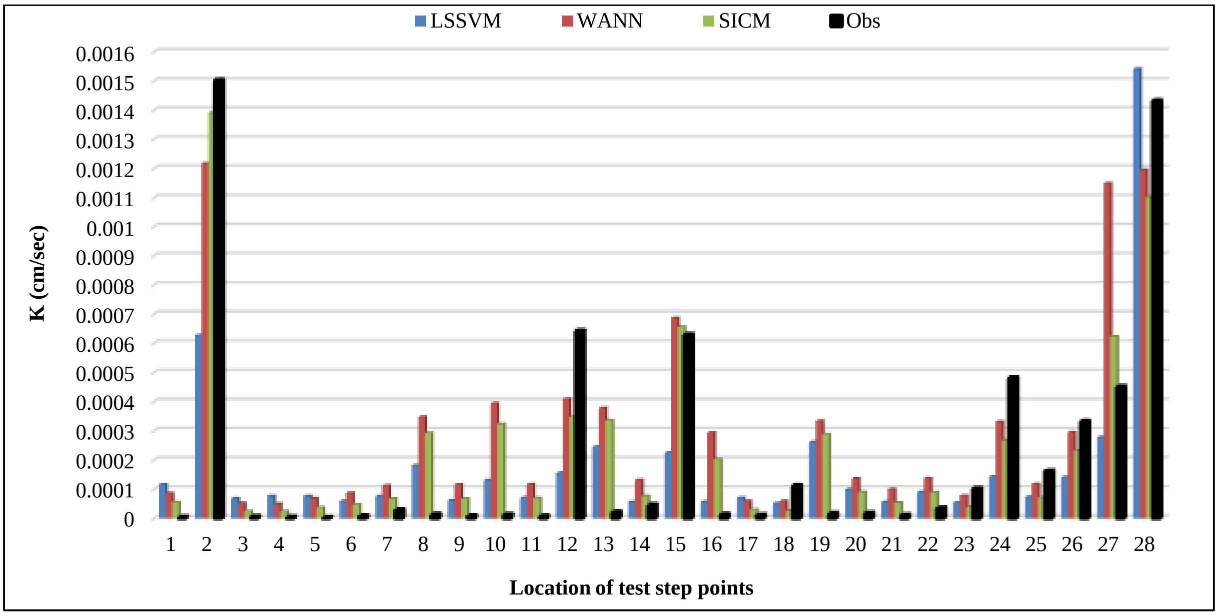

Fig. 1. Comparative chart of computational values of artificial intelligence models with observational values in the test step.

Conclusions

In this study, two individual artificial intelligence models including LSSVM and WANN were used to estimate hydraulic conductivity. For optimal application of the advantages of the individual models, a multiple model under the name of SICM was presented. Comparison of test step results of the three models showed that all the three models had a relatively good performance in predicting hydraulic conductivity, but SICM model provided better results than the individual models. Comparison of the prediction results of this multiple model (SICM) with the individual models showed 30% and 20% increase in R^2 and 32% and 27% decrease in RMSE compared to the LSSVM and WANN models, respectively, also WANN has provided better results than LSSVM model.

Relation between the grout take, rock quality and permeability of radiolarite and limestone at the Roudbal Dam Site (SW Iran)

Document Type: Research Paper

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Abstract

Understanding the relationship between the rock geomechanical characters and its cement take is very important to estimate the cost of the dam and grout curtain constructions. Most of the studied relations belong to limestone since dams are mainly located on karst terrains. A positive relation between cement grout absorption and the permeability of limestone is reported by many researchers. Roudbal Dam, with a reservoir capacity of 82 million cubic meters, is located in the Fars Province, SW Iran. The dam site is mainly consisted of radiolarite and limestone. In this study, an attempt has been made to determine the relationship between the cement consumption, rock quality and rock permeability of these geological units. Considering the rock quality index, limestone showed better quality than radiolarite. Based on the results of the water pressure test, limestone was more permeable than radiolarite. By analyzing the cement take values, it was detected that most of the sections with high consumption were located in the limestone. The cement take values only showed a well positive correlation with rock permeability. A correlation of 0.87 indicates a much stronger relationship between cement take and permeability in limestone than a correlation of 0.43 measuring the relation between these parameters in radiolarite. The results of this study showed that in sites with different lithology, estimation of cement consumption based on the results of the Logan test and the rock quality index requires more accuracy and attention. By separating the data obtained from drilling in different rock units and performing calculations separately, the estimation error can be greatly reduced.

Keywords: Cement take, Lugeon, Rock-quality designation, Roudbal Dam, Water leakage.

Introduction

Cement grouting is one of the common methods for water tightening of dam reservoirs (Milanovic, 2004). Assessing the amount of cement consumption is essential to estimate the cost of any dam construction since the grouting is a cost and time-consuming process. In order to know the natural characteristics of the rocks before grouting, core drilling, permeability testing (Lugeon) and measuring cement consumption in exploration boreholes are very common. The relation between different characteristics of rock mass and its cement take has been studied in many dam sites. Most of these studies have been focused on carbonate rocks. The positive and well relationship between rock permeability and cement consumption has been reported in some studies (Foyo et al., 2005; Gürocak et al., 2012; Uromeihy and Farrokhi, 2012; Sohrabi-Bidar, 2016). Fuyo et al. (2005) defined the secondary permeability index for the qualitative evaluation of rock mass. Gürocak et al. (2012) evaluated the depth of the grout curtain based on the Lugeon test and permeability assessment methods in Atasu Dam. Uromeihy and Farrokhi (2012) by comparing Lugeon and geo-mechanical classification of rock mass, geological strength index and rock quality index, concluded that the quality index of rock in Kamal Saleh dam site is directly related to Lugeon. Azimian and Ajalloeian (2013) based on the data from the Nargesi and Cheshmeh Ashegh dam sites, investigated the relationship between Lugeon and the secondary permeability index and presented an experimental relationship based on the correlation of these two variables. Sadeghiyeh et al. (2013) by comparing cement intake, secondary permeability and Lugeon values in the Middle Store Dam site, concluded that the more convergent in the selected data trend would lead to a higher cement take rate. Qureshi et al. (2014) presented an experimental relationship between rock quality index and permeability in sedimentary rock discontinuities in which discontinuity characteristics (such as length, opening, and orientation) were limiting factors. Kayabasi et al. (2015) developed a model for determining rock mass permeability in which the results of the Lugeon test, rock quality index, and separation and surface properties of discontinuities were used. The researchers stated that in the absence of field measurements of rock mass characteristics, the results of the proposed model were acceptable and usable. Sohrabi Bidar et al. (2016) evaluated the correlation between cement volume and Lugeon, secondary permeability index and joint opening in the Bakhtiari dam site and found a general correlation between cement take and the mentioned characteristics.

The Roudbal Dam, an earth-fill dam with 82 million cubic meter capacity, is constructed on the Roudbal River in SW Iran (Fig. 1). The Bardeno Anticline is the main geological structure at the study area, mainly consisted of Sarvak Limestone and radiolarite. The water tightness system of the reservoir consists of a one-row grout curtain built in radiolarite and a three rows grout curtain constructed in limestone (Fig. 2). The object of this study is to assess the relationship between the amount of cement taken and the values of rock quality and permeability in limestone and radiolarite.

Materials and methods

In this research, geotechnical information from 10 exploratory boreholes (five boreholes drilled in the Sarvak Formation and others drilled in radiolarite has been used. At these boreholes, rock quality index, permeability and cement take were measured. The reason for using the data from the exploratory boreholes was to study the natural characteristics of the rocks. After data gathering, each character belonging to the limestone and radiolarite units was evaluated separately. Then, the correlation of cement consumption with rock quality and permeability was determined.

Results and Discussion

Values of rock quality index measured in limestone and radiolarite units were divided into five categories based on the criteria presented by Deere (1989). In radiolarite units, about 80% of cases showed very poor quality, and the share of poor and relatively good qualities was 19.5%. In none of the sections, the radiolarite units presented good or very good quality. The reason for this phenomenon can be the high frequency of joints and weathering of the rocks, which has reduced the amount of recovered core during drilling and as a result, its quality index was low. In the limestone rock located at the right abutment, 25, 23.5, 24, 23.5 and 4% of the cores showed respectively very good, good, relatively good, weak and very poor quality. In general, it can be concluded that the limestone has better quality and fewer joints, and only a small percentage of it had poor quality. Low-quality limestone cores were mostly located near the ground surface and in the Epikarst zone or near the faulted rocks.

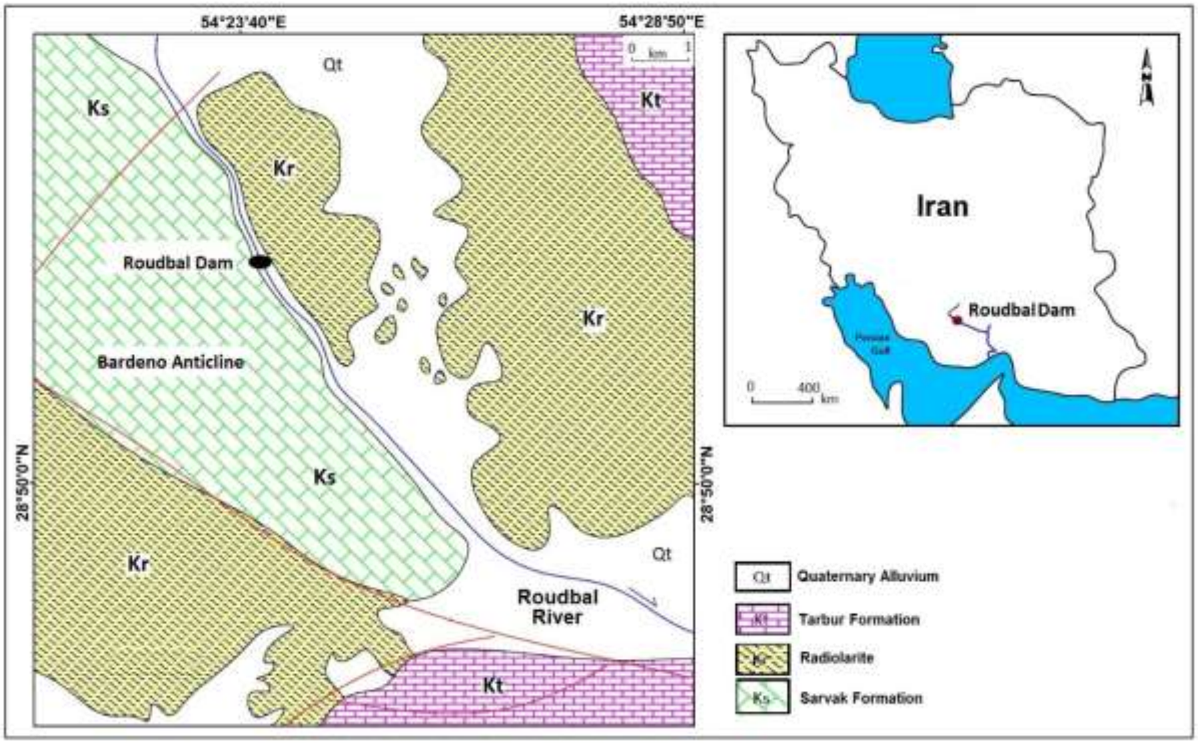

Fig. 1. Location of the Roudbal Dam.

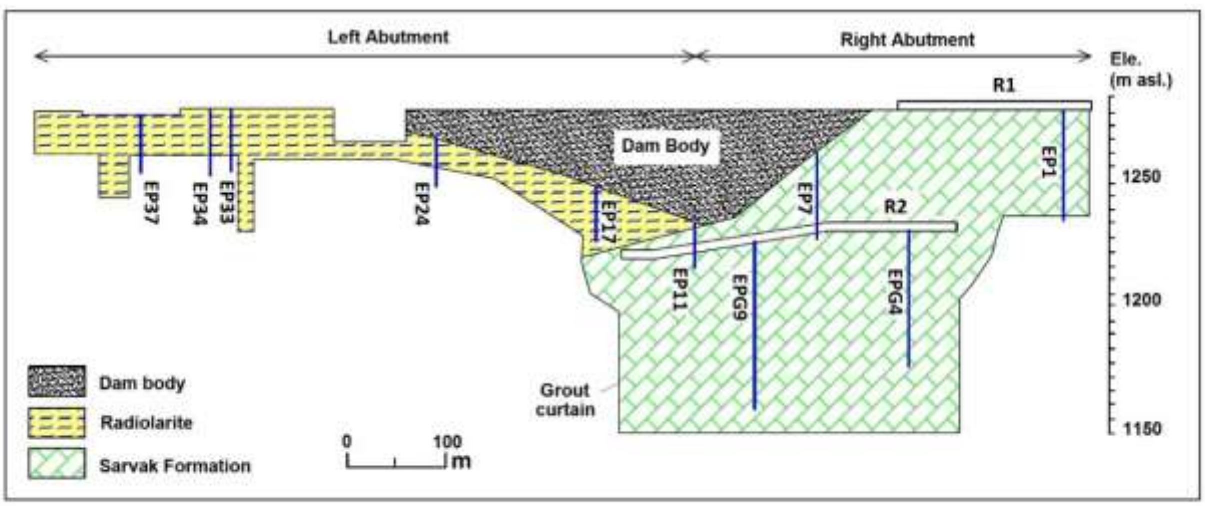

Fig. 2. A geological cross-section along the dam site.

The existence of sections with high cement take in limestone was affected by the karst development in this carbonate unit. In the radiolarite units, all sections with moderate cement take have been observed near the ground surface, which can be due to weathering, the presence of seams and cracks, and/or the washing out of the cores.

In the studies conducted by several researchers, various results have been reported for the relation between the geo-mechanical properties of rocks (especially limestone). Regarding the permeability and rock quality index, some reports have not provided a significant relationship between these two variables, but some have indicated an indirect linear relationship (with a negative correlation coefficient) between them (Foyo et al., 2004; Bakhshandeh and Masoudi, 2016; Farid and Rizwan, 2017). The results of this study also showed the existence of an indirect and weak relation between the permeability and rock quality index (in limestone and especially radiolarite) at the Roudbal Dam site (Fig. 3). Regarding the relationship between cement take and rock quality index, most studies have shown the existence of a linear or indirect exponential relationship between these two characteristics (Bakhshandeh and Masoudi, 2016; Rastegarnia et al., 2018; Kayabasi and Gokceoglu, 2019; Sohrabi Bidar and Et al., 2020), while in this study, a weak relationship was found between these two characteristics. Most studies on the relationship between cement take and permeability in limestone indicated a direct linear relation (Yang, 2004; Fan et al., 2016; Bakhshandeh and Masoudi, 2016; Kayabasi and Gokceoglu, 2019) or exponential relation (Fan et al., 2016; Sohrabi Bidar et al., 2016) with moderate to high correlation. In this study, between cement take and permeability, an exponential relationship was observed with a weak correlation coefficient in radiolarite and a strong correlation coefficient in limestone.

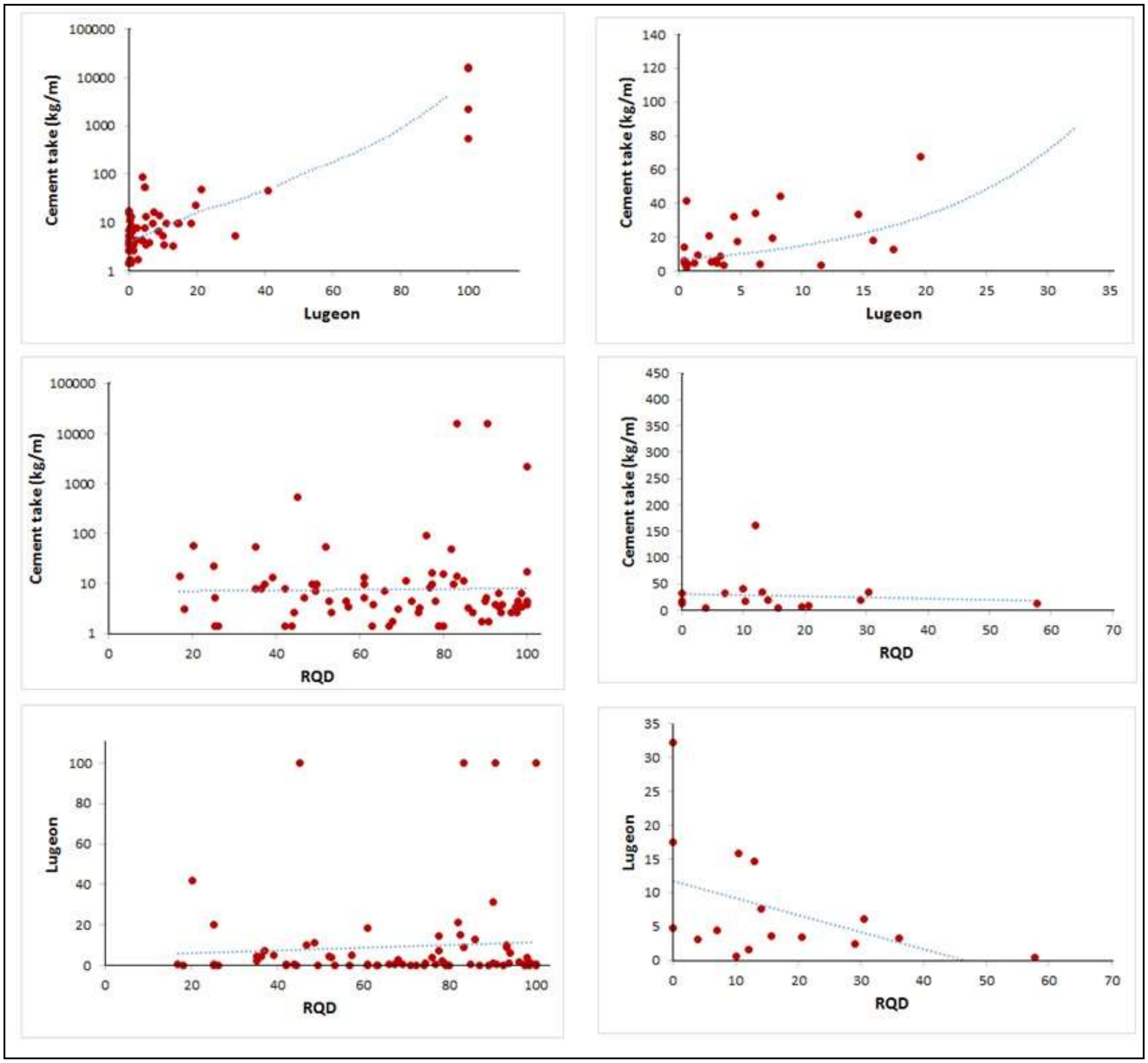

Fig. 3. Distribution of data in the right and left abutments

Conclusions

The existence of Sarvak Limestone and radiolarite units in the Roudbal Dam site has caused differences in the correlation and relationships between the values of cement to take, permeability and rock quality index. The results of this study showed that estimating the amount of limestone and radiolarite grout taken based on their quality index would be greatly misleading. A positive relation between cement take and the permeability of limestone and radiolarite was observed. The relation between cement take and permeability in limestone was much stronger than its measuring in radiolarite. Results showed that in sites with different lithology, estimation of cement taken based on the results of permeability and the rock quality index requires more accuracy and attention.

Aquifer transmissivity estimation using different interpolation methods (Case study: Damaneh-Daran Aquifer)

Document Type: Research Paper

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Abstract

Aquifer transmissivity is one of the important parameters for groundwater quantitative and qualitative studies and modeling. Due to the limited number of pumping tests or the ambiguity in the accuracy of the measured values in some places, it is necessary to estimate the transmissibility value using the available information. In this research, the values of this parameter are determined using different interpolation methods including Inverse Distance Weighted (IDW), ordinary kriging (by use of circular, exponential, Gaussian and spherical variograms), universal kriging (including linear and quadratic trend), spline (regularized and tension) and trend (include linear and logistic regression) Therefore, here, the transmissivity coefficient of the Damaneh-Daran aquifer, as a case study, is determined and the results are presented and compared. A comparison of the results shows that performing interpolation with Regularized Spline leads to the lowest accuracy and using the Ordinary Kriging method in power mode leads to the highest computational accuracy (with 20.11% relative error). However, this method is not effective for interpolating points located in the boundary areas of the study state. In contrast, the IDW method with a maximum of 21.36% relative error can be used for interpolation in all parts of the region. Finally, in order to evaluate the performance of this method, the Damaneh-Daran aquifer is simulated based on the results of the IDW method as initial values and using GMS software. By comparing the results obtained from the calibration of the aquifer with values obtained from interpolation, the maximum relative error value is 22.22% and the average relative error at the aquifer level is 15.69%. Also, with a significant reduction in the number of iterations in the calibration phase of the model, the computational cost is significantly reduced.

Keywords: Aquifer, Damaneh-Daran, Geo statistic, Interpolation, Transmissivity.

Introduction

Investigation and simulation of the quantity and quality of the groundwater in aquifers require the use of relatively accurate values of hydraulic parameters of the aquifer. Therefore, determining these parameters is necessary to study, evaluate and manage groundwater resources. Usually, three parameters of hydraulic conductivity, transmissivity, and specific storage, known as aquifer hydrodynamic coefficients, are defined to describe the hydraulic properties of the aquifer. This parameter shows the amount of water storage value and the mechanism of movement through the porous environment, and changes the water level or piezometric level of the aquifer. Generally, Transmissivity is the amount of water that moves horizontally from the entire thickness of the aquifer under a unit hydraulic slope per unit of time. One of the best and most accurate methods for estimating aquifer hydrodynamic coefficients is using pumping test in the study area. If the pumping test cannot be sufficiently performed, it is not easily possible to estimate the aquifer hydrodynamic coefficients in the study area using the available information. Therefore, it is necessary to propose effective and proper methods for this purpose.

Reviewing the previous studies shows that the transmissivity values of the aquifer are determined using different methods such as extending the Jacob equation based on the correlation between the transverse resistance and transmissivity values, similarity of groundwater and electricity flow characteristics in the porous environment, analysis of vertical electrical sounding results or using experimental relationships. So far, different interpolation and geostatistical methods were also used to estimate the various quantitative and qualitative parameters of the aquifer. In this research, in order to reduce the costs, interpolation and geostatistical methods are proposed and used to determine the aquifer transmissivity. The values of this parameter for the Damaneh-Daran aquifer, as a case study, are determined using various interpolation methods such as Inverse Distance Weighted (IDW), kriging, spline and trend methods and the results are presented and compared. Finally, in order to investigate the accuracy of the obtained results, the aquifer is modeled and calibrated by GMS software using the interpolated values of the transmissivity (as initial values) and the results are analyzed.

Materials and Methods

In this research, by using different interpolation methods, the transmissivity values of the Damaneh-Daran are determined and compared with the obtained values of the pumping test. For this purpose, the value of this parameter is determined using various interpolation methods at the location of the pumping test wells. Then, to evaluate the accuracy of the interpolation methods, the interpolation values of each method are compared with the measured values of the pumping test. For this purpose, in the ArcMap software, the value of the measured transmissivity at the desired point is removed from the initial information file. Then, based on the information of other points, the values of this parameter are interpolated and determined using different interpolation methods. These methods include weight inversion distance, kriging, trend and spline. In order to evaluate the results of the IDW method, the values obtained from this method are used as initial values for modeling the aquifer using GMS software and the results of the calibrated model are compared with the results obtained from the interpolation method. For this purpose, by subtracting the water level from the bedrock level, measured at the location of observation wells, the aquifer thickness is calculated. Then, the aquifer thickness values are determined at other points by interpolating the values based on the IDW method. In addition, the hydraulic conductivity is calculated by dividing the transmissivity and the thickness of the aquifer at each point. Finally, the aquifer is polygonized using these values and the average values calculated for each polygon are considered as the initial value of hydraulic conductivity to simulate the aquifer using GMS software.

In this method, the model is calibrated using the measured water level values and the calculated values at the location of the observation wells. For this purpose, at first, automatic calibration is done using the PEST code for the software. Then, manual calibration of the aquifer is also done using the values of measured water level at the location of observation wells. This step is continued until the difference between the calculated and measured water level values at the location of the observation wells is decreased. At this stage, according to the results of the previous iteration as well as the ground layers component, the hydraulic conductivity values are corrected for the next iteration. At the end of the calibration process, the aquifer thickness values are recalculated based on the computational water level value at each point. By multiplying this value with the calibrated hydraulic conductivity value, the aquifer transmissivity at different points is obtained. Finally, the obtained transmissivity values are compared with the values obtained from interpolation using the IDW method.

Results and Discussion

According to the obtained interpolation results, presented in Tables 1 and 2, the following conclusions can be obtained:

Table 1- Measured and calculated values of transmissivity at the location of observation wells (m^2/day)

method	values of transmissivity						
	Well 1	**Well 2**	**Well 3**	**Well 4**	**Well 5**	**Well 6**	**Well 7**
Measured values	2821	1760	2142.75	565	197.75	201	183.33
IDW	953.19	548.18	1461.01	1512.33	295.67	316.12	1061.08
ordinary kriging- spherical variogram	1249.01	779.16	1087.72	2119.46	516.71	305.34	1142.58
ordinary kriging- circular variogram	1368.92	789.68	1049.65	2144.77	491.84	287.61	1130.56
ordinary kriging- exponential variogram	1370.11	765.39	1493.54	1846.59	620.78	558.66	1159.03
ordinary kriging- Gaussian variogram	1307.11	538.59	654.61	3015.56	570.21	459.51	1130.51
universal kriging- linear trend	1252.31	739.61	6399.34	3581.36	446.23	645.01	846.36
spline- regularized	4970.93	525.27	2620.96	4857.78	261.41	-	1020.23
Spline- tension	2138.62	559.38	3635.51	2032.73	38.02	160.08	1051.15
trend -linear	1252.31	739.61	6399.34	3581.36	446.23	645.01	846.36

Table 2- Measured and calculated values of transmissivity at the location of observation wells (without considering wells No 4 and 7) (m^2/day)

method	values of transmissivity				
	Well 1	**Well 2**	**Well 3**	**Well 5**	**Well 6**
Measured values	2821	1760	2142.75	197.75	201
IDW	2167.39	1571.44	1908.7	262.84	259.41
ordinary kriging- spherical variogram	1662.2	1560.47	1523.12	-	-
ordinary kriging- circular variogram	1626.07	1539.55	1522.79	-	-
ordinary kriging- exponential variogram	1619.14	1543.41	2026.47	-	-
ordinary kriging- Gaussian variogram	1494.22	1635.03	2647.06	-	-
Universal kriging- linear trend	1675.8	3238.09	-	13.46	382.19
spline- regularized	1689.91	-	-	-	-
Spline- tension	2070.6	1452.16	3761.36	-	-
trend -linear	1875.8	3238.09	-	13.46	382.19

• In general, using the Universal kriging method with linear drift and the Ordinary kriging method with an Exponential semi-variogram model leads to the maximum and the minimum amount of error, respectively. The main reason for this fact is maintained as follows.The Universal kriging method is based on the assumptions of the regional variability theory and the parameter values of each point are a function of its geographical coordinates. However, in the Ordinary kriging method, the trend of mean changes in the whole area is assumed to be a constant value.

• Kriging, spline and trend methods cannot be used in some places. However, it is possible to determine the value of the desired parameter in different places by using the IDW method. The reason for this is maintained as follow. In the IDW method, the effects of the desired characteristic are decreased by increasing distance. In other words, this method is based on the assumption that the continuous phenomenon at unmeasured points is most similar to the nearest known points.

• The obtained results indicate that using the spline method for interpolation eliminates the maximum points and reduces the breaking points, and as a result, the points with sudden changes in the values of the transmissivity are deleted. The reason for this fact is maintained as follows.In this method, interpolation is performed using polynomials, and the values of unknown points are estimated by fitting a polynomial function based on the sample data. Therefore, the amount of surface curvature is minimized and a relatively smooth surface is obtained.

• In the IDW method, the distance of individual points remains well compared with other methods. However, the uniformity of the values of the studied coefficient is ignored. The reason for this fact is that the method is proposed based on the principle that, to estimate unknown points, the surrounding samples should be more participated than those at a greater distance. In the kriging method, the highest mode of data averaging occurs, so the use of this method in areas with low transmissivity leads to semi values. Because this method is a regional scheme, unlike the IDW method, it is a local interpolation method. This fact indicates that this method uses all the observations of the target area. In the trend method, the weight of the input values may also change depending on the obtained equation.

• The IDW method can be used to intercept transmissivity values for all points of the study area. However, the results of other methods are not accurate enough in some places. Due to this fact, in this method, by increasing the distance of the known data from the unknown point, the impact factor value of that data is decreased based on the distance value.

• Comparison of the hydraulic conductivity values obtained from the simulation of this aquifer in GMS software with the obtained values from the IDW method shows that the maximum difference in the results occurs in the eastern boundary areas with a value of 22.22% and the average difference in different parts of the aquifer is 15.69%.

Conclusions

Determining the hydraulic parameter values of the aquifer such as the transmissivity coefficient is essential for the evaluation and management of groundwater resources. Due to a lack of available information because of the limited number of pumping tests or inaccurate information measured in some aquifers, estimation of aquifer hydrodynamic coefficients is inevitable. Therefore, in this research, different interpolation methods were used to determine the transmissivity coefficient of the Damaneh-Daran aquifer, as a case study, and the results were compared with the obtained values of the pumping test. These methods included IDW, ordinary kriging (using circular, exponential, Gaussian and spherical variogram), universal kriging (including linear and quadratic trend), spline (regularized and tension) and trend (including linear and logistic regression). The obtained results of the relative error index showed that using the regular spline method for interpolation led to the lowest accuracy and using the exponential variogram for the ordinary kriging method led to the highest accuracy with a maximum error value of 20.11%. In addition, the IDW method could be used for determining the coefficients of all points in the study area with a maximum error value of 21.36%. Finally, obtained interpolation values of the IDW method were used as initial values for aquifer modeling in GMS software and the model was calibrated automatically and manually. Comparing the calibration results and the obtained results of the mentioned interpolation methods showed that the average difference in hydraulic conductivity values in different parts of the aquifer was 15.69%. The results indicated the proper performance of the IDW interpolation method for determining the aquifer transmissivity coefficient and therefore this method is recommended to estimate this parameter.

Numerical modeling of unconfined aquifer artificial recharge plan using Isogeometric analysis method

Document Type: Research Paper

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Abstract

Currently, uncontrolled extraction of groundwater resources has led to a decline in the water table of aquifers, especially in arid and semi-arid regions. Today, one of the ways to improve the water table of aquifers is the use of artificial recharge plans. This study has been done to numerically simulate the artificial recharge plan of Birjand plain through the construction of injection wells using the numerical model of Isogeometric analysis. In this regard, first, a standard example with two wells with discharges of 1142.85 and 1428.57 m^3/day was used to simulate the water table for 210 days. After evaluating the accuracy of the model, the water table before injection was simulated based on the existing conditions and after injection using 20 injection wells with a constant flow of 7638.44 m^3/day in 12 time steps in the unconfined aquifer of Birjand plain. Comparison of the results of Isogeometric analysis and analytical solution model in standard aquifer with estimated evaluation criteria equal to ME=-0.0096, MAE=0.0111 and RMSE=0.0146 and also in Birjand plain unconfined aquifer with evaluation criteria of ME=-0.033, MAE=0.372 and RMSE=0.229 shows the model accuracy in simulating the water table before injection. Also, after running the numerical code of the injection wells construction plan, by interpolating the water table obtained at the control points in the location of 10 existing observation wells, the results at the end of the simulation period shows increasing the water table maximum of 60.53 cm in the observation well number 2 and minimum 1.25 cm in the observation well number 9.

Keywords: Artificial recharge plans, Groundwater resources, Injection well, Isogeometric analysis, Numerical simulation.

Introduction

To global warming, we will have a short time to groundwater resources are coming to end are continuously replenished using new artificial recharge methods. This problem has drawn the attention of researchers around the world to the use of tools and various types of numerical models for the simulation of the hydrological processes of groundwater recharge (Kulkarni, 2015).

Doulabi et al., (2019), simulated groundwater artificial recharge by Injection well Using Meshless Local Petrov-Galerkin as a standard example. The results showed that the water table rise is 1.8 m and the low error of this model indicates its high accuracy. Poursalehi et al., (2020), using Modflow numerical model, investigated the effect of artificial recharge by injection well method on the unconfined aquifer of Birjand plain. The results indicate the model's ability to simulate the water table. Also, the aquifer injection plan results showed an average of 77 cm increase in the water table in the observation wells.

For the first time, the entrance of computer-aided design techniques into the structural analysis field was implemented by Kiggan in 1998 (Kagan et al., 1998); In that, instead of the Shape functions used in finite element, were used of Spline Basis functions. In 2005, this idea evolved by Hughes et al., (2005) using Non-Uniform Rational B-Spline functions (NURBS) which are derived from the development of Spilin functions and were called the Isogeometric analysis method (Kagan et al., 1998).

Many studies have been done around the world on the application of the Isogeometric analysis method in water engineering and its comparison with other numerical methods yet. Shahrokhabadi et al., (2017) proposed a solution to solve the Richards equation for transition flow in the Soil unsaturated area using the Isogeometric method. The results showed that the isogeometric analysis method can simulate the variation of pore pressure at the site of soil connection using lower degrees of freedom and higher orders of approximation compared with the conventional finite element method. Shahrokhabadi et al., (2017) presented the rapid solution of convergence for the modeling of transitional flow in saturated soils using the Isogeometric analysis method. The results showed that the higher order of NURBS can predict the wet front in nonlinear problems. The geometric analysis model is also implemented correctly across a wide range of unsaturated flow problems, while the higher order of the finite element model is divergent, especially in problems with nonlinear levels. Kalantari et al., (2017) using the Isogeometric method developed a model of groundwater flow in an unconfined aquifer. The results show the high accuracy of this model compared to the finite difference model.

The purpose of this study is to numerically simulate the water table of the unconfined aquifer using the numerical method of Isogeometric analysis before and especially after injection through the construction of injection wells.

Materials and Methods

Groundwater governing equation in the unconfined aquifer

Hardness matrix, passive vector, and force vector after discretization of the Relations Groundwater flow in a two-dimensional and unsteady state in the unconfined aquifer are summarized by the finite element weighted residuals method and fractional integration as relationships (1), (2), and (3) (Kalantari et al., 2017):

$$[K] = k\left[\iint_{\Omega} \frac{\partial \varphi_i}{\partial x} H^n \frac{\partial \varphi}{\partial x} d\Omega + \iint_{\Omega} \frac{\partial \varphi_i}{\partial y} H^n \frac{\partial \varphi}{\partial y} d\Omega\right] + \iint_{\Omega} \varphi_i S_y \left(\frac{1}{\Delta t}\right) d\Omega \qquad (1)$$

$$[U] = H^{n+1} \qquad (2)$$

$$[F] = \iint_{\Omega} \varphi_i S_y \left(\frac{H^n}{\Delta t}\right) d\Omega - Q_K - \iint_{\Omega} \varphi_i q d\Omega \qquad (3)$$

In the above relations [K] is the stiffness matrix, [U] is the passive vector and [F] is the force vector. φ_i, Q_K, and q are the basis functions, centralized discharge of wells, and widespread discharge such as rainfall or evaporation, respectively.

In this standard example, an unconfined aquifer with 3200 m long and 2800 m wide and a thickness of b=100 m was considered. The effective porosity and hydrodynamic properties of the aquifer, including T and Sy were entered into the model n=0.3, T=885.7 m^2/d, and S_y=0.15 in. Then, the model boundary was selected in the upstream and downstream areas of the aquifer Dirichlet type at a constant elevation of 100 m and on the left and right sides of the aquifer Neumann type were selected. Also, the initial values of the water table were considered equal to 100 m.

In the definition of the IGA model in the standard example, First, the order of basis functions was determined and it was considered 3 in both directions ξ and η (p=q=3). Also, the number of knot vector members which is obtained based on the sum of the number of control points and the order of the basis functions, was estimated as follows in the direction of ξ 20 and in the direction of η 18.

Also, the number of control points in the direction ξ and η were defined respectively as an equivalent of n=17 and m=15 points at a distance of 200 m from each other which resulted in a total of 255 control points. Due to the two-dimensional flow, four points of Gaussian integrals were used. In Birjand plain aquifer, to prepare the IGA code, the degree of basis functions was considered in direction ξ p = 3 and in direction η q = 2.

In this regard first, a standard example with two wells with discharges of 1142.85 and 1428.57 m^3/day for 210 days was used to simulate the water table before injection. After evaluating the accuracy of the model, the water table before injection was simulated based on the existing conditions and the water table after injection was simulated using 20 injection wells with a constant flow rate of 7638.4438 m^3/day in 12 monthly time steps in the real aquifer.

Results and Discussion

The analytical solution of the extraction wells scenario shows that during 210 days of extraction from the aquifer, the water table at the observed well location decreases to 42.5 cm, and this parameter in the numerical solution of the IGA in the same conditions of the analytical solution in the standard example was estimated equal 39.90 m.

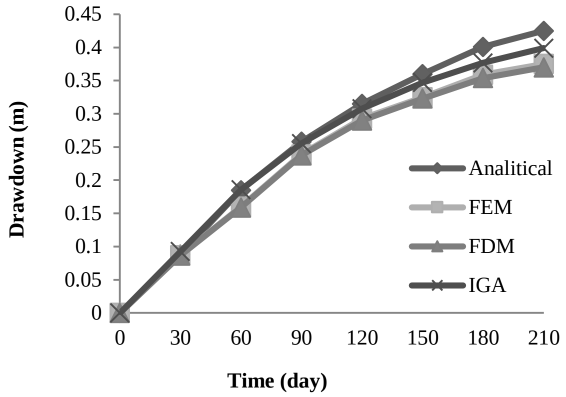

Fig 1- Comparison of calculated water table drop with analytical solution methods, finite elements, finite

Difference and IGA model

Table 1 shows the results obtained from the evaluation criteria in an unsteady state. Therefore, based on the rule that if the calculated RMSE is in the range ± 1.9, the accuracy of the simulation is confirmed (Anderson et al., 2015), the results obtained from the IGA model are acceptable.

Table 1- Calculation of mean error, absolute mean error and root mean square error in an unsteady state

evaluation criteria (m)	IGA model
ME	-0.033
MAE	0.372
RMSE	0.229

The injection results show that water injection into the aquifer has more effect on the water table of observation wells No. 1, 2, 6 and 8 and also has little effect on the water table of observation wells No. 7 and 9 that among these, greatest effect of the injection is on observation well No. 2 equal to 60.34 cm.

Table 2- Water table of Birjand plain aquifer before and after injection at the end of the simulation period

Observation well number	UTMx	UTMy	Simulated water table before injection (m)	Simulated water table after injection (m)	Increasing the water table (cm)
1	672076.9	3626500	1264.00	1264.27	27
2	673616.7	3629000	1290.32	1290.92	60.53
3	674670.8	3638500	1306.91	1307.00	8.967
4	675659.3	3634500	1300.52	1300.61	9.583
5	677358.1	3628000	1299.98	1300.07	8.787
6	681191.5	3638000	1309.65	1309.88	22.49
7	684659.6	3637500	1322.45	1322.46	1.696
8	693716.3	3641500	1342.50	1342.74	24.79
9	701775.4	3639000	1362.54	1362.56	1.25
10	716167.1	3636000	1393.18	1393.29	11.25

Conclusions

This study was performed with the goal of numerical simulation of the artificial recharge plan of Birjand plain by injection well construction method using a numerical model of Isogeometric analysis. Comparison of the results of the Isogeometric Analysis model and analytical solution in the standard aquifer with the estimated evaluation criteria equal to ME=-0.0096, MAE=0.0111 and RMSE=0.0146 and also in the unconfined aquifer of Birjand plain with the evaluation criteria of ME=-0.033, MAE=0.372 and RMSE=0.229 indicates the accuracy of the model in simulating the water table before injection. The simulation results show that this numerical model can be used in the simulation of the water table before and after injection. Also, the implementation of an artificial recharge plan by injection well method causes the water table of observation wells to increase by a maximum of 60.34 cm and a minimum of 1.212 cm. It also reduces the rate of drop in the aquifer caused by uncontrolled extractions. It is also suggested that due to the positive effect of water injection into the aquifer in increasing the water table, to reduce the drop in the aquifer water table, by observing water quality issues and also increase the life of injection wells by preventing clogging of them, The implementation of this plan will continue in the future years.

Investigation of rock mass groutability at Kaleybar Peygham-Chay dam foundation based on field data

Document Type: Research Paper

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Abstract

Cement grouting is the most common method used for improving, treating and sealing the foundations of structures and construction sites of dam projects. In this method, through injecting the cement grout by pressure, joints and fractures of rock mass subjected to filling and as a result, the geomechanical characteristics of the rock mass improve due to integrity and reduction of permeability. The key to success in using this approach is to correctly evaluate the grout-ability of rock mass and, consequently, to determine the mixing plan and designing of grouting parameters. Peygham-Chay Reservoir Dam is an embankment dam with a clay core and a height of 46 meters from the riverbed, which is under construction in East Azerbaijan province, 15 km southwest of Kaleybar city. The bedrock of the dam site is basalt, which is covered by alluvial deposits in the riverbed and the left abutment. The bedrock is fractured due to 3 main joints and a number of sub-joints and faults. Based on the results of Lugeon tests in the construction site along the dam axis, in most test sections, the permeability is less than 3 Lugeon. The rock mass quality index (RQD) in the study site in 75% of the sections is less than 25% and in only 1% of sections is more than 75%. Investigation of the relationship between RQD and Lugeon values shows that most sections with low to high RQD have low permeability and there is no logical relationship between these two parameters. In different RQDs, the cement take is low which indicates the presence of rock mass with a low to a high degree of jointing with filled and/or with low aperture as well as very low continuity. The study of the relationship between the cement take and different classes of secondary permeability index (SPI) shows that there is no logical relationship between these parameters in the study site. Based on the obtained results, the rock mass forming the study site is low grout-ability.

Keywords: Cement take, Dam Foundation, Groutability, Lugeon, SPI.

Introduction

One of the most important issues in embankment dams is the control of seepage through the foundation and body of the dams. Based on the geomechanical characteristics of the dam site, to increase the length of the flow path and reduce the flow rate and hydraulic gradient caused by seepage, there are various methods, of which creates a sealing curtain by cement grouting, especially under the clay core of embankment dams, is one of the most common methods (Komasi and Beiranvand, 2019).

Compared to other ground improvement methods in civil engineering, the cement grouting technic is a relatively new method, so it is necessary to conduct new experiments and research for its development (Heidarzadeh et al., 2013). The correct prediction of the groutability of cement grout can lead to the appropriate selection of grout components, determining the spacing and sequence of grouting boreholes, and minimizing the uncertainty of grouting efficiency (Marko, 2019).

Cement is the main component of grout. One of the most important specifications of the cement is the size of the grains, the particles should be so small that they have the possibility to penetrate into the narrow joints and cracks of the rock masses (Salimian et al., 2017). Implementation of the grouting curtain creates a hydraulic barrier and reduces water seepage through the foundation of the dam. However, due to the inability of grout to penetrate into narrow fractures and empty spaces in the rock mass of the dam foundation, it is difficult to estimate the efficiency of cement grouting (Li et al., 2017).

In order to evaluate the effect of discontinuities on the grouting, it is necessary to carefully investigate the characteristics of the discontinuities. The characteristics of the joints greatly affect the permeability and cement take of the rock mass. These include aperture, roughness, resistance and filling material (Azimian and Ajalloeian, 2014). Choosing a correct mixing design of grout based on the geomechanical characteristics of the rock mass is key parameter that control the success of the cement grouting technics.

The three main factors including properties of the grouting environment, grout specification and grouting pressure have controlled the groutability of the rock mass. Among these, the grouting environment is a more important factor because also determines the other two factors (Nonveiller, 1989).

Cement grouting to improve geological features is an underground activity that is associated with many uncertainties and its results can be monitored indirectly. Correct estimation of the amount of groutability of the rock mass, in addition, to increasing the confidence factor of the success of the grouting efficiency, can significantly reduce the costs. Correlation between cement taken as an indicator of groutability of rock mass with other measurable parameters such as permeability and RQD has been one of the main topics of the recent research in this field.

Sohrabi-Bidar et al. (2019) based on the studies conducted in the Khorasan 2 dam site, concluded that the cement take has an inverse relationship with RQD and joint spacing, but it has a direct relation with the joints opening and the lugeon values. Sadeghiyeh et al. (2013) investigated the relationship between Secondary Permeability Index (SPI), Lugeon, Rock Quality Index (RQD) and cement take (CT) in the Osture dam site and concluded that there is an inverse relationship between permeability and RQD, and the groutability of the rock mass is greatly affected by the veins and the joints opening. The SPI index is one of the basic parameters for classifying the rock mass in order to determine the need for improvement and to determine the grout mixing design, which was presented by Foyo et al. (2005).

In this paper, through the correlation between RQD, Lugeon, SPI and the amount of cement taken, the groutability of the rock mass of the Peygham-Chay dam foundation has been investigated. The geology of the study dam foundation is composed of intrusive magmatic rock masses. Which has been crushed due to three main joint sets and some sub-joints, cracks and faults. The dam is located in East Azerbaijan province and 15 kilometres south of Kaleybar city.

Materials and Methods

The study area is located in the Alborz-Azerbaijan geological region (Aghanbati, 2015). The bedrock in the dame site is composed of basic lavas and carbonate shale. The bedrock on the left bank and the river bed is covered by alluvial deposits and debris. Based on joint studies, three main joint sets and some sub-joints and faults have been identified in the dam site. The permeability in the right abutment varies from low (Lu<3) to medium (10≤LU<30) and about 63% of the test sections have permeability less than 3 Lugeon. A number of 28 boreholes have been drilled and grouted in the river bed. About 78 percent of the test sections in the riverbed have less than 3 Lugeon. In the left abutment, 9 boreholes were drilled in alluvial deposits. The permeability tests conducted on the abutment show impermeable to a permeability of fewer than 10e-5 cm/s.

On the base of SPI, in the right abutment, class B is the most and class C is the least abundant, and in the river bed, class A is the most and class C is the least occurrence. Class D was not observed in the tests. In the right abutment, out of 19 permeability test sections, 10 sections are in class B, 7 sections are in class A, and 2 sections are in class C. In the rock mass located under the alluvial sediments in the river bed, out of the total of 152 test sections, 101 cases are in class A, 46 cases are in class B and 5 cases are in class C.

The zoning of rock mass quality index (RQD) in the study dam site, shows that in 75% range between 0-25 % (very poor), 18% between 25-50% (poor), 6 % is between 50-75 (moderate) and in 1 % is between 75-100 (excellent).

A combination of the cutoff wall (for alluvial deposits) and double-row grouting curtain (for rock mass) has been used for the sealing of the Peygham-Chay dam foundation. The depth of grouting curtain in the right abutment is about 60 m. In the river bed, the rock mass is covered by alluvium with a thickness of about 14 m, so a 16-meter cutoff wall and a grouting curtain with a maximum depth of 45 meters have been constructed for the underlying rock mass. The left abutment is made of cemented alluvial deposits with low permeability, which is not required to be further sealing system. In order to grouting in the alluvial deposit and weathered rock, Tube-a-Manchette grouting technics were employed. In this study, the data of grouting boreholes of the downstream row with the number 489 grouting sections were used. Classification of grouting section based on cement take shows that 92% of the sections have less than 100 kg/m (meter of the borehole) cement take, 7% of the sections have

100 - 200 kg/m cement take and only 1% of the sections have more than 500 kg/m cement take.

The grouting curtain has been done through boreholes in three different series (P, S and T series) using split spacing. Investigation of the amount of cement taken in different series separately shows that in all three series, about 70% of the sections have less than 10 kg/m cement taken. The remarkable point is decreasing of cement take in consecutive series of grouting boreholes. It was seen the S and T series of boreholes have more cement take compared to the P series. The reason for this occurrence is the presence of filled joints with low continuity, which cause the to joints not to connect to each other and have a separate role in grouting.

Results and Discussion

One of the methods to evaluate the groutability of a rock mass is to compare the amount of cement taken with permeability. In general, what is expected is that these two variables have a good correlation, but in many cases, such a relationship is not observed. The relationship between these two parameters can be classified into four states (Houlsby, 1990):

(a) Sections with high permeability and low cement corrosion: This state mostly occurs in rock mass containing small joints with low aperture. The groutability of this type of rock mass is low. In this case, it is necessary to use fine-grained cement (high Blaine) for grouting.

(b) Sections with low cement take and low permeability: This state indicates the presence of very small or filled joints or rock mass with a low degree of jointing. Grouting of this type of rock mass is suggested while the economic value of leaking water is more than the cost of grouting.

(c) Sections with high cement take and permeability: This state indicates the presence of rock mass with a high degree of jointing or unfilled joints with a good aperture that is suitable for grouting.

(d) Sections with low permeability and high cement take: The main cause of this phenomenon can be attributed to the occurrence of hydraulic fracturing, filled joints, or the erosion and washing of filling materials of joints. In the grouting operation, by applying the appropriate grouting pressure based on the quality of rock mass, try to prevent to the occurrence of this situation as possible.

Almost 90 % of the grouting sections in the study dam foundation are in category B (low permeability and low cement take), which indicates the low groutability of the dam site.

Undoubtedly, one of the effective parameters on the groutability of the rock mass is the degree of jointing or RQD. The relationship between cement take and RQD of the studied dam foundation can be classified as follows:

a) Low RQD and high cement take: Indicate the high density of joints with good opening or fractured rock mass that joints that have a large aperture.

b) Low RQD and low cement take: Occurs in a rock mass with filled or tight joints.

c) High RQD and high cement take: Implies low density of jointing but with high aperture or dilation capability.

d) High RQD and low cement take: which is related to rock masses containing a low degree of jointing with filled or very tight openings.

In this study, most sections are category (b) and some are category (d), which specify the low cement take in different RQD and the presence of rock mass with low to a high degree of jointing with filled or tight openings and very little continuity.

Experimentally and according to the characteristics of joints and SPI, it is expected that rock masses in class A have cement takes in the range of 0 to 50 kg/m, class B cement takes in the range of 50 to 200 kg/m, class C has a cement takes in the range of 200 to 500 kg/m and class D had a cement take more than 500 kg/m. A study of grouting sections in the studied dam foundation shows that, based on the SPI classification, out of 153 test sections, 66% are class A and had a cement take of 1 to 192 kg/m. 29.4 % are class B and had a cement take of 1 to 180 kg/m. 4.6% are class C and had a cement take of 5 to 148 kg/m. Among class A, 97% of the grouting sections had a cement take of less than 50 kg/m. 3% of the rest sections had cement take between 50-200 kg/m. The average cement taken from the sections in class A is about 8.5 kg/m. In sections class B, 9% had cement take between 50-200 kg/m and 91% of the rest had cement take less than 50 kg/m. The maximum and average cement takes in these sections are 180 and 24 kg/m respectively. In all sections of class C, the average and maximum cement take is 56.3 kg/m and 148 kg/m, respectively. Despite the expectations, SPI classes B and C, which should have a moderate to good groutability, in this study show a low amount of cement take, which can be referenced to the effect of joint characteristics. Therefore, it can be concluded that practically based on

SPI, it is not possible to definitely determine the amount of cement take and groutability in this type of rock masses.

Conclusions

The conducted investigations showed the rock mass of the Peygham-Chai dam foundation is crushed due to three main joints and some sub-joints and faults. Permeability classification of rock mass in the dam site indicates that 71% of the test sections have permeability less than 3 Lu and only permeability in 1% of the test sections is more than 30 Lu. The classification of the amount of cement taken in grouting sections in the drilled boreholes using ArcGIS showed that in 48 % of the grouting sections the cement taken is 1-10 kg/m and only in 1 % of the grouting sections, the amount of cement take is more than 500 kg/m. Investigation of the relation between lugeon number and cement take indicates in most cases, the permeability and cement take are low and only in a few cases, the average cement take is more than 100 kg/m, which occurred in sections with low permeability those related to the class B. In various RQDs, the amount of cement taken was low which indicates the presence of rock mass with a low to a high degree of jointing with filled joints or very tight openings and low continuity. A study of cement take of the study dam site in different classes of the SPI shows that there is no clear relationship between these classifications and cement take. Based on the obtained results, the study dam foundation has low groutability.

Land subsidence susceptibility mapping using WALPSRFT model and Fuzzy- AHP method (Case Study: Damaneh-Daran Plain in the west of Isfahan Province)

Document Type: Research Paper

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Abstract

The phenomenon of land subsidence, which is affected by human activities and various geological and hydrogeological parameters, is occurring in different parts of Iran. Land subsidence susceptibility mapping is a necessary prerequisite for land subsidence management. Proper assessment of land subsidence requires the determination of parameters affecting land subsidence to discover the spatial relationships between them and land subsidence. For this purpose, first, according to the land site subsidence, eight parameters affecting the subsidence in the Damaneh-Daran plain, two models were prepared. In the first model, eight parameters including annual groundwater level drawdown, aquifer medium, land use, pumping volume, aquifer thickness, net charge, distance from fault and topography called WALPSRFT based on weighting parameters and the second model based on optimization and compatibility of eight effective layers in subsidence, Was prepared by AHP-Fuzzy2 method and the final map of land subsidence vulnerability was obtained by combining layers in ArcGIS. Radar images and a Radar Interferometer (InSAR) were used to validate the models. The results show that both maps show a good correlation with radar data, and the map prepared by the hierarchical-fuzzy method shows the highest correlation with real radar data and subsidence in the plain. It separates in more detail of the whole surface of the plain. According to this model, most areas of the plain, especially the eastern part, are subject to subsidence, and management programs should be considered to control subsidence.

Keywords: Aquifer of Damaneh-Daran plain, Analytic Hierarchy Process-Fuzzy, Interferometry Synthetic Aperture Radar, land subsidence, WALPSRFT model.

Introduction

The subsidence phenomenon is influenced by several factors, including the most important and the most common groundwater discharge from alluvial aquifers on the one hand and the decline in aquifer recharge due to multiple climate changes and droughts. Other factors affecting the subsidence are related to the geometrical, geological, and tectonic properties of the alluvial aquifer as well as human activities such as the over-development of agriculture in the area. In recent years, the alluvial aquifer of Damaneh-Daran plain, which is one of the sub-basins of the Gavkhoni wetland, is facing several problems, including subsidence (Fig. 1). The problem of land subsidence in the city of Damaneh in the middle of this plain has become very pronounced and has caused numerous fractures and cracks in the residential area (Fig. 2).

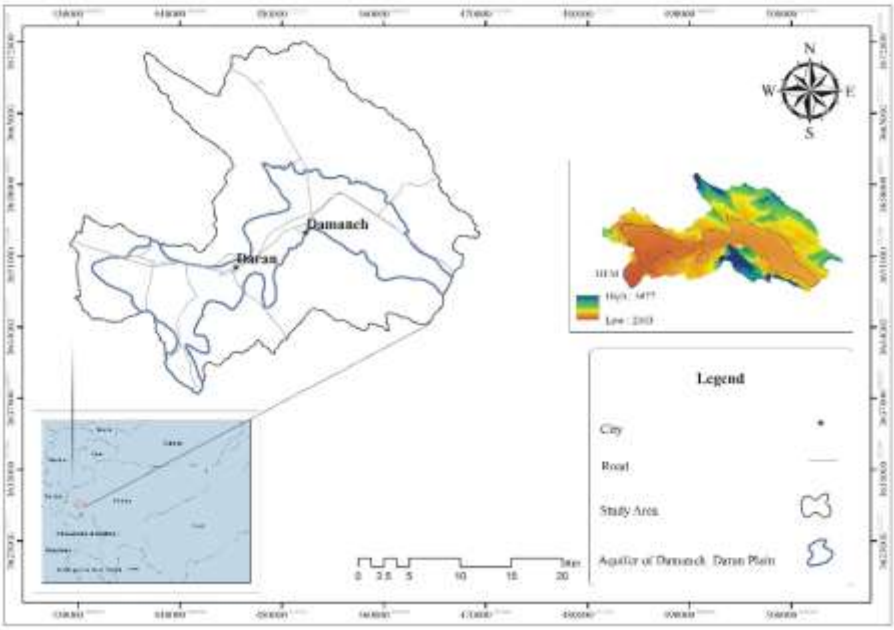

Fig. 1. Location of the study area.

Fig. 2. Numerous fractures and cracks in the residential area

Therefore, in this paper, with the aim of a more detailed study of subsidence vulnerability in Damaneh-Daran plain, a model called WALPSRFT design and its results have been evaluated and optimized with the help of AHP-fuzzy method and finally verified by radar images and using radar interferometer (InSAR) method.

Materials and methods

Damaneh-Daran plain is located about 140 to 180 km west of Isfahan. Alluvial aquifer with an area of 220.3 square kilometres includes 75% of the total area of the plain (293.7 square kilometres). According to previous studies, the type of aquifer is unconfined and in many parts, especially the eastern parts, due to the diversity between the clay layers, the aquifer operates as a confined and aquitard on a local scale. The main direction of groundwater flow is from east, northeast and northwest of the plain to the southwest. The WALPSRFT was used to investigate the subsidence vulnerability in the Damaneh-Daran alluvial aquifer. In the WALPSRFT model, eight parameters are used: annual water table decline, aquifer media, recharge, pumping, and land use, distance from the fault, topography, and aquifer thickness. In the WALPSRFT method, each parameter is assigned a rank and a weight according to the parameter importance. First, layers were prepared for different parameters of the WALPSRFT model. Then, the maps were re-classified and by applying the weighted overlap model in Arc GIS10.4 software, to perform the overlap operations and prepare the maps for modeling. Finally, the Vulnerability map of subsidence was obtained for the Damaneh-Daran plain. The larger the index, the greater the risk of potential subsidence. It should be noted that the obtained index provides only a relative assessment and separates the highly probable subsidence areas from the less likely areas.

Then, to optimally evaluate the parameters used in the above model and evaluate it, a combined AHP-fuzzy method has been used to prepare a subsidence vulnerability map in the plain. To prepare the subsidence vulnerability map in the aquifer by the combined method of AHP-fuzzy analysis, the same ranked maps of eight parameters of the WALPSRFT model have been used. Comparison and evaluation of parameters with the opinion of experienced experts (based on the impact of each parameter on subsidence in the study area), previous studies in other plains of the country that have similar hydrogeological conditions.

Eventually, the radar interferometer method was used to validate the above models and the subsidence of the aquifer was calculated, using SLC-type radar data with iw imaging system in Sentinel.1 satellite and processing in the Snap software environment.

Results and discussion

The ranked maps of each layer were weighted using the raster calculator tool in ArcGIS10.4 software to run the WALPSRFT model. Then, the weighted overlay function was combined with the raster calculator tool to integrate the layers. In this way, the final map of the WALPSRFT model was obtained. The subsidence vulnerability index in the Damaneh-Daran plain aquifer ranged from 103 to 189. Then, based on the values of the above index, the aquifer was divided into four areas with low, moderate, and high vulnerability. Accordingly, about one-third of the area of the aquifer has a high vulnerability. Then, based on the above index values, the aquifer was subdivided into four zones with low, medium, high, and very high vulnerability.

With the aim of optimizing the weights in the preparation of the WALPSRFT model, in order to evaluate this model in the preparation of the subsidence vulnerability map in Damaneh-Daran plain, has been used combined AHP-fuzzy analysis method. Accordingly, in the first stage, with the design of the questionnaire and obtaining comments from several experts in Isfahan regional water companies regarding the evaluation of the effective parameters on subsidence in the Aquifer and previous studies conducted on the evaluation of the vulnerability of other plains which has the same hydrogeological conditions, prioritizing the effect of the parameters on the subsidence occurrence in Damaneh-Daran plain was determined. Assessing the vulnerability of the subsidence of the aquifer with the help of the fuzzy-AHP method also shows an acceptable adaptation to the WALPSRFT model's results.

In order to validate the results of the aquifer vulnerability analysis, the subsidence rate in the Damaneh-Daran plain was determined using the radar interferometer method and compared with the results of the two models. An acceptable overlap is observed in the subsidence-prone areas by comparing the results of the radar interferometer method and the results of the WALPSRFT model and the AHP-Fuzzy method. In order to ensure more results, the correlation coefficient between the maps of the eight parameters used in both methods was obtained with the vulnerability maps obtained by the SDM Toolbox tool in the GIS10.4 ARC software. The results also confirmed eight effective parameters on subsidence in the range of slopes showed a different correlation and significant correlation with the vulnerability maps of the two methods, and on the other hand, the correlation coefficients of these parameters with the map of the AHP- Fuzzy method has more solidarity. Investigating the actual conditions of the region, the areas that are more involved, and the fractures in residential areas and tubing of wells, also confirm the results.

Conclusions

This study aimed to identify possible areas of subsidence in an alluvial aquifer. In this context, the WALPSRFT model was prepared for subsidence analysis in the alluvial aquifer of the Damaneh-Daran plain. The WALPSRFT model results show that the residential areas of Damaneh city and its vicinity, as well as much of the eastern and southeastern part of the study area known as the Qahiz Plain, are highly vulnerable to subsidence. Then, to optimize the assigned weights in preparing the WALPSRFT model, and to evaluate this model in developing the subsidence vulnerability map in the plain, the combined method of AHP-fuzzy analysis was used. Comparison of the map obtained from this method with the WALPSRFT model shows that the AHP-Fuzzy method according to the allocation of optimal weights and based on the principles of correct decision-making in prioritizing and weighing the parameters, with more details in the whole plain, talent subsidence in the aquifer in its various parts. A comparison of the results of the radar interference map with vulnerability maps obtained from the WALPSRFT model and AHP-Fuzzy models shows that the AHP-Fuzzy map has complete subsidence areas aquifer over the above four years. Thus, it was concluded that the AHP-Fuzzy vulnerability map was more efficient in analyzing the aquifer's subsidence area. Therefore, using the AHP-Fuzzy method, more probable regions in an aquifer can be identified in terms of land subsidence, and proper management of the aquifer can prevent this destructive phenomenon.

Assessment of vulnerability and risk mapping in a karst watershed using a combination of VESPA & EPIK indices

Document Type: Research Paper

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Abstract

The exploitation of karst water resources has become very important due to supply and demand tensions and water shortage problems. Utilization of these resources without management and planning causes severe pollution. One of the important tools for this issue is the use of vulnerability indicators and determining the degree of risk of exploiting it. In this study, the dependence of spring appearance as the output of the karst catchment and its catchment is investigated by combining vulnerability indicators. VESPA is one of the most important methods to calculate a spring's vulnerability using effective parameters such as salinity, discharge and water temperature. Moreover, in this study, we applied the EPIK method to assess the vulnerability of the karst watershed. Then, by ranking the effective parameters and combining it with the vulnerability index, it determines the level of risk in the basin. Accordingly, Perikdan and Sarabtaveh springs are in a very high class in terms of vulnerability with the VESPA index and have a high correlation with the EPIK index in assessing the vulnerability of the catchment basin. After determining the vulnerability, the risk of exploitation was determined by ranking the slope parameters, geological formations, natural features and land use. The results showed that the highest risk rate of 74% is located in the southern parts of the region. This area has a large number of sinkholes and permeable karst formations. By combining the risk map and vulnerability index, the risk of the basin was assessed, which showed that about 90% of the basin is in medium and low risk.

Keywords: EPIK, Risk, Sinkholes, VESPA, Vulnerability.

Introduction

Renewable water resources are one of the strategic water sources for supply. About 12% of the earth's surface has carbonate rocks (hard formation) which is the source of water supply for about 25% of the world's population (Zarei et al., 2019). Karst systems indicate the lithological and hydrological situation of soluble formations such as carbonate and evaporite rocks that lead to aquifer formation. VESPA Vulnerability Index is one of the vulnerability indices in karst springs that shows the sensitivity based on the time series of measured data (Lernzo Galini, 2011). This index was evaluated to validate the vulnerability of the karst spring protection areas. EPIK Vulnerability Index by Doyer Fligger (1996) with the aim of evaluating and preparing vulnerable maps of karst water resources and using four indicators of Epicarst (E), protective cover (P), Infiltration conditions (I), and degree of karst network development (K) presented. In 2019, Javadi et al., by combining the vulnerability method of the VESPA spring and MDHT protection index, determined the quality of karst spring in the Yasuj region. The new method, based on the combination of the vulnerability index in the appearance of the spring and the protected area in the spring basin is formed.

Materials and Methods

Case Study

Tang-Kanareh karst area is one of the karst sections in the south of Yasuj city, with an area of km^2, which provides a significant volume of recharging the Yasuj aquifer and water resources in this area. The average annual temperature is 13.5 C$^{\circ}$ in the plains and 13.4 C$^{\circ}$in the highlands. Also, the average annual rainfall in the highlands and in the plains is 795 and 788 mm, respectively. The study of the geological formations of the region indicates that the major part of the region is composed of the Asmari Oligo-Miocene Formation. This formation is one of the youngest formations in the Zagros Mountains in southwestern Iran, which includes carbonate, Mixed carbonate-evaporite, and Mixed carbonate-siliciclastic facies (Van Buchem et al., 2009). In this formation, cream to brown resistant limestones with mountainous morphology are located. Asmari limestone is the most important reservoir of the Zagros sedimentary basin of Iran. Inside this formation, there are fossils belonging from the Oligocene to Miocene.

VESPA Vulnerability Index

The VESPA Vulnerability Index is used to determine the vulnerability condition and conservation areas based on the analysis of the outflow hydrograph of the springs, considering the upstream basin that recharges the springs. Based on Table 1, the classification and level of VESPA are determined.

Table 1- VESPA index values and level of vulnerability

Vulnerability	VESPA
Very High	V≥10
High	10≤V≤ 1
Medium	0.2≤ V ≤ 0.1
Low	0.1≤ V ≤ 0

EPIK Vulnerability Index

The EPIK vulnerability method is based on hydrogeological characteristics developed in karst aquifers and mainly examines 4 characteristics (Doerfliger, 1998). Epicarst (E) based on karst morphology observed in karst surface layers, the protective coating layer (P) based on the presence or absence of soil cover and its thickness, as well as the permeability of soil cover units, infiltration layer (I) based on feeding condition Concentrated or diffuse, and the karst mesh layer (K) is also determined by the characteristics of the ducts.

The value of the vulnerability index of this method varies between 9 to 34 and is divided into four classes: high (19≥), medium (20-25), low (<25), and very low (if the P factor is P4).

Determining catchment risk

In order to determine the level of vulnerability of the catchment area, is done by preparing a probability and vulnerability map of the area. According to the studies conducted and the identification of 4 effective parameters of the slope, land use, geological formations, and natural features, the ranking and the probability are obtained with the expert opinion. The slope parameter was considered according to the nature of the land surface and water-keeping time and pollutants. This parameter has been used in the vulnerability indices of alluvial aquifers and has been used in the karst area risk. Increasing the slope will speed up the transfer of water and salts and thus reduce the risk. The type of geological formations in the region affects the infiltration and transmission of subsurface flows. Land use is very important due to the type of land use. Areas whose use is involved in human activities will be more dangerous than other areas. Areas whose use is involved in human activities will be more dangerous than other areas.

Results and Discussion

Vulnerability assessment of springs with VESPA index

Analysis of three parameters of water temperature, electrical conductivity, and discharge of two springs was obtained to evaluate the VESPA index in accordance with Table 2. Analysis of the curves shows that in Sarabtaveh spring the rate of discharge reaction against electrical conductivity is high and in the months when the amount of recharging due to precipitation and surface runoff was high in the same month the amount of electrical conductivity decreased but in Perikdan spring this reaction was intermittent. It has been accompanied for some time. Analysis of the physical characteristics of the two springs catchment basin indicates that the rate of karst mesh development in Sarabtaveh spring, due to its size, is higher than Perikdan spring or has higher karst development.

Table 2- Vulnerability analysis of springs in the case study based on the VESPA index

Spring	VESPA Index	γ	β	C(ρ)	ρ	Vulnerability Status
Sarabtaveh	8	1.07	17.6	0.42	0.84	high
Perikdan	90.07	2.67	100	0.34	0.67	Very high

The results showed that the Perikdan spring has a very high vulnerability and the Sarabtaveh spring has a high vulnerability. According to the values obtained for the vulnerability index and analysis of the karst development mesh in the Perikdan spring catchment area and relative to the catchment area, the result indicates that the vulnerability situation is critical and the risk of high pollution in this spring. In the Sarabtaveh spring, the value of the vulnerability index was high but was lower than the Sarabtavah spring.

Vulnerability assessment of the region using the EPIK index

According to Table 3, the percentage of vulnerability classification area is determined by the EPIK method. The results show that the most vulnerable class is the middle class.

Table 3- Vulnerability classification area by EPIK method

Vulnerability	Area-km^2	Ranking	Percentage of area
Low vulnerability	28.2	34-26	15
Moderate vulnerability	85.8	25-20	45
High vulnerability	77.4	19-9	40

Integration of spring and catchment vulnerabilities

A spatial study of the vulnerability of the Cheshmeh Sarabtaveh catchment area shows that about 40% of the basin is in the high vulnerability class and the remaining 60% is in the medium vulnerability class. The central part of this basin has a karst process with lower speed due to the waterway of this region and the land use of this region.

Ranking of parameters affecting risk

Most of the Tang-Kanareh area with Asmari karst formations has an important role in recharging and transmitting groundwater flows. Table 4 presents the ranking of geological formations.

Tang-Kanareh region, due to its special morphological and hydrogeological conditions, is less affected by human factors and the activity of the villagers and livestock has the greatest impact on the risk of the region.

The results of the risk rating in the Tang-Kanareh area show that the rating changes are between 16% to 74%. The northeastern and central parts of the region are in the lowest rank.

Table 4- Classification of operating parameters of geological formations

Formation type	Rank
Gray shale, marl with middle loess	0.25
Bluish white shale	0.1
Thick limestone layer to mass	0.7
Marl, conglomerate and sandstone	0.2
Barracks and alluvial fans	0.4

Conclusions

Today, the exploitation of karst water resources has grown significantly due to climate stress and various developments. Although this operation has reduced the stresses of water supply and demand, but also increases the risk of pollution. Karst water sources are very vulnerable due to being located in a high porosity basin, which will cause a variety of pollution. This study evaluated the vulnerability of the Tang-Kanareh region in the south of Yasuj city. Accordingly, the vulnerability of the region was assessed using the EPIK vulnerability index and this index was evaluated in the two main springs of the region, which are Sarabtaveh and Perikdan springs.

The vulnerability of the region was assessed using the EPIK vulnerability index and this index was evaluated in the two main springs of the region, which are Sarabtaveh and Perikdan springs. Based on this, the vulnerability of two springs was measured using the VESPA index, which showed that Sarabtaveh spring is in a high vulnerability condition and Perikdan wool is in a very high vulnerability situation. After assessing the vulnerability of the area, the risk of the area was assessed by ranking the four factors of the land slope, land use, natural karst landforms, and geological formations. Based on these four factors and combining them with the vulnerability of the area by the EPIK method, the area was assessed. The results showed that most of the region is in a low and very low-risk situation and the southern part of the region, where the main volume of springs and water holes is located, is in a high-risk situation.