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Effects of Changes in Heavy Metal Concentration on Effluent Quality in the Water Recovery Cycle Using the Storage-Recovery Technique

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Abstract

Declining water tables in groundwater aquifers and increased wastewater production are some of the important problems of our country today. This challenge could be converted into an opportunity through proper planning, in such a way that effluents and other surplus waters are used to implement the storage-recovery system of the aquifer, the quality of the effluent is improved using soil's self-purification potential, the water level in the aquifer is raised and water is withdrawn from this source when needed. The present study was conducted to investigate the changes in the effluent and aquifer water quality by passing it through the unsaturated area and moving in the saturated area in the Chalous aquifer storage-recovery project. In simulating the study area for the measurement of the mentioned parameters, we first created a rectangular hole with specific dimensions of about 5 to 10 meters in the basement (depending on the conditions of the area). The effluent was injected into the hole by creating small pits on the surface. The volume of the hole was considered to be 5000 liters. To prevent water from penetrating from the bottom of the pit and to simulate using an aquifer, a layer of cement and sand mixture was directed into the hole to prevent water infiltration from the bottom of the pit. A daily volume of 1000 liters of effluent was injected for 5 days. After 60 days, recycled effluent and soil samples were collected for analysis from the outlet using a piezometer tube. Along the route, the content of heavy metals such as lead and cadmium was measured and the transfer of solutes was examined by the MODFLOW model in the saturated and unsaturated regions. The results showed that cadmium and lead were deposited in the first few centimeters of the route. The concentrations of nitrate, as well as microbial contaminants, were reduced to almost zero by denitrification and adsorption after a short distance.

Keywords; storage – recovery, aquifer, effluent, heavy metals.

Introduction

Only 31% of the total volume of renewable freshwater is available for human consumption. On a global scale, the annual amount of water withdrawn for irrigation accounts for more than 65% of total human consumption (1). Industrial water consumption is about 20% and urban water consumption is about 10%. North Africa and the Middle East, especially Egypt and Saudi Arabia, are among the countries with the least amount of fresh water. Currently, water reclamation and recovery projects are increasingly being implemented in water-deficient countries. Other factors, such as the infiltration of saline water into freshwater resources in coastal areas and the ban on sewage disposal in environmentally sensitive environments, will also influence the decision to retrieve water (2).

Water recovery protects the environment by reducing the discharge of treated wastewater into natural waters. The treated water obtained from the treated effluents contains essential elements that, if used to irrigate agricultural land, provide a small amount of chemical fertilizer for crop growth. Therefore, modified water meets the need for chemical fertilizers, which results in the conservation of resources. The most important applications of water recovery from municipal wastewater are mentioned in the following in descending order of water use volume. The majority of water recovery projects are for non-drinking uses such as agriculture, green space, and industrial uses. Where groundwater is fed with treated water, the drinking water can be indirectly recovered (4).

The Storage-recovery technique, by collecting aquifer information, storage of wastewater in a safe place, and reuse of rainwater, returned excess waters, etc., is of great importance and consideration as a purposeful and optimal methodology. In this method, in addition to storing effluents and excess water using the aquifer soil, the quality of effluent is improved. The use of aquifer soil is a widespread, low-tech, and low-cost method for wastewater treatment and is known as an important method to improve water quality. The wastewater is treated to an intermediate level and then injected into a local aquifer (5). Microorganisms, suspended solids, and inorganic toxic compounds, such as heavy metals, are removed from soils and aquifers through physical, chemical, and biological processes. Storage of the effluent behind dams creates many environmental problems. Pollution in the effluent behind the dam and exposure to light causes the growth of microbes and algae, which in turn contaminates the freshwater. Using the storage-recovery technique in the aquifer can be a good alternative for surface water storage (6).

In a study by Abolfazl Pouzan, Majid Khayat Kholghi, and Abdolhossein Hoorfar in 2015 at the University of Tehran, the management of storage-recovery of groundwater aquifers was investigated. In recent years, the Fashafoyeh plain in the south of Tehran has faced a sharp drop in groundwater levels. Also, with the full commissioning of the treatment plant in the south of Tehran, a large volume of effluents is produced. Therefore, the Fashafoyeh area in the south of Tehran was selected as the study area. For this purpose, after hydrogeological studies and understanding the structure of the Fashafoyeh aquifer, the storage-recovery sites in this plain were selected. The best places for feeding in storage-recovery systems in the aquifer were determined after geological studies and investigation of soil permeability, land use, groundwater depth, etc. The results showed that six areas are suitable for the construction of these systems. Then, numerical modeling of the region was performed based on the information of the region, and systems were managed using a numerical model. Some of the effluents were injected into the systems and simulated. The results showed that one year after the establishment of the 23 systems, the groundwater level in the center of the study area increased up to … meters. The general results of the present study showed that this system could be used for storing water up to 43 meters and in the northern and southern parts up to … m. They can be used to prevent the severe drop in the level of groundwater and to save the plains, as well as to use groundwater for agricultural lands (7).

Amir Niazi (2014) concluded that using effective water resources management strategy, the evaporated water losses and groundwater level reduction during water supply for agricultural activities could be minimized through water storage-recovery of drinking water in a long period (8).

Castro (2011) reviewed aquifer storage-recovery projects and his studies showed that aquifer storage-recovery projects are an effective and inexpensive solution to increase storage and eliminate pollution.

Storage-recovery wells in the aquifer can store a significant amount of treated water. With a storage-recovery well, the aquifer can supply more than eight percent of peak drinking water requirements. Note that aquifer storage-recovery wells can be built anywhere and can be used to replace storage tanks, which are limited and expensive. As a result, aquifer storage- recovery systems are simple, easy to implement, and have significant storage capacity. These systems can be located anywhere in distribution systems and are significantly cheaper than conventional storage methods. One of the most comprehensive long-term behavioral assessment programs for a large area affected by nutrition was implemented in Los Angeles, California, where recycled effluent has been injected into the aquifer since 1962. Using a sulfate ion tracer model, the percentage of feedwater that has been used for public consumption can be accurately estimated and used to determine the actual populations that use it (9).

David Chon et al. (2019) used a SWAT-MODFLOW model for groundwater level (GW-SW) to study climate conditions and the potential effects of climate change and groundwater usage on GW-SW interactions at the regional scale in western Canada. The pieces of the model were calibrated and validated using monthly river data and hydraulic data for the period 1986-2007. Weather forecasts from five general circulation models (GCM) were calibrated in the model under RCP 8.5 for the period 2010-2034. The results showed that, in the upstream, the GW-SW changes had the highest fluctuations between wet and dry months in historical conditions (10).

The present study aimed at obtaining the required data and providing the intended model, which paved the way for appropriate decision-making in all scenarios. These results allow project managers and executives to make the best implementations and decisions to maximize profits and minimize environmental and social damages. Objectives of the present study include determining the appropriate places for feeding, amount of feed, and management methods for storage-recovery systems in the aquifer. All of these objectives are to determine the best possible case for decision-making that can be used during project implementation. Of course, it is very difficult to determine the optimal feeding state in the implementation of projects, because there are many limitations, all of which must be considered along with the social issues.

Methodology

This study aimed to investigate the trend of changes in aquifer water quality and injected wastewater using the storage-recovery technique in Chalous city, Mazandaran province. Considering that to achieve the objectives of the research, first, the necessary conditions should have been met for injecting effluent before measuring the quality of retrieved water, the main stages of the research can be summarized as follows:

A. Selection of a suitable aquifer: To fully achieve the objectives of this study, it was necessary to be careful in selecting the aquifer.
B. Creating a test hole to simulate the aquifer: The purpose of creating a simulation hole is to sample and analyze the incoming effluent and the soil and injecting the effluent by surface injection method and its soil infiltration.
C. Additional and comparative tests: Sampling and analysis of effluent and soil sampling and re-analysis were performed at this stage.

Area of study

The present study aimed at investigating the trend of changes in aquifer water quality and injected wastewater using the storage-recovery technique in Chalous city, Mazandaran province. Chalous city is located at the latitude of 36.6459 and the longitude of 51.4070. The city is bordered by the Caspian Sea from the north, Noor city from the southeast, Qazvin province from the south, and Tonekabon city from the west (11).

Figure 1. Location of Chalus aquifer

The location of Mazandaran province includes two main coastal and mountainous plains 1of Alborz. The extension of the Alborz mountain range surrounds the coastal strip and the plains along the Caspian Sea like a high and long wall. Throughout Mazandaran province, the slope and height of the earth decrease from the heights to the plains and towards the Caspian Sea. At the intersection of the plains and foothills of northern Alborz, due to the erosion severity and alluvial density, part of the old terrain is covered with newer sediments and in some places, it has turned into hills. Under the influence of the breeze from the sea and local winds, coastal dunes have formed in the plains of the southern and eastern shores of the Caspian Sea. They have created a natural and low-level dam between the sea and the plain. Also, in the eastern part of the Mazandaran Plain, there are thick sediments in the form of relatively high rough countries, whose western extension is bordered by the cities of Behshahr and Neka. Mazandaran province’s nature is affected by its latitude, Alborz heights, altitude, proximity to the sea, local and regional winds, displacement of north and west air masses, and even dense forest cover. Therefore, despite its small size (and contrary to popular belief that its climate is considered to be temperate consistently), this region has a special climate variability. Two major currents play a major role in the province's climate conditions - one being the north and northeast air currents from Siberia and the Arctic to the south and southwest, causing cold weather, frost, snow, and rain. This air mass is pushed toward the north in the summer and has little effect on the climate of Mazandaran. Another one is the flow of westerly winds that cross the Atlantic Ocean, the Mediterranean Sea, and the Black Sea in winter, causing heavy and continuous rainfall after entering Iran. The precipitation power of these winds decreases during the summer and only causes increased humidity and sultry weather, creating unfavorable living conditions. In addition to the wind and the movement of the major air masses, there are other local winds such as Surtrak (a branch of Siberia in winter), Khoshabad Darreh Noor, Orzerva (cold winter wind from east to west), Gilva (from Mazandaran to Gilan) and Sam (winds from south to north during spring and summer), that locally and seasonally affect the climate of Mazandaran province. Considering the temperature and precipitation rate, the climate conditions of Mazandaran province is divided into several types: Caspian temperate climate: western and central plains of the province have a temperate Caspian climate up to the northern foothills of Alborz and its extension in a narrow strip toward the east, which is bounded to the main path of Gorganrood from the north. Due to its proximity to the Caspian Sea on the one hand, and the short distance between the Alborz mountain wall and the sea, on the other hand, these areas have a moderate temperature (12).

Quality of effluent used

Since the effluent used in this study was obtained from the domestic wastewater treatment plant of Chalous city, lead and cadmium were added to the effluent manually. Then, pH, EC, K, Na, Ca, Mg, CL, SAR, Cd, Pb, BOD5, COD, coliform, and Escherichia coli were determined in the effluent.

Table 1. Physicochemical and biological analysis of domestic wastewater from the treatment plant

Measured parameter	Unit	Concentration
COD	mg/L	**232**
BOD5	mg/L	**150**
EC	$d\,s/m$	**83.1**
PH	**-**	**9.7**
Nitrogen	mg/L	**11.32**
phosphorus	mg/L	**41.3**
Potassium	mg/L	**18.12**
Total organic carbon	mg/L	**47.150**
Nickel	mg/L	**83.1**
Cadmium	mg/L	**0.40**
SAR	**-**	**01.1**

Sodium	meq/L	**82.13**
Calcium	meq/L	**51.3**
Magnesium	meq/L	**71.2**
Sulfate	meq/L	**42.3**
bicarbonate	meq/L	**18.11**
Chlorine	meq/L	**2.8**
Iron	mg/L	**51.1**
Lead	mg/L	**0.1**
Fecal coliform	**No./100ml**	$1/2 \times 10^{18}$
Parasite eggs	**No./L**	**<1**

Determination of physical and chemical properties and soil texture

In this study, the soil texture was determined based on classification and hydrometric methods. In this project, before starting, the soil tests performed in the laboratory were analyzed and some of the chemical parameters were measured.

Table 2. Physical and chemical properties of soil

Measured parameter	Unit	Concentration
Sand	**%**	**58.72**
Clay	**%**	**19.9**
Slit	**%**	**22.09**
Farm capacity (Fc)	Volume percentage	**0.34**
Permanent wilting *point* (PWP)	Volume percentage	**0.22**
Electrical conductivity	Desi Siemens Barometer	**0.75**
pH	**-**	**7.90**
Calcium	mg/kg	**29.8**
Magnesium	mg/kg	**27.4**
Phosphorus	mg/kg	**38**

Potassium	mg/kg	**21**
Iron	mg/kg	**11.03**
Lead	mg/kg	**1.73**
Cadmium	mg/kg	**0.01**
Copper	mg/kg	**1.49**
Manganese	mg/kg	**8.08**
Zinc	mg/kg	**1.83**
Nickel	mg/kg	**0.005**
Organic material	**%**	**0.88**
Lime	**%**	**11**
Carbonate	meq/L	**0.00**
BiCarbonate	meq/L	**4**
Sulfate	meq/L	**2.08**
Chlorine	meq/L	**6**

Chemical parameters of effluent and aquifer

In this study, the following parameters were measured: Bicarbonate, cadmium, and lead.

Methods of measuring the chemical parameters of effluent and aquifer before and after testing:

To measure these parameters, different methods and devices were used to suit each parameter, including:

Titration: Measurement of bicarbonate

Atomic absorption: Measurement of cadmium and lead

Procedure

After making preparations for the project and determining the severe drop in the aquifer which provided the necessary conditions for feeding the aquifer, after coordination, the domestic sewage effluent was transported to the site by a 1000-liter trailer, and the effluent was injected through the surface in a concentrated way. It should be noted that before and after the test, the physical, chemical, and microbial properties of the effluent and soil of the area were analyzed and studied. The simulation of the study site to measure the mentioned parameters was as follows: First, we dug a 5 - 10 m rectangular hole in the ground (depending on the conditions of the area). The effluent was injected through the surface into small pits in the hole. The volume of the hole was considered to be 5000 liters. To prevent water infiltration from the bottom of the pit, a layer of cement and sand mixture was directed into the hole. Injection of 1000 liters of effluent per day continued for 5 days. After 60 days, the affluent and soil sample was collected from the hole outlet by a piezometer tube for analysis.

MODFLOW model

MODFLOW software is considered the best model of groundwater simulation. This software simulates the movement of groundwater by solving the equation governing the flow of water in a porous medium. The finite-difference equation was the numerical method used in this software. Therefore, to simulate this model, we first meshed the model. Then the required parameters are entered. The cells formed in this model are divided into 3 categories: active, inactive, and with a fixed aqueous load. In the inactive cells, there is no current and the flow and solute transfer could not be simulated in these cells. MODFLOW is a computer program that solves water flow equations in groundwater layers. This software has been obtained using hydrogeology to simulate groundwater flow through aquifers. The source code of the software is free public property.

Groundwater flow equation

The governing partial differential equation for a compressed aquifer used in MODFLOW is as follows:

$$\frac{\partial}{\partial x}\left[K_{xx}\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_{yy}\frac{\partial h}{\partial y}\right]+\frac{\partial}{\partial z}\left[K_{zz}\frac{\partial h}{\partial z}\right]+W=S_S\frac{\partial h}{\partial t}$$

Where, K is the values of hydraulic conductivity along the X, Y, and z axes

h is the potentiometric water level

W is a volumetric flow per unit volume

Ss is the storage coefficient of porous material

And, t is time.

Finite difference equation

The finite-difference equation of the partial differential form in a discrete aquifer domain (representing rows, columns, and layers) is as follows:

$$\begin{aligned}
&P^{i,j,k}h^{m}_{i,j,k}+Q^{i,j,k}=SS^{i,j,k}\left(\Delta r_j\Delta c_i\Delta v_k\right)\frac{h^{m}_{i,j,k}-h^{m-1}_{i,j,k}}{t^{m}-t^{m-1}}\\
&CV^{i,j,k-\frac{1}{2}}\left(h^{i,j,k-1}_{m}-h^{i,j,k}_{m}\right)+CV^{i,j,k+\frac{1}{2}}\left(h^{i,j,k+1}_{m}-h^{i,j,k}_{m}\right)+\\
&CC^{i-\frac{1}{2},j,k}\left(h^{i-1,j,k}_{m}-h^{i,j,k}_{m}\right)+CC^{i+\frac{1}{2},j,k}\left(h^{i+1,j,k}_{m}-h^{i,j,k}_{m}\right)+\\
&CR^{i,j-\frac{1}{2},k}\left(h^{i,j-1,k}_{m}-h^{i,j,k}_{m}\right)+CR^{i,j+\frac{1}{2},k}\left(h^{i,j+1,k}_{m}-h^{i,j,k}_{m}\right)+
\end{aligned}$$

To be solved, this equation is formulated into a system of equations:

Where,

$h^{m}_{i.j.k}$ is the hydraulic water level in cells I, J, K at time m

CV, CR, and CC are electrical, hydraulic, or conductive transfer between nodes i, J, K, and a neighboring node

P is the sum of the water level coefficients of the source and sink

Q is the sum of constants of the source and sink, where Q <O.O is the output current from the groundwater flow system (such as a pump) and Q> O.O is the input current (such as injection)

SS is the storage coefficient

Δ is the dimensions of the cell I, J, K, when multiplied by cell volume

And t is time (m).

Modular models

The US Geological Survey developed several hundred models for groundwater in the 70s. These models were written in different versions of the Fortran programming language. At that time, there was a need for a common endeavor to rewrite a new model in line with the need for the new groundwater scenario. The MODFLOW concept was developed in 1981, which led to the introduction of a common modular groundwater model (3).

$$\begin{aligned}
&CV_{i,j,k-\frac{1}{2}} h^m_{i,j,k-1} + CC_{i-\frac{1}{2},j,k} h^m_{i-1,j,k} + CR_{i,j-\frac{1}{2},k} h^m_{i,j-1,k} \\
&+ \left(-CV_{i,j,k-\frac{1}{2}} - CC_{i-\frac{1}{2},j,k} - CR_{i,j-\frac{1}{2},k} - CR_{i,j+\frac{1}{2},k} - CC_{i+\frac{1}{2},j,k} - CV_{i,j,k+\frac{1}{2}} + HCOF_{i,j,k}\right) h^m_{i,j,k} \\
&+ CR_{i,j+\frac{1}{2},k} h^m_{i,j+1,k} + CC_{i+\frac{1}{2},j,k} h^m_{i+1,j,k} + CV_{i,j,k+\frac{1}{2}} h^m_{i,j,k+1} = RHS_{i,j,k}
\end{aligned}$$

Results and findings

Changes in the concentration of heavy metals in the effluent after passing through the porous soil environment

To make optimal use of the effluent and also to fill the empty spaces of the aquifer, we injected the sewage into the aquifer for 5 days. 1000 liters of effluent was injected daily to a depth of 5 meters. Since this element is not present in the effluent, to investigate the effect of soil on this element, we added a small amount of it to the effluent manually. To compare and draw linear diagrams, the physical properties of the effluent and soil were first tested. 5 and 15 days after the injection of the effluent, new samples of the effluent were collected and sent to the laboratory. Here, we compare the Cd in the effluent. We collected the effluent in the following intervals and measured its Cd content in a laboratory: On the fifth, tenth, fifteenth, thirtieth, forty-fifth, and sixtieth days after the injection.

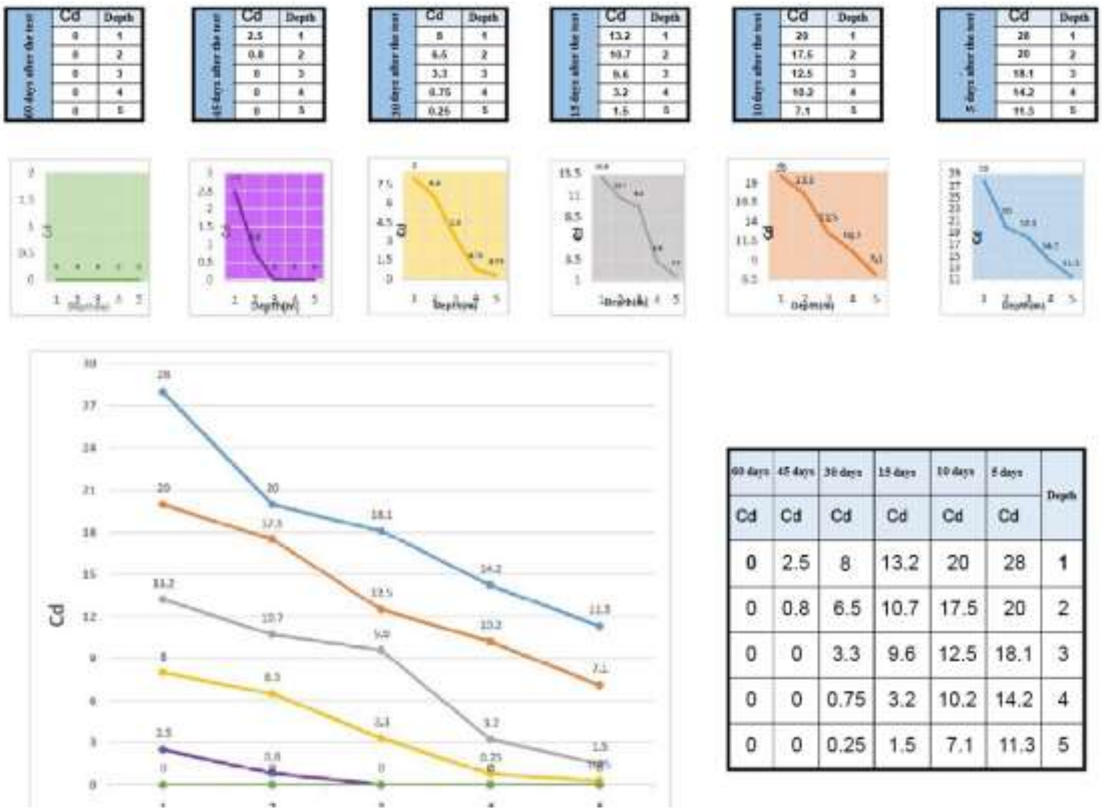
To perform this test on April 21, 2019, we received the results of an effluent test from the Chalous Wastewater Treatment Plant, whose initial Cd content was measured at 36 mg/L. Then, 5000 liters of effluent were injected into the hole dug in the ground on April 22-26, 2019 (1000 liters per day). First, on May 1st (the fifth day after the last effluent injection), the effluent was sampled from depths of 4, 3, 2, 1, and 5 m and sent to the laboratory. Then on May 6 (the tenth day after injection), May 11 (15th day after injection), May 26 (30th day after injection), June 10 (forty-fifth day after injection), and June 25 (60th day after injection), we repeated the same procedure. We simulated the results using the MODFLOW software so that the results of the software become closer to the results obtained from the aquifer.

The results of Cd in the mentioned days and depths were entered into an Excel file for comparison as well as for generating the linear graphs, and as a result, we attached the obtained graphs and tables to this experiment. Since the presence of nitrate is very harmful to humans and the environment and causes many diseases in humans, only a small amount of this element would be acceptable in the groundwater. As can be seen from the results, due to the filtration properties of the soil, the content of this element in the soil has a decreasing trend and in the end, we can see that the content of this element is quite within the acceptable and standard range and is quite satisfactory. The amount of cadmium also reduces to zero.

Table 3. Changes in cadmium content through the depth

An initial amount of Cd is 36 mg/L						
Depth	5th day	10th day	15th day	30th day	45th day	60th day
1	-22.0%	-44.0%	-67%	-78.0%	-93.0%	0.0%
2	-44.0%	-51.0%	-76.0%	-82.0%	-98.0%	0.0%
3	-50.0%	-65.0%	-91.0%	-91.0%	0.0%	0.0%
4	-61.0%	-72.0%	-95.0%	-98.0%	0.0%	0.0%
5	-69.0%	-80.0%	-97.0%	-99.0%	0.0%	0.0%

Figure 2. Changes in cadmium content



60 days	45 days	30 days	15 days	10 days	5 days	Depth
Cd	Cd	Cd	Cd	Cd	Cd	
0	2.5	8	13.2	20	28	1
0	0.8	6.5	10.7	17.5	20	2
0	0	3.3	9.6	12.5	18.1	3
0	0	0.75	3.2	10.2	14.2	4
0	0	0.25	1.5	7.1	11.3	5

Changes in the concentration of heavy metals in the effluent after passing through the porous soil

To make optimum use of the effluent and also to fill the empty voids of the aquifer, we injected the wastewater into the aquifer for 5 days. We injected 1000 liters of effluent daily to the depth of 5 meters into the soil. For comparison and drawing linear diagrams, we first tested the physical properties of the effluent and soil to take new samples of the effluent and send them to the laboratory within 15 days from the time of injection. In this article, we compared the NO_3 in the effluent. For this purpose, we collected the effluent in the following intervals and measured the NO_3 in a perpendicular laboratory (on the first, second, tenth, twentieth, thirtieth, fortieth, fiftieth, and sixtieth days after injection).

To perform this test, we received the test results of the effluent taken from the Chalous Wastewater Treatment Plan on April 21, 2019. The initial NO_3 was measured at 22 mg/L. Then, 5000 liters of effluent was injected into the hole from April 22 to April 26, 2019 (1000 liters per day). On April 27, 2019 (one day after the last effluent injection), we sampled the effluent for the first time from depths of 1, 2, 3, 4, and 5 m and sent the samples to the laboratory. We repeated the same process on April 28, May 6, May 16 (20th day after injection), May 26 (30th day after injection), June 5 (40th day after injection), June 15 (50th day after injection), and June 25 (60th day after injection). We simulated the results using the MODFLOW tool so that the results obtained using this software are close to the results obtained in the aquifer. We entered the NO3 results related to the mentioned days and depths to compare them and draw a diagram in an Excel file. As a result, the obtained diagrams and tables were attached to this experiment. Because the presence of nitrate is very harmful to humans and the environment and causes many diseases in humans only a small amount of this element would be acceptable in groundwater. As can be seen in the results, the content of this element decreases due to the filtration of the soil, and finally, we see that this element is completely within the acceptable and standard range and is completely satisfactory.

Table 5. Changes in nitrate content by the depth

An initial amount of NO3 is 22 mg/L								
Depth	1st day	2nd day	10th day	20th day	30th day	40th day	50th day	60th day
1	0.0%	-2.3%	9%	4.5%	2.3%	-16%	-16%	-24%
2	0.0%	-2.3%	9%	-2.3%	-1.4%	-26%	-34%	-31%
3	0.0%	-2.3%	9.5%	-6%	-9%	-21%	-43%	-35%
4	0.0%	-4.5%	12%	-11%	-13%	-30%	-47%	-37%
5	0.0%	-4.5%	5.5%	-17%	-15%	-31%	-50%	-45%

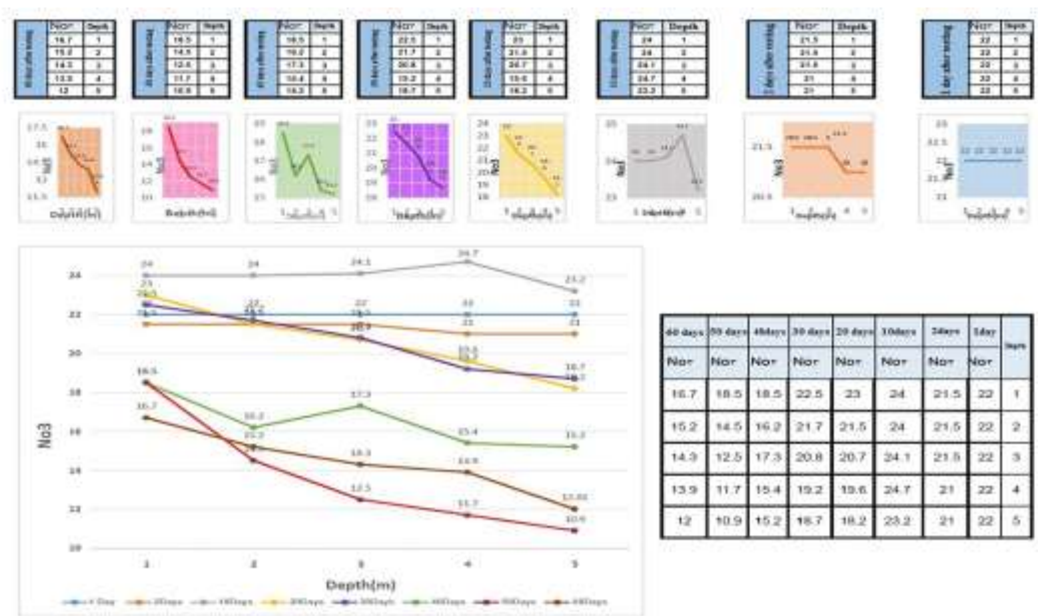


Figure 3. Changes in nitrate content

Changes in the concentration of heavy metals in the effluent after passing through the porous soil

To make optimum use of the effluent and also to fill the empty voids of the aquifer, we injected the wastewater into the aquifer for 5 days. Since this element is not present in the effluent, to investigate the effect of soil on this element, we added a small amount of it to the effluent manually. We injected 1000 liters of effluent daily to the depth of 5 meters into the soil. For comparison and drawing linear diagrams, we first tested the physical properties of the effluent and soil to take new samples of the effluent and send them to the laboratory within 15 days from the time of injection. In this article, we compared the Pb in the effluent. For this purpose, we collected the effluent in the following intervals and measured the Pbin a perpendicular laboratory (on the fifth, tenth, fifteenth, thirtieth, forty-fifth, fiftieth and sixtieth days after injection).

To perform this test, we received the test results of the effluent taken from the Chalous Wastewater Treatment Plan on April 21, 2019. The initial Pb was measured at 20 mg/L. Then, 5000 liters of effluent was injected into the hole from April 22 to April 26, 2019 (1000 liters per day). On May 1st, 2019 (five days after the last effluent injection), we sampled the effluent for the first time from depths of 1, 2, 3, 4, and 5 m and sent the samples to the laboratory. We repeated the same process on May 6 (10th day after injection), May 11 (15th day after injection), May 26 (30th day after injection), June 10 (45th day after injection), and June 25 (60th day after injection). We simulated the results using the MODFLOW tool so that the results obtained using this software are close to the results obtained in the aquifer.

We entered the Pb results related to the mentioned days and depths to compare them and draw a diagram in an Excel file. As a result, the obtained diagrams and tables were attached to this experiment. Because the presence of Pb is very harmful to humans and the environment and causes many diseases in humans only a small amount of this element would be acceptable in groundwater. As can be seen in the results, the content of this element decreases due to the filtration of the soil, and finally, we see that this element is completely within the acceptable and standard range and is completely satisfactory.

Table 6. Changes in Pb content through the depth

An initial amount of Pb is 20 mg/L						
Depth	5th day	10th day	15th day	30th day	45th day	60th day
1	-10%	-20%	-34%	-49%	-62%	0.0%
2	-10%	-30%	-47%	-58%	-74%	0.0%
3	-13%	-42%	-52%	-69%	-82%	0.0%
4	-13%	-54%	-84%	-93%	-96%	0.0%
5	-13.5%	-83%	-93%	-97%	0.0%	0.0%

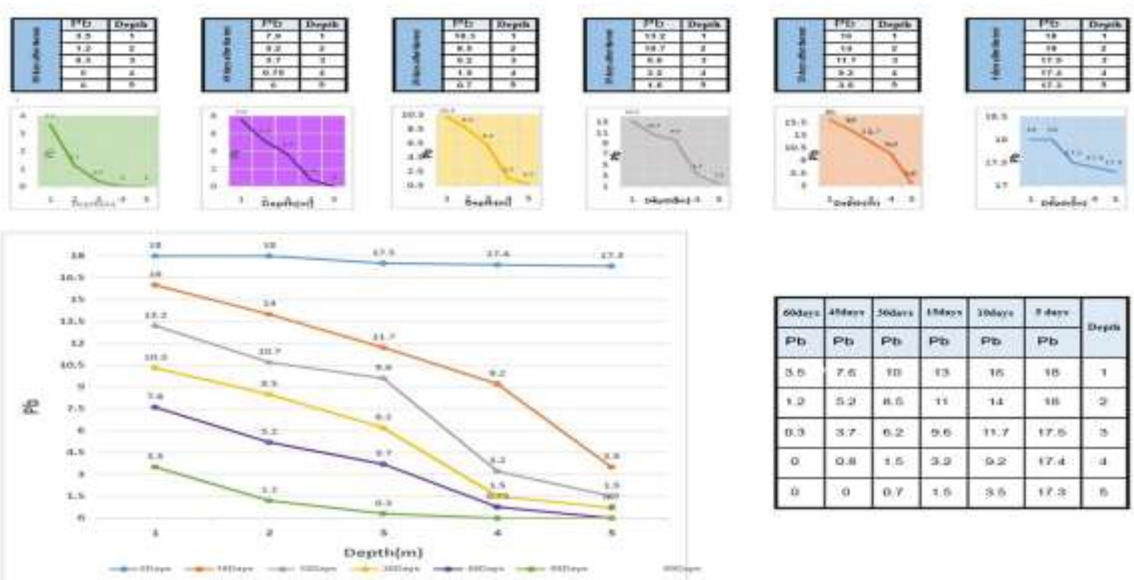


Figure 4. Changes in Pb content

Conclusion

In this study, the effect of changes in heavy metal concentrations on the quality of effluent in the recovery cycle was investigated using the storage-recovery technique. The results are as follows:

1-The carbonate content in the effluent, aquifer, and soil is zero and over time, no change was observed in this parameter. However, the bicarbonate content in the effluent and aquifer is relatively high but was improved by passing the effluent through the unsaturated area. Continuing to the area of mixing with the aquifer water, the quality of this water was also improved. Also, moving in the saturation zone along the path, the quality was further improved. The trend of changes shows that the quality gets better by moving a higher distance. 16 days after the start of injection, the efficiency of the system in improving the quality of effluent and aquifer water in terms of the bicarbonate content is still suitable. The concentration of nitrate in the effluent decreased significantly by passing through the unsaturated area and then the quality of the aquifer water was improved so that after moving 1 meter from the beginning of the model, the concentration of nitrate approached zero. This sharp decrease in concentration is due to denitrification that occurs along the route. The nitrogen gas produced was collected and removed during the sampling. Therefore, it can be seen that this system has been very successful in improving the quality of effluent and aquifer water in terms of nitrate concentration. The aquifer storage-recovery system should be implemented in such a way that the denitrification phenomenon is performed there as well, to improve not only the quality of the effluent along the path but also the quality of the aquifer water. One of the aggravating factors in denitrification is temperature because ideal temperature conditions increase the population of bacteria performing denitrification activity. During the day in the project area, the temperature inside the soil and water increased to about 96 degrees Celsius. However, the factor of temperature has little effect on denitrification and it occurs at both high and low temperatures.

2-Both heavy metals of cadmium and lead precipitated in the first few centimeters of the route and the soil showed a high potential to hold these metals and bring the quality of the effluent to a good level in terms of the content of these two metals. There is no concern about the movement of these metals and their penetration into the groundwater during the aquifer storage-recovery project, because, the soil of this area is alkaline and heavy metals are strongly deposited in the alkaline soil and only have small movements.

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