Journal of Civil Aspects and Structural Engineering

www.case.reapress.com

J. Civ. Asp. Struct. Eng. Vol. 2, No. 2 (2025) 135–154.

Paper Type: Original Article

Investigating the Performance of Hydraulic Structures (Artificial Recharge) in the Bushehr Plain, Dashestan County, Bushehr Province

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Citation:

Received: 07 September 2024 *Revised: 04 October 2024* *Accepted: 11 February 2025*	Kashefi, K., & Amirnia, S. (2025). Investigating the performance of hydraulic structures (Artificial rechargeshehr province. *Journal of civil aspects and structural engineering, 2*(2), 135–154.

Abstract

Artificial recharge schemes have been implemented in the country for more than forty years in various ways. In the past years, the artificial recharge pond method has had the largest share, but for nearly two decades, their implementation has been mostly in the form of water distribution in the pond method and flood distribution. For this purpose, this research was conducted with the aim of investigating the performance of hydraulic structures (Artificial recharge) in the Bushekhan Plain, Dashestan County, Bushehr Province. This research seeks to identify factors that lead to positive or negative effects in artificial recharge schemes, so that they ultimately lead to the success or failure of these types of schemes. This research also describes the role and impact of factors affecting the performance of artificial recharge schemes. The present study is actually a retrospective study in which, based on the experiences gained with the help of researchers, an attempt has been made to identify important factors. More than 50 researchers have participated in the survey based on their experiences. The results of the study showed that, in accordance with the prevailing conditions in the country, 16 factors are of great importance in the success of artificial recharge schemes in the country, of which seven factors were identified as the main factors. The main factors include 1) the number of field withdrawal periods per year, 2) field permeability, 3) groundwater depth, 4) aquifer hydraulic conductivity, 5) strength of the recharge facility, 6) water quality, and 7) the importance of water in the recharge area. The findings of the study showed that the artificial recharge scheme of the Bushekan Plain in the first three months of recharge has been able to increase the water head by up to 600 meters at intervals of 500 meters from the center of the recharge basin in a three-month period.

Keywords: Artificial recharge, Performance evaluation, Bushekan plain.

1 | Introduction

Freshwater resources are very limited to support food production in different regions of the world. Future climate projections include wetter and longer periods of increased rainfall, which will increase the occurrence of floods and flash floods. Groundwater demand management and MAR, also known as groundwater

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10.48314/jcase.v2i1.52

recharge, water banking and artificial recharge, is the targeted feeding of water into aquifers for subsequent recovery or environmental benefits. It is an essential strategy to overcome the challenges associated with groundwater depletion [1], [2].

Water scarcity is a global issue and tackling it is of paramount importance. Groundwater is a precious source of freshwater and a major part of the total water supply. The increasing demand for water, as a result of population growth, industrial development and agricultural activities, has led to increased exploitation of groundwater resources, and this, combined with droughts caused by climate change, has led to a sharp decline in Groundwater Levels (GWL). Estimating the potential recharge of aquifers is essential for improving the hydrodynamic and environmental status as well as for intelligent management of groundwater resources; therefore, artificial recharge of aquifers can be used to provide water resources and restore water resources [3].

Artificial recharge projects are a set of activities that are generally carried out to store water in underground reservoirs. In general, any project, such as artificial feeding projects carried out in the context of a natural environment, includes activities that must be completed on specific dates with specific costs and with a specified quality. The success of such projects requires achieving all three factors of time, cost, and quality, and any of the three factors mentioned above outside the specified limits can make a project unsuccessful and uneconomical. Therefore, the expected useful life of an artificial feeding project, and the costs incurred or incurred for its construction and maintenance are important in the success or failure of such projects [4].

The main goal and main task of project planning and control systems is to achieve project goals by optimizing the implementation period, implementation cost, and quality of project results. However, Iran is generally experiencing a water shortage, and if the current situation and trend continues, the demand for water will increase due to population growth and agricultural, industrial, and social development, and the amount of water resources will decrease due to climate change, droughts, and the reduction in the quality of water resources, ultimately leading to a decrease in per capita water; the decrease in per capita water will subsequently lead to the emergence and intensification of social conflicts, migration, water shortage restrictions, water tensions, and the occurrence of crises. In order to optimally manage water resources and achieve a desirable situation in the future, measures such as implementing water resource development plans and flood control are of great importance, and in this regard, managing these projects and identifying factors affecting the success or failure of such plans in order to fully and optimally achieve the set goals is essential. In general, in a natural system or, better said, in a natural ecosystem, various factors are in a complex relationship with each other, and each factor has a unique role and position in the ecosystem, and therefore, artificial feeding plans implemented in the natural bed of the earth are also affected by various environmental factors. In other words, after implementation, the artificial feeding plan, as a part of the ecosystem area, is in connection and interaction with other factors in the ecosystem, and for this reason, many factors affect its performance and efficiency.

The success of such plans is subject to various quantitative and qualitative factors related to various sciences, including engineering geology, hydrology, hydrogeology, meteorology, physiography, economic, social and environmental issues, etc. In fact, the evaluation of artificial feeding systems is an integral part of the stages of studying the implementation and exploitation of such plans, with the implementation of more than 350 artificial feeding plans in the country, which have generally been carried out in the form of water distribution using the feeding pond and flood distribution methods. Also, considering that today both the Ministry of Energy and the Ministry of Agricultural Jihad, through their affiliated organizations and with the advice of consulting engineering companies, are locating and implementing more artificial recharge projects using the flood spreading method in the country, and strengthening groundwater resources has always been one of the main goals of such projects.

Therefore, the existence of a coherent model to evaluate the performance and determine the success rate of such projects has become more necessary than ever before, because managers, researchers, and experts in the country's water industry have always considered evaluating the success rate of water resource projects, and this question has always been raised as to how successful an implemented artificial recharge project has been in meeting its implementation goals? With awareness of the importance of this issue, numerous studies have been conducted in the field of evaluating such projects, most of which have attempted to compare groundwater conditions before and after the implementation of the artificial recharge project and evaluate the success rate of the project. However, the result of the present study leads to the presentation of a model that can be used to evaluate the overall success rate of recharge projects implemented in the country.

Gómez-Escalonilla et al. [5] presented an approach to estimate the effects of a managed recharge experiment in a multilayered aquifer characterized by the presence of water tables in the Medina del Campo (MC) groundwater body, Douro Basin, central Spain. A numerical model was developed to assess the effect of artificial recharge on the shallow part of an aquifer at a regional scale and in former active wetlands. The model was developed in the Visual MODFLOW Pro v.2011.1 environment in order to represent and analyze the regional impact of this artificial recharge event. The results showed that the assumption of a steady system may be useful in regional contexts where data are limited. From the perspective of the study site, managed recharge is observed to increase shallow storage along the river banks, which is considered valuable for environmental purposes. However, downstream wetlands are unlikely to experience significant improvements. Furthermore, only a small percentage of the artificial recharge is expected to reach the deep aquifer of the region. This method can be extended to settings characterized by the presence of groundwater aquifers and groundwater-dependent ecosystems.

Noori and Singh [6] in their study investigate the feasibility of using rainwater harvesting for urban flood management and groundwater recharge. The study examines various aspects of rainfall patterns such as variability, rainy days, seasonality, probability and maximum daily rainfall. Analysis of rainfall statistics shows that rainfall exceeding 30 mm occurs approximately every 3–4 years. Rainfall in Kabul follows a seasonal pattern with a coefficient of variation of 127% in October and 46% in February during the wet season. The study then evaluates the potential of RWH in Kabul city as a solution for stormwater management and groundwater recharge. Based on land use and land cover typology, the implementation of a Rainwater Harvesting and Recharge System (RWHRS) can increase the average annual infiltration from 4.86 Million Cubic Meters (MCM) to 11.33 MCM. A weighted Curve Number (CN) of 90.5% indicates the dominance of impervious surfaces. This study identifies a rainfall threshold of 5.3 mm for runoff generation. Two approaches to rainwater harvesting for groundwater recharge are considered: RWHRS for a 300 m2 residential house, which yields approximately 88 m3/year, and RWHRS for a street sidewalk to collect water from streets and sidewalks. These findings highlight the potential of RWHRS as an effective strategy for urban flood management and artificial groundwater recharge.

In his study, Sherif et al. [1] showed that groundwater augmentation through recharge dams is a common practice in various countries around the world. Most dams in the MENA region are built to enhance groundwater recharge, and even a few protective dams act as recharge dams in some way. However, the operating system of these dams is largely dependent on the natural infiltration of water accumulated in the reservoir area, with limited application of MAR. This review provides analyses of groundwater recharge and the effectiveness of recharge dams on groundwater recharge, as well as the potential of MAR technology. The study shows that the recharge efficiency of dams ranges from 15 to 47%, mostly clustered around the lower limit. The efficiency decreases as the reservoir bed becomes clogged with fines. Therefore, there is a need to improve the performance of dams using MAR technology.

Shafa et al. [7] in his study investigated the effect of optimal exploitation of groundwater and Artificial Recharge Systems (ARS) on GWL fluctuations and changes in pollution concentration of the Shahriyar Plain aquifer. Therefore, there was a need for a comprehensive multi-objective simulation-optimization model that could solve the existing problem. For this purpose, a multi-objective modeling platform that included two independent simulation-optimization models was developed. In the first model, an Artificial Neural Network (ANN) was used to simulate changes in GWL and its quality as a function of TDS index in the Shahriyar Plain aquifer. Then, regression was used to predict groundwater quality. Finally, a multi-objective genetic algorithm (NSGA-II) was used to optimize groundwater resource withdrawal. The second model simulated the flood storage volume in the ARS reservoirs using ANN and then optimized the optimal use of the ARS using (NSGA-II). The results of the first model showed that the optimal volume of water withdrawn from the aquifer and the optimal TDS value of the aquifer decreased by 29% and 18%, respectively, and the optimal groundwater level changes increased by 28 meters. Also, based on the results of the second model, the total optimal recharge volume during the study period increases by 119% due to the existence of the ARS, followed by an increase in the optimal groundwater level changes by 14%. In summary, it can be concluded that the multi-objective modeling method can simultaneously meet the objectives of this study.

Maréchal et al. [8] conducted a study entitled Economic Feasibility Mapping of MAR. MAR is a potential and promising solution to address several water management issues: water scarcity, water table decline, groundwater pollution, and saltwater intrusion. Among them, the appropriate location and cost assessment of such a solution constitute sources of uncertainty for the implementation of MAR projects. In this study, we proposed a method to assess the levelized cost of recharged water through the infiltration basin, including investment and operational costs. The method was implemented in a GIS tool to generate levelized cost maps at the aquifer scale. Sensitivity analysis allows the identification of the main natural (Water quality and availability, etc.), technical (System lifetime, recharge volume target, etc.) and economic parameters (Energy price, discount rate, etc.) characteristics that dominate the final cost estimate. The method was applied to a specific case study in an alluvial aquifer in southern France. This new information on the economic feasibility of the MAR scheme should be combined with the more classical GIS-MCDA (Based on soil characteristics, aquifer storage capacity, land use, etc.) in order to correctly locate the system. More information on the financial and economic feedback from the implementation of MAR and research on the fate of recharged water are needed to better assess the benefits of this solution.

Hamed et al. [9] showed in their study that there are spatial-temporal variations in recharge values. The highest values (13.3 mm) were recorded in the north of the study area during the wet season, while the lowest values, which reached -0.5 mm, were recorded in the south during the dry season. The recharge period of these transboundary aquifers, using isotopic tools (3H, 2H, and 18O), coincides with the wet periods of the Late Pleistocene and Early Holocene. This Pleistocene and Holocene period could be responsible for groundwater recharge in the Middle East and North Africa region. Then, management and georemediation of unconventional water processes using artificial groundwater recharge are proposed, which will lead to better use of water resources.

Hossain et al. [10] conducted a study titled opportunities and challenges for implementing managed aquifer recharge models in drought-prone barind district, Bangladesh. The study focuses on the Barind tract, a drought-prone area located in the northwestern region of Bangladesh, where inadequate rainfall and limited surface water have created a high dependence on groundwater for irrigation and other purposes, leading to a significant decline in groundwater levels. MAR offers a potential solution for groundwater recharge. This study identifies the opportunities and challenges for implementing MAR in the Barind system. To achieve this objective, various datasets including borehole lithology, rainfall, groundwater level, information on re-drilled ponds, dikes, khris, bilges, check dams, rubber dams, drilled wells and other necessary information were collected from the Barind multipurpose development. Major opportunities for MAR have been identified for about 2000 km of re-dug canals, which include about 750 check dams, over 3000 re-dug ponds, a number of bunds (Relatively large swamps) and other water bodies used for conservation. Storm water runoff for supplementary irrigation The stored water can be used to recharge groundwater and subsequently harvested for irrigation. In addition, rainwater from roofs of buildings can also be used for groundwater recharge purposes. In contrast, the main challenges include the high turbidity of storm water runoff leading to clogging of MAR structures, the inadequacy of conventional methods for direct surface recharge due to the presence of an upper clay layer of 15 m or more with limited infiltration capacity, and the lack of practical knowledge about MAR. Therefore, overcoming the challenges to MAR application is a prerequisite for maximizing the opportunities of MAR that can support the sustainable use of groundwater resources.

Henao Casas et al. [10] conducted a study titled mitigating drought and water scarcity in the Mediterranean region through MAR. Drought and water scarcity can significantly disrupt the sustainable development of groundwater resources, a scenario commonly found in aquifers in the Mediterranean region. Water management measures to address these drivers of groundwater depletion are highly relevant, especially given the increasing intensity of droughts under climate change. This study evaluates the potential of MAR to offset the adverse effects of drought and water scarcity on groundwater storage. The Los Arenales (LA) aquifer (Central Spain), which was unsustainably exploited for irrigation in the second half of the 20th century, is used as a case study. Two neighboring areas in this aquifer, LA and MC, are located opposite each other. The main difference between them in terms of water resource management is the widespread implementation of MAR systems in Los Angeles since the early 2000s. Several groundwater statistical methods are used. Analysis of groundwater level trends and mean piezometric levels in LA shows that LA has a faster recovery of aquifer storage and a lower sensitivity to drought compared to MC. On the other hand, the standard precipitation indices and standardized groundwater level indices of the time series of reduced groundwater levels, which do not include the effects of MAR, indicate that LA can be negatively affected by drought and groundwater withdrawal. The more accurate recovery of piezometric levels in LA when considering MAR, and the larger drought effects observed when excluding the effects of this measure, indicate that MAR can effectively mitigate the effects of water scarcity and drought and provide a solution to climate change adaptation worldwide.

2 | Research Method

2.1 | Examination of the Role of Main Factors

2.1.1 | Number of water intake periods

In principle, in the design and implementation of artificial recharge schemes, the time and duration of water intake of the schemes are determined according to forecasting models. However, what happens in practice is sometimes very different from what is expected. In principle, the greater the number of water intake periods per year, the more water is stored in the groundwater reservoir and provides satisfaction to managers. A review of the water intake records of artificial recharge schemes implemented using the flood distribution method in the country (*sTable 1*) shows that flood distribution schemes in different provinces have had different numbers of water intakes. The Tasuj flood diversion plan has had the highest number of water diversions with 17 water diversions per year, and the Qomrud flood diversion plans in Qom have had only 5 water diversions over the past 12 years, and the Jarmeh flood diversion plan in Khuzestan has had an average of 2 water diversions per year, and the aforementioned plan has had no water diversions from 2007 to 2009 [11], [12].

Table 1. Average and total number of flood distribution network intakes [14].

Row	Station Name	Province Name	Total Number of Water Intakes	Average Number of Water Intakes Per Year
1	Tasuj	East Azerbaijan	206	17
2	Poldasht	West Azerbaijan	79	17
3	Meimeh	Isfahan	2	Less than 1
4	Hosseinabad	Ilam	8	Less than 1
5	Kashan	Busheh	4	Less than 1
6	Dehloran	Tehran	49	4
7	Ahram	North Khorasan	105	9
8	Chandab	South Khorasan	38	3
9	Jajarm	Khorasan Razavi	37	3
10	Nehbandan	Khuzestan	21	1

Table 1. Continued.

Row	Station Name	Province Name	Total Number of Water Intakes	Average Number of Water Intakes Per Year
11	Gonabad	Balochistan	8	Less than 1
12	Sabzvar	Semnan	4	4
13	Kashmar	Fars	49	Less than 1
14	Sarbisheh	Qazvin	105	2
15	Jarmeh	Qom	38	2
16	Soran	Kohkiluyeh and Boyer Ahmad	21	3
17	Biarjomand	Central Lorestan	8	3
18	Gosheh	Hormozgan	46	3
19	Garbaygan	Yazd	6	5
20	Darz and Sayban	East Azerbaijan	22	3
21	Chesgin	West Azerbaijan	22	2
22	Taghroud	Isfahan	30	Less than 1
23	Imamzadeh Jafar	Ilam	34	2
24	Kuhdasht	Busheh	36	5
26	Saveh	Tehran	54	1
27	Sarchahan	North Khorasan	3074	1
28	Miankouh	South Khorasan	206	3

2.1.2 | Permeability of the water distribution area

Permeability is actually the ability of water to penetrate from the soil surface into it. By reducing permeability, the efficiency of artificial recharge projects, whose main goal is to penetrate water into the aquifer, is greatly reduced. On the other hand, it is important to pay attention to this issue because although the initial condition of the water distribution area may have high permeability at the time of location and project implementation, its permeability decreases sharply during the operation period due to the entry of fine-grained sediments [13], [14]. In location studies of artificial recharge schemes, various classes have been presented for the permeability rate of the pond or water intake area. In some location studies, areas with surface permeability higher than 45 mm/h are considered very suitable for implementing the artificial recharge scheme, and areas with permeability between 25 and 45, between 15 and 25, and less than 15 mm/h are considered suitable, moderate, and unsuitable, respectively. The classification of soil surface permeability by the American Soil Conservation Society is also presented in *Table 2*, in which the penetration rate higher than 25.4 cm/h is classified as very fast and higher than 12.7 cm/h is classified as fast.

Table 2. Descriptive classification of soil surface permeability based on SCS classification.

Penetration Rate (cm/h)	Penetration Classification
More than 4.25	Very fast
12.7 to 4.25	Fast
2 to 6.33	Somewhat fast
0.5 to 2	Moderate
0.127 to 0.15	Somewhat slow
Less than 0.127	Very slow

As previously acknowledged, the decrease in permeability rate following water abstraction is a factor that, despite expectations, can lead to a decrease in efficiency and, as a result, the failure of the recharge scheme. The recharge ponds located in the southwest of Shahrood have practically been depleted due to sedimentation in the first year of operation. It should be noted that the failure of some artificial recharge schemes is not limited to projects within the country, but many projects in different parts of the world have also suffered from relative failure and failure for similar reasons [17].

2.1.3 | Groundwater depth

Regarding the conditions of groundwater depth, various classes for groundwater depth have been presented in studies on the location of artificial recharge schemes. In a study conducted to determine suitable flood spreading areas in Meimeh, Isfahan, the groundwater depth class has been presented in 4 classes according to *Table 3*, with a depth of more than 30 meters being described as very suitable for implementing artificial recharge and flood spreading projects. It is also stated in the standard instructions for implementing artificial recharge dams that the greater the groundwater depth, the more suitable the implementation of these projects will be.

Table 3. Groundwater depth class for implementing artificial recharge [14].

Utility Class	Groundwater Depth (m)
Very inappropriate	0 to 10
Medium	10 to 20
Suitable	20 to 30
Very suitable	More than 30

2.1.4 | Water quality

Injection of water of appropriate quality can improve the quality of groundwater and vice versa. In other words, the lower the quality of water injected into the aquifer, the lower the quality of groundwater in the area and may cause severe damage to the aquifer. Regarding the assessment of water quality, the electrical conductivity of water is widely used as a suitable quality criterion. Water injection with an electrical conductivity above 5000 microsiemens/cm can have an adverse effect on the performance of the project and the project will ultimately not receive a passing grade from managers and stakeholders. In some flood spreading and artificial recharge projects, water injected into the aquifer has reduced the quality of groundwater in the area. The performance of artificial recharge projects is presented in *Table 4*, in proportion to the quality (EC) of the injected water [15], [16].

2.1.5 | Water value of the area

Implementation of artificial recharge projects upstream of aquifers with a negative balance will be more justified. In some cases, implementing such projects in small aquifers or limited aquifers will result in a waste of capital. The report of the Iranian Water Resources Basic Studies Office shows that in 300 Plains of the country, the amount of groundwater withdrawal exceeds the amount of aquifer recharge and the balance in these Plains is negative. Implementing artificial recharge projects in aquifers that are facing water shortages is more recommended. Simply put, in some areas of the country, the value of 2 buckets of water (80 liters) is sometimes more than the value of a water tanker (1000 liters), so implementing such projects in such areas can have a desirable performance from the perspective of managers. The performance of the project is proportional to the value and importance of water in the region according to *Table 5*.

Table 4. Description of the role of injected water quality in the performance of flood spreading and artificial recharge schemes.

Feedwater EC Range	Description of the Project Performance
More than 5000	Completely unsuitable
2250-5000	Unsuitable
1000-2250	Average
500-1000	Adequate
Less than 500	Very suitable

Table 5. Description of the role of water importance in the region in the performance of flood spreading and artificial recharge schemes.

Feedwater EC Range	Description of the Project Performance
Low	Completely unsuitable
Normal	Inappropriate
Medium	Average
High	Adequate
Very high	Completely suitable

2.1.6 | Hydraulic conductivity of the aquifer in the region

The hydraulic conductivity of the aquifer plays a fundamental role in the distribution, transfer, and elimination of the artificial recharge dome. If the aquifer has a higher hydraulic conductivity, a larger area of the aquifer is affected by artificial recharge, and this factor controls the amount of dome elevation [17], [18], because a higher elevation of the recharge dome leads to a decrease in water infiltration. If the aquifer has a low hydraulic conductivity, a small area will be directly affected by the design, and due to the lack of transfer of injected water, it will increase the height of the recharge dome and reduce the efficiency of the design. The description of the performance of flood spreading and artificial recharge designs with respect to the aquifer hydraulic conductivity criterion is presented in *Table 6*.

Table 6. The role of aquifer hydraulic conductivity in describing the performance of artificial recharge schemes.

Aquifer Hydraulic Conductivity Range (m/day)	Performance Description
Less than 1	Very good
1-5	Not good
5-12	Average
12-45	Good
More than 45	Very good

2.1.7 | Water slavery of feeding facilities in water intake

One of the important issues in the implementation of artificial feeding projects is the surface distribution of water in order to feed groundwater, but if the water distribution operation is not carried out properly or if the facilities are damaged during water intake and the water becomes unavailable, the artificial groundwater feeding operation will not be carried out properly. Therefore, it is important to note that the issue of water slavery of feeding facilities occurs together with water intake, and if the facilities are damaged in each water intake, the plan will certainly fail to achieve the intended goals. The Gachsaran artificial feeding project was damaged during the first water intake, and a significant volume of water that could have been stored in the groundwater reservoir became unavailable. Accordingly, the classification of the performance of artificial feeding schemes in relation to the water enslavement criterion of feeding facilities will be as shown in *Table 7*. This criterion will be the inverse criterion of the number of water withdrawals per year. If an artificial feeding scheme has more than one case of destruction in a year, the efficiency of the scheme will be severely reduced.

Table 7. The role of facility water entrainment in describing the performance of artificial feeding schemes.

Number of Water Enslavements Per Year	Performance Description
More than 10 times	Perfectly appropriate
7 to 10 times	Unsuitable
4, 5 and 6 times	Average
2 and 3 times	Adequate
0 and 1 time	Perfectly Appropriate

3 | Findings

3.1 | Summary of Artificial Recharge in Iran

In Iran, artificial recharge is usually required to strengthen groundwater resources and compensate for losses to the aquifer for storage and updating surface flows. Excessive exploitation of groundwater resources in some Plains has caused various damages such as lowering the groundwater level, emptying parts of the reservoir, changing the quality of groundwater, etc., so that today, out of 550 aquifers in the country, more than 300 have a negative balance and 220 aquifers are prohibited for drilling and new exploitation. To preserve these resources, either the withdrawal from them must be reduced or, if the necessary conditions are met, the aquifer must be recharged. So far, numerous artificial recharge projects have been implemented and utilized in many parts of Iran. In many cases, artificial recharge projects have been combined with flood control projects and are referred to as multipurpose projects. To date, more than 350 artificial recharge projects have been implemented in the country, generally using the water distribution method. Projects that have been constructed in large networks and in the form of ponds include the artificial recharge projects of the Plains of Varamin, Garmsar, Qazvin, Khoy-Sahrin, Zanjan-Lar, Ardo-Borazjan, Lamerd, Aduri, Gohar-Kuh, and Imamzadeh Jafar Gachsaran. The dimensions of the ponds have been varied in designs, with their width varying between 45 and 200 meters and their length varying between 200 and 2500 meters. The facilities of these systems generally include diversion dams, transfer channels, and infiltration facilities. Artificial recharge schemes using the pond method have different recharge capacities.

Artificial recharge has been constructed using an underground recharge dam in the Golrobar River in Semnan. An outlet system is foreseen for the dams that gradually directs the stored flow downstream. The indirect (inductive) artificial recharge method has been implemented in the Hamedan Bahar Plain. This aquifer is connected to the Hamedan Plain aquifer by only an alluvial gorge about 2 kilometers wide. In fact, in this method, the groundwater level of the region is lowered to increase natural recharge. The small Hamedan Bahar Plain ends in heights on all sides. Well-fed projects have been implemented in Zanjan province, and the largest well-fed project is the river (Zaker) project in the northeast of Zanjan city, with 20 wells with a capacity of 1.5 cubic meters per second, an average feed rate of about 75 liters per second, and a total feed rate of 15 MCM per year. The goal of this project is to strengthen the aquifer and provide drinking water to Zanjan.

Flood spreading is another type of artificial feeding method in Iran, which is more common today than other methods, and in the last two decades, most artificial feeding projects have been implemented using the flood spreading method, such as the Tasuj, Poldasht Gonabad, Bam, Soran, Herat, Sabzevar, Nehbandan, Ahram, Bushehr, and Garibaygan Fasa projects [5], [19], [20].

3.2 | Study Area

The study area is in the south of Dashtestan County and in Bushehr Province. The Bushekan Plain is part of the Bushekan watershed in the Mand watershed. This area has geographical coordinates of 51 degrees, 51 minutes and 45 seconds to 51 degrees, 36 minutes and 54 seconds east longitude and 28 degrees, 43 minutes and 5 seconds to 28 degrees, 56 minutes and 5 seconds north latitude. The Bushekan Plain is also part of the folded Zagros region in southwestern Iran. The ruggedness around it is stretched in a northwest-southeast trend as a folded belt, and the mentioned Plain is located as a trough between the Ashkeflo heights in the east and northeast and the Maval Kashte heights in the west and southwest. The Dasht-e Palang River passes through the southern part. According to the geological map of the study area, the majority of the Plain is covered by the Quaternary formation, which is formed by the destruction and erosion of the conglomerate and Mishan and Aghajari formations located in the upstream heights. This area has an area of 154.93 square kilometers, and except for the city of Bushkan and a few of its affiliated villages, most of the Plain is under agricultural cover. The climate of the study area is dry, and its average annual rainfall is 258.5 mm.

3.2.1 | Data

In this study, documentary and library studies and existing reports related to flood distribution conditions were used. Also, various maps and Google Earth images were used to prepare base maps for performing the fuzzy model. Finally, field studies were conducted to match the results with reality. In order to investigate and evaluate the suitability of the land for optimal flood distribution zoning, using environmental parameters that affect flood distribution and their effect on the speed of water penetration into the ground, and considering points such as the scale of work and the desired accuracy, the goal, the conditions of the area and the degree of influence of each of the indicators, the weight of the layers, appropriate indicators were selected. Eight factors including slope, alluvial thickness, electrical conductivity were used for this purpose to take into account the impact of areas that have higher levels of salts and are not suitable for groundwater recharge in zoning, geology, land use, drainage density, transportability and height were identified. Then, using the data conversion information and reports, a map of each factor was prepared and analyzed as follows using the geographic information system.

Slope: Slope plays a very important role in water permeability and determining flood distribution locations. A 30-meter DEM map of the study area was used to prepare the slope map.

Alluvial thickness: For the alluvial thickness layer, the linear layer of the same depth of the Bushehr Provincial Regional Water Company was used, which was converted into a surface layer (Polygon) using linear interpolation.

Water quality (Electrical conductivity): If the alluvial has too many salts, it is affected by various ions due to the movement of water in this porous environment and the water quality decreases, so it is necessary to examine the electrical conductivity of the existing alluvial. The electrical conductivity layer was converted into a surface layer based on the linear layer of the Bushehr Provincial Regional Water and using information from ready observation wells with a linear interpolation command.

Geology: Areas with young, Quaternary alluvium are suitable for flood spreading. To extract the geological layers of the study area, a geological map with a scale of 1:100,000 from the Oil Company was used.

The drainage density of the Bushkan watershed is from the surface of the Bushkan watershed, and the layer used for drainage density is also related to the surface of the study area, namely the Bushkan Plain. To prepare the drainage density map based on the Bushkan watershed watershed map extracted from Google Earth, the Bushkan Plain watershed map was clipped from it and made the same coordinate system as the rest of the maps in the Arc map environment, and then the drainage density layer was prepared using the Density command.

Transmissibility: The transmissibility or water permeability coefficient shows the water permeability throughout the thickness of the aquifer. The transmissibility layer was also prepared from the statistics and coordinates of several observation wells and converted to a point layer, then transformed into a surface layer by interpolation.

Altitude is a very important factor in hydrological phenomena. This factor was used considering the geology of the region, which is characterized by the Aghajari and Mishan formations above 600 meters, which do not have good quality for flood spreading. To obtain the altitude, a 30-meter Dem map of the studied area was used.

3.2.2 | Introduction to the project

The artificial recharge project under study is located in the eastern part of the Bushegan Plain. *Figs. 1* and *2* shows the location of this project in the Bushegan Plain. The artificial recharge project of the Bushegan Plain includes a sedimentation basin and 4 recharge basins with a total area of 28.7 hectares. The type of structures is earth, stone and cement and has been in operation since 2003. The water supply sources of the project are floods from the upstream catchment area and its storage capacity is 0.52 MCM per year. The length of the water transfer channels is 70 meters, the height from the river bed is 4.85 meters, and the length of the spillway is 34.7 meters.

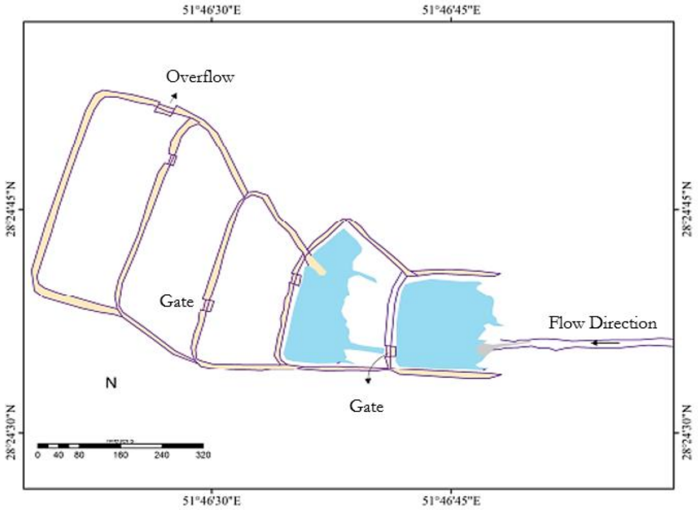


Fig. 1. Graphic map of the Bushegan Plain artificial feeding plan.

Fig. 2. View of the entrance to the Bushegan Plain project.

3.2.3 | Geology of the project

In terms of geology, the heights overlooking the Chah Gah Plain are, in order from old to new, briefly composed of the Hormoz Formation, the Salt Series, the Khami Group (Massive and thin, layered limestone), the Kozhdami (Fossilized limestone, gray to brown mass of the Bangestan Group mainly), lime and shale composed of the Surak, Surgah and Ilam formations, the Gurpi (Shale and marly limestone), the Asmari-Jahrom (Dolomite, nummulitic, clay and marly limestone, the Gachsaran bituminous shale limestone, salt anhydrite and marl), the Razak (Silty marl), the Mishan (Dark gray marl, layered and shelly limestone, the Aghajari limestone, the gypsum-bearing red sandstone of the Bakhtiari conglomerate and the sediments of the present era. *Fig. 2* shows the geological map of the region. The Chah Gah alluvial aquifer is continuous and It is heterogeneous and its constituent sediments are mostly alluvial sediments. In terms of grain size, the aquifer sediments include sand, silt, and clay. Groundwater is recharged from the northern and eastern heights of the Plain and discharged from the southwestern parts of the Plain. In terms of climate, the average annual rainfall in the region is 272 mm and its average temperature is 30.5 degrees Celsius, and according to the Amberge classification, it has a hot mid-desert climate. The average altitude of the Chah Gah Plain is 90 meters above sea level. The maximum temperature is in July and the minimum in February, and the average maximum and minimum temperatures are 31.7 and 17.3 degrees Celsius, respectively, and the average temperature is 24.8 degrees Celsius. The highest precipitation in the basin overlooking the project occurs in the months of December, January, and February, which accounts for 71% of the total precipitation.

3.3 | Performance of the Bushkan Plain Recharge Scheme

As previously acknowledged, in order to investigate the effects of the artificial recharge scheme, groundwater level statistics from three observation wells with codes AB02, AB01 and A03, which are located at a distance of 829, 863 and 1725 meters from the scheme, were used. *Figs. 3-5* show the fluctuations in groundwater depth in the aforementioned observation wells, respectively. The trend of changes in all three observation wells, presented in *Figs. 3-6* to *Figs. 3-8*, indicates a downward trend in groundwater level. *Figs. 3-9* shows the recharge dome assuming a percolation rate of 6 cm/hour, which was obtained using the Hentoush analytical model. The Hentoush analytical model was implemented assuming a decrease in permeability for different percolation rates, and the results are presented in Tables 4-8 and 4-9. Therefore, it is expected that after three months of dewatering, the groundwater level in the AB01 and AB02 observation wells will show a rise of about 5 to 10 meters, assuming a decrease in permeability rate of 1 cm/hour. Examination of the groundwater level fluctuation graph in the observation wells does not show such a rise.

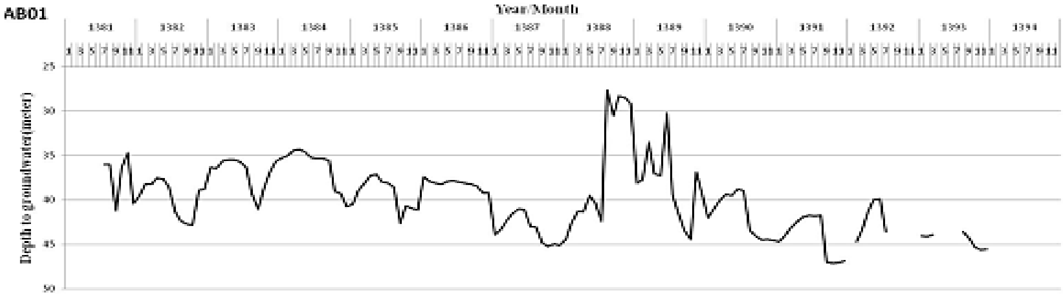


Fig. 3. Graph of groundwater depth changes in observation well AB01.

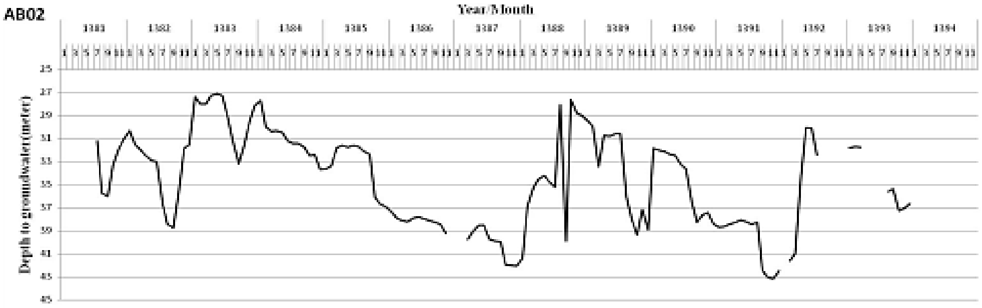


Fig. 4. Graph of groundwater depth changes in observation well AB02.

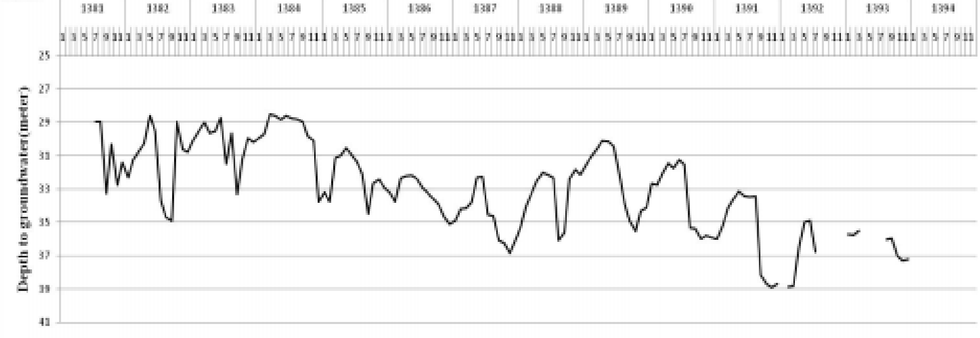


Fig. 5. Graph of groundwater depth changes in observation well AB03.

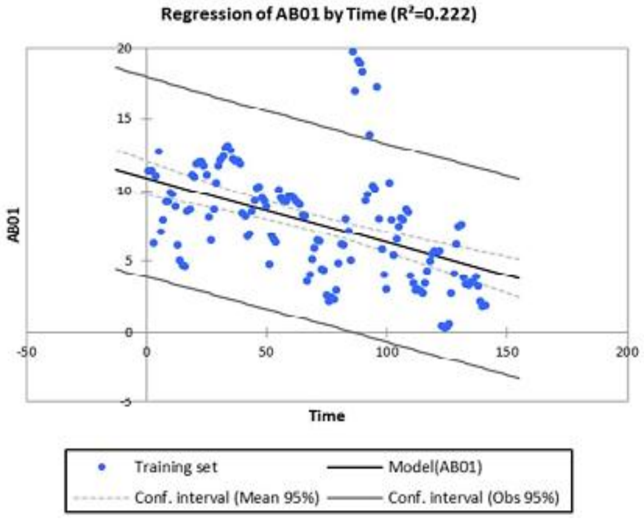


Fig. 6. Linear regression of groundwater level in observation well AB01.

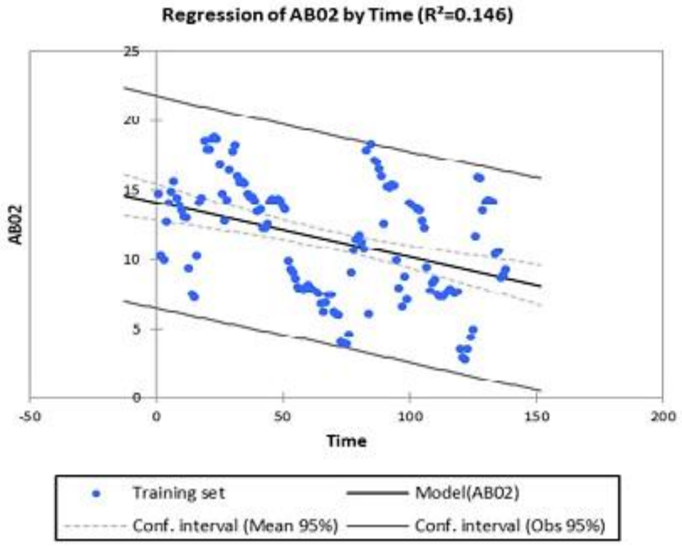


Fig. 7. Linear regression of groundwater level in observation well AB02.

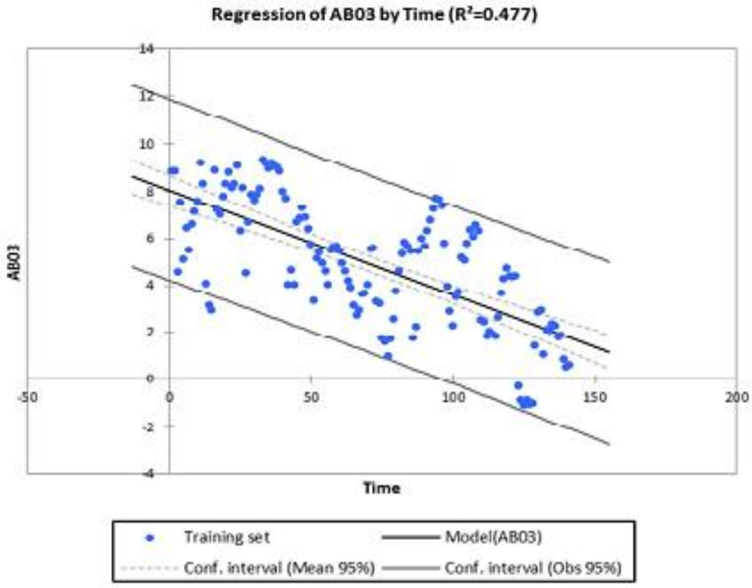


Fig. 8. Linear regression of groundwater level in observation well AB03.

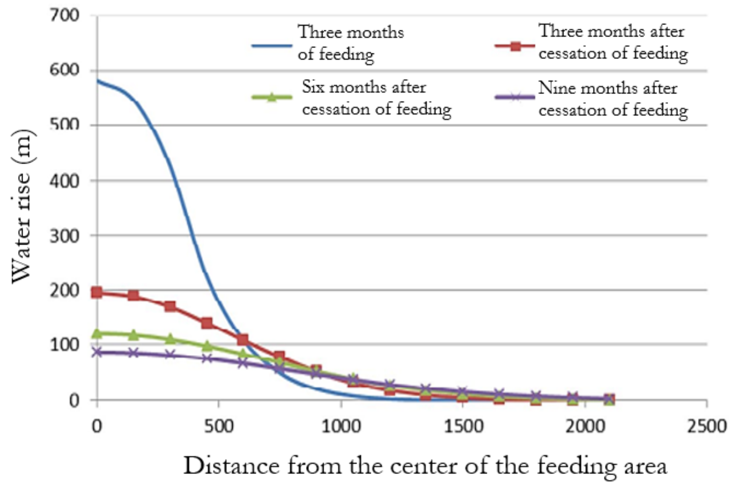


Fig. 9. Prediction of groundwater level rise in the study project.

Table 8. Water rise in observation wells overlooking the Bushkan project with different infiltration rates after 3 months of feeding.

Observation Well	Distance from Center Feed (m)	Different Penetration Rates (Centimeters Per Hour)						
		6	5	3	1	1	0.1	0.01
AB01		4.11	3.4	2.05	1.37	0.68	0.07	0.007
AB02	1170	5.53	4.6	2.76	1.8	0.8	0.09	0.009
AB03	1130	0.001	0.001	0	0	0	0	0

Table 9. Water rise in observation wells overlooking the Bushkan project with different infiltration rates after 9 months of feeding.

Observation Well	Distance from Center Feed (m)	Different Penetration Rates (Centimeters Per Hour)						
		6	5	3	2	1	0.1	0.01
AB01		31	25.8	15.5	10.3	5.2	0.52	0.052
AB02	1170	33.3	27.7	16.6	11.1	5.5	0.55	0.055
AB03	1130	3.8	3.2	1.6	1.3	0.64	0.064	0.006

According to observational data in the Bushegan Plain project, in 2009 and 2010, following the implementation of the development plan and the construction of a new infiltration basin, the groundwater level in wells AB01 and AB02 increased significantly and reached more than 15 meters, but this increase in groundwater level was not seen in subsequent years. As a result, the permeability of the Bushekan recharge basin bed has also decreased, and in practice, water is recharged much less than expected.

3.4 | Model Calibration Results

To run the model in a stable state, all information, including the discharge rate, recharge, water level of piezometers, river network, and hydraulic boundaries, was entered into the model in a fixed period of 30 days starting from the water year, October (1400-01). Considering the ground surface as the initial groundwater level, the model was run stably and the groundwater level in this period was estimated by the model. The results of this stage are reflected in the MODFLOW model as a difference in the water level of the piezometers. The error of the piezometers in the first run of the model in the studied area is shown in *Fig. 10*.

In order to reduce the computational errors against the observational data, the created model must be calibrated. The change in the hydraulic conductivity parameter was used to calibrate the model. The changes in the hydraulic conductivity in the studied area were obtained from 10 to 90 meters per day. The map of the change in hydraulic conductivity is shown in *Fig. 11*.

The status of the existing piezometers in terms of observational and computational errors after calibration is shown in *Fig. 12*.

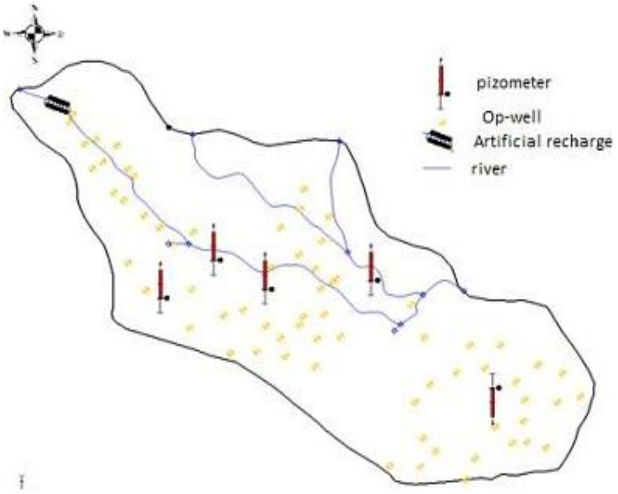


Fig. 10. Condition of piezometers before calibration.

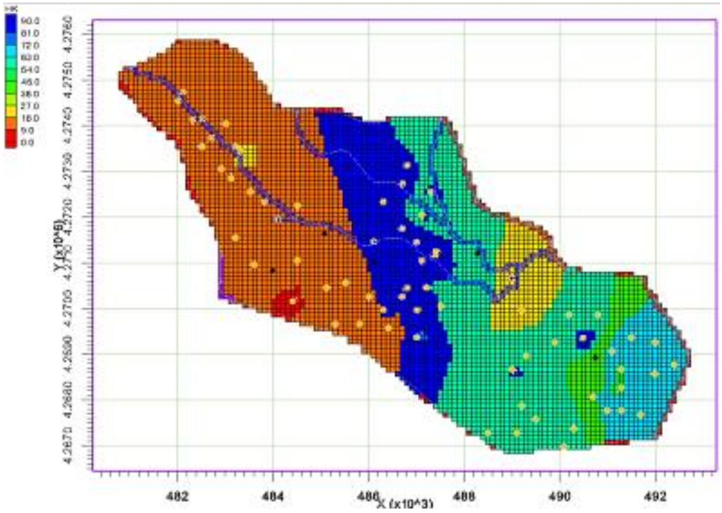


Fig. 11. Hydraulic conductivity map of the Bushkan area after model calibration.

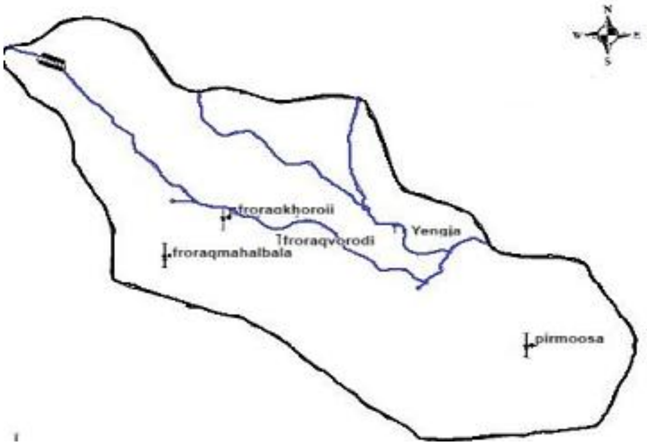


Fig. 12. Status of piezometers after calibration.

3.5 | Model Validation Results

According to the previous material, for validation, the groundwater level in the region was predicted for 12 months from October 1391 to the end of September 1392 (2013), and the field observed values were compared with the values predicted by the model. *Figs. 3-13* shows the correlation between the input and computational data in the first two steps (October 1400) and the last step (September 1401). The consistency of the graphs shows that acceptable results have been obtained from the modeling.

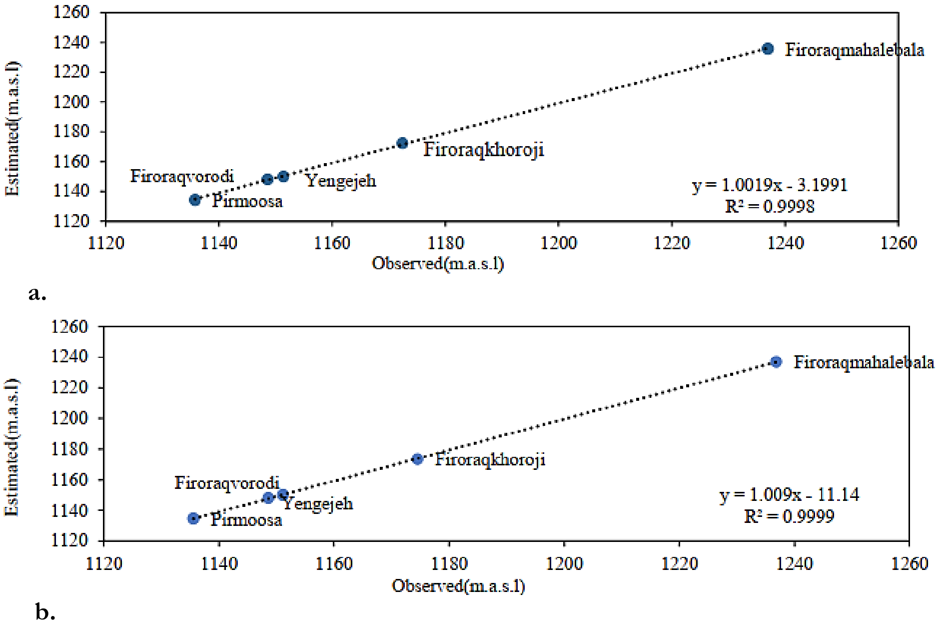


Fig. 13. Scatter plot of observational and computational data points; a. last step, b. first step.

3.6 | Results of Sensitivity Analysis

Fig. 13 show the sensitivity of the model to changes in hydraulic conductivity and specific water yield coefficient. According to the results of the sensitivity analysis, the highest sensitivity of the studied aquifer model was related to hydraulic conductivity and storage coefficient, respectively, so that with a 40% decrease in hydraulic conductivity, the model error increased to 48.4%, and with a 40% decrease in aquifer storage coefficient, the model error increased to 13.83%.

3.7 | Results of Model Error Estimation

The results of the statistical index estimation of the comparison of the observed and calculated groundwater levels are presented in *Table 1*, considering the permissible values of the NRMS rate, even in the final steps, are below 1%, and these values indicate high modeling accuracy. The high correlation between the observed and calculated groundwater levels indicates sufficient accuracy of this model, and this model can be used due to the reliability of the calculations in predicting the aquifer status after applying the desired scenarios. Since the permissible range of NRMS is less than 10% and the simulated model with NRMS below 1% has passed the validation period, it can be acknowledged that this model has been well calibrated.

3.8 | Results of Scenario Building in the Model

Given that the model was calibrated and validated in two stable and unstable states, it can be used to manage and predict the future state of the aquifer as well as manage existing projects. In the first to third scenarios, changing the amount of artificial recharge in order to observe changes in the groundwater level downstream and within the scope of each scenario was implemented in 11 time steps from November 1400 to September 1401 with an increase of 20% and 50% of the water intake volume and also conditions of no water intake in the model. The results of this scenario building are presented in *Fig. 14 (a)*.

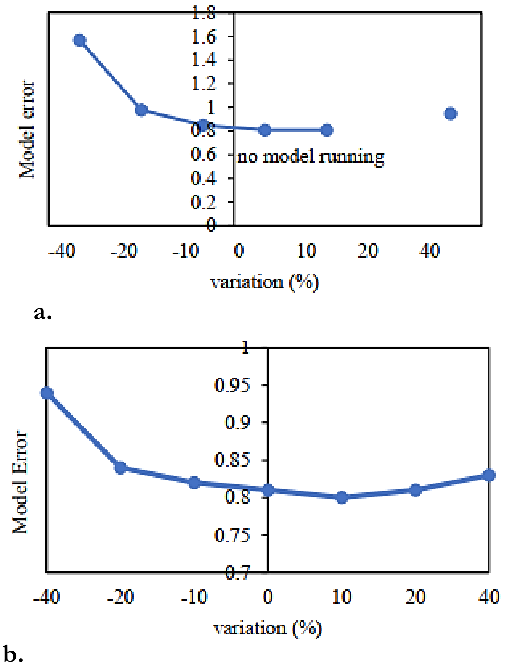


Fig. 14. Sensitivity analysis; a. model sensitivity analysis to hydraulic conductivity, b. model sensitivity analysis to specific discharge.

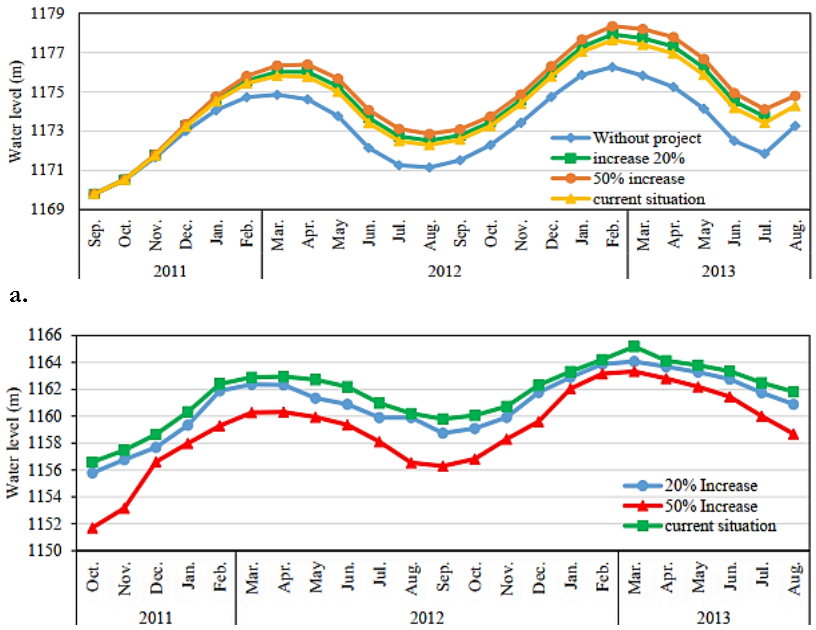
Table 10. Statistical summary of comparison of calculated and observed groundwater levels.

Priod	**Steady State**										
Step	**-**	**Total**	**Step 2**	**Step 4**	**Step 7**	**Step 9**	**Step 12**	**Step 1**	**Step 5**	**Step 8**	**Step 12**
RMSE (m)	0.27	0.59	0.30	0.29	0.19	0.36	0.18	0.37	0.46	0.35	0.36
R2	0.99	-	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1
MR	-0.07	-	-0.35	-0.27	-0.22	-0.34	-0.05	0.61	-0.63	-0.54	0.67
MAE (m)	0.54	0.56	0.61	0.54	0.37	0.61	0.39	0.65	0.82	0.75	0.39
NRMS	0.6	-	0.88	0.88	0.89	0.89	0.88	0.83	0.83	0.84	0.83

The groundwater level change graph of the studied area is shown in *Fig. 15 (a)*; with the current water abstraction rate of the Bushegan artificial recharge scheme, the groundwater level increases; however, with the absence of this scheme, the groundwater level decreases significantly. With an increase in abstraction by 50%, the average groundwater level increases by about 1.103 meters compared to the current situation, and with an increase in abstraction by 20%, the average groundwater level increases by about 0.5 meters compared to the current aquifer status. The average groundwater level in the current conditions is 1161.67 meters, which drops to 1160 meters in the absence of the scheme. This means that the absence of artificial recharge causes a decrease of 1.67 meters in the groundwater level.

Also, in the (Fourth and fifth) scenarios, changes in the rate of withdrawal from exploitation wells were applied to observe changes in the groundwater level by 20% and 50% increase in withdrawal, the results of which are presented in *Fig. 15 (b)*. As can be seen in *Fig. 15 (b)*, the groundwater level of the studied area has shown significant changes after applying the scenario of increasing withdrawal from agricultural wells, considering the increase in the withdrawal rate.

So that a 50% increase in withdrawal from exploitation wells causes a 13.3 meter decrease and a 20% increase in withdrawal from exploitation wells causes a 0.9 meter decrease in the groundwater level. Also, considering the decrease in rainfall in recent years and the increase in withdrawal from groundwater, it is necessary to control the withdrawal rate from these sources. Withdrawal control can be achieved through solutions such as installing smart meters on exploitation wells by relevant organizations. In this study, aquifer modeling was performed for both stable and unstable conditions.



a.

b.

Fig. 15. Changes in groundwater level in the studied area; a. after applying the scenario of changes in the water withdrawal rate of the artificial recharge plan, b. after applying the scenario of increased withdrawal.

Throughout the year, different rainfall and recharge conditions occur in the aquifer, which affect it and cause a decrease and increase in the groundwater level. At times when artificial recharge occurs, the groundwater level rises. The study case requires more information in modeling in the unstable state than in the stable state, and finally it can be concluded that; modeling was successful despite little information from the aquifer simulation area and the effect of stress changes was well displayed.

4 | Conclusion

This research was conducted with the aim of investigating the performance of hydraulic structures (Artificial recharge) in the Bushekhan Plain, Dashestan County, Bushehr Province. Artificial recharge projects have been implemented in different ways in the country for more than forty years. In previous years, the artificial recharge pond method has had the largest share, but for nearly two decades, their implementation has been mostly in the form of water distribution in the pond method and flood distribution. In general, the implementation of development projects with specific objectives has positive and negative effects and consequences, and water projects, including artificial feeding projects, are no exception to this rule and may have undesirable effects and consequences. This research seeks to identify factors that lead to positive or negative effects in artificial feeding projects, so that they ultimately lead to the success or failure of these types of projects. This research also describes the role and impact of factors affecting the performance of artificial feeding projects. The present study is actually a retrospective study in which, based on the experiences gained with the help of researchers, an attempt has been made to identify important factors. More than 50 researchers have participated in the survey based on their experiences, and the results of the study showed that, in accordance with the prevailing conditions in the country, 16 factors are of great importance in the success of artificial feeding projects in the country, of which seven factors were identified as the main factors. The main factors include 1) the number of water withdrawal periods per year, 2) the permeability of the field, 3) the depth of groundwater, 4) the hydraulic conductivity of the aquifer, 5) the strength of the recharge facility, 6) the quality of water, and 7) the importance of water in the recharge area. The research findings showed that the artificial recharge scheme of the Bushkan Plain in the first three months of recharge was able to increase the water head by up to 600 meters at distances of 500 meters from the center of the recharge basin during the three-month period.

During the three-month period of recharge, the water head was up to 50 meters at distances of 100 meters from the recharge scheme. And at distances of more than 1500 meters, the water head was less than 50 meters. And at distances of 2000 meters from the artificial recharge scheme, the water head was less than 10.

The research findings showed that in the three-month period after the cessation of artificial recharge, the water head was between 80 and 100 meters at distances of less than 500 meters from the artificial recharge scheme. In wells that were located at distances of more than 1000 meters from the theoretical plan, the water rise was about 40 meters. And at distances of more than 1500 meters, the water rise reached less than 20 meters.

In the period of 6 months after the cessation of artificial feeding, it was about 110 meters for wells that were located at distances of 500 meters, and for wells that were located at distances of 1000 meters from the feeding plan, the water rise was about 70 meters, and in wells that were located at distances of more than 1500 meters, the water rise was up to 30 meters, and for wells that were located at distances of 2000 meters, the water rise was very small and less than 5 meters.

In the period of 9 months after the cessation of the artificial feeding plan, the water rise was less than 100 meters for wells that were located at distances of less than 500 meters from the feeding plan. For wells located 1000 meters from the artificial feeding scheme, the water rise was up to 70 meters, for wells located 1500 meters from the artificial feeding scheme, the water rise was less than 20 meters, and for wells located 2000 meters away, the water rise was about 5 meters [7], [21], [22].

Funding

There was no financial backing provided for the preparation of this manuscript.

Data Availability

The data supporting the results of this study can be obtained from the corresponding author upon a reasonable request.

Consent for Publication

Consent for publication has been obtained from the author.

Ethics Approval and Consent to Participate

This article does not include experiments involving humans or animals.

References

[1] Sherif, M., Sefelnasr, A., Al Rashed, M., Alshamsi, D., Zaidi, F. K., Alghafli, K., ... & Ebraheem, A. A. (2023). A review of managed aquifer recharge potential in the Middle East and North Africa Region with examples from the Kingdom of Saudi Arabia and the United Arab Emirates. *Water*, *15*(4), 742. https://doi.org/10.3390/w15040742

[2] Dillon, P., Stuyfzand, P., Grischek, T., Lluria, M., Pyne, R. D. G., Jain, R. C., … & Sapiano, M. (2019). Sixty years of global progress in managed aquifer recharge. *Hydrogeology journal*, *27*(1), 1–30. https://doi.org/10.1007/s10040-018-1841-z

[3] Abdulkerim, E., Fufa, F., & Takala, W. (2022). Identification of groundwater recharge site using geographical information system and remote sensing: Case study of Sude district, Oromia, Ethiopia. *Environmental earth sciences*, *81*(2), 56. https://doi.org/10.1007/s12665-022-10170-w

[4] Albo-Salih, H., Mays, L. W., & Che, D. (2022). Application of an optimization/simulation model for the real-time flood operation of river-reservoir systems with one-and two-dimensional unsteady flow modeling. *Water*, *14*(1), 87. https://doi.org/10.3390/w14010087

[5] Gómez-Escalonilla, V., Heredia, J., Martínez-Santos, P., López-Gutiérrez, J., & De la Hera-Portillo, Á. (2024). Modelling regional effects of artificial groundwater recharge in a multilayer aquifer characterized by perched water tables. *Hydrological processes*, *38*(2), e15085. https://doi.org/10.1002/hyp.15085

[6] Noori, A. R., & Singh, S. K. (2023). Rainfall assessment and water harvesting potential in an urban area for artificial groundwater recharge with land use and land cover approach. *Water resources management*, *37*(13), 5215–5234. https://doi.org/10.1007/s11269-023-03602-0

[7] Shafa, N. S., Babazadeh, H., Aghayari, F., & Saremi, A. (2023). Optimal utilization of groundwater resources and artificial recharge system of Shahriar Plain aquifer, Iran. *Physics and chemistry of the earth, parts A/B/C*, *129*, 103358. https://doi.org/10.1016/j.pce.2023.103358

[8] Maréchal, J. C., Bouzit, M., Rinaudo, J. D., Moiroux, F., Desprats, J. F., & Caballero, Y. (2020). Mapping economic feasibility of managed aquifer recharge. *Water*, *12*(3), 680. https://doi.org/10.3390/w12030680

[9] Hamed, Y., Hadji, R., Ncibi, K., Hamad, A., Ben Sâad, A., Melki, A., … & Mustafa, E. (2022). Modelling of potential groundwater artificial recharge in the transboundary Algero-Tunisian Basin (Tebessa-Gafsa): The application of stable isotopes and hydroinformatics tools. *Irrigation and drainage*, *71*(1), 137–156. https://doi.org/10.1002/ird.2647

[10] Hossain, M. I., Bari, M. N., & Miah, M. S. U. (2021). Opportunities and challenges for implementing managed aquifer recharge models in drought-prone Barind tract, Bangladesh. *Applied water science*, *11*(12), 181. https://doi.org/10.1007/s13201-021-01530-1

[11] Henao Casas, J. D., Fernández Escalante, E., & Ayuga, F. (2022). Alleviating drought and water scarcity in the Mediterranean region through managed aquifer recharge. *Hydrogeology journal*, *30*(6), 1685–1699. https://doi.org/10.1007/s10040-022-02513-5

[12] Akhavan, K., Kheiry, M., Abbasi, S., Daneshfaraz, R., & Kalateh, F. (2023). Evaluation of hydraulic performance and operation of sluice and neyrpic modules in water distribution canals (Case study: Moghan irrigation network, Ardabil). *Irrigation and water engineering*, *13*(3), 1-22. (**In Persian**). https://www.waterjournal.ir/article_168163.html

[13] Jorenoosh, M., Pakparvar, M., Ghahari, R., & Kowsar, S. (2023). The evaluation of artificial recharge performance in a historic flooding in southern Iran. *Iran agricultural research*, *41*(2), 117-127. (**In Persian**). https://doi.org/10.22099/iar.2023.46521.1522

[14] Nassimi, A., & Zare, M. (2015). Site selection of basins for artificial recharge of groundwater in Boushkan Catchment based on analytical hierarchical process (AHP). *Water and soil science*, *25*(1), 125-141. (**In Persian**). https://B2n.ir/kz7487

[15] Zamani, S., Parvaresh Rizi, A., & Kouchakzadeh, S. (2021). Variable height whirling weir-VHW weir: Design and hydraulic performance. *Journal of hydraulics*, *16*(3), 29-40. (**In Persian**). https://doi.org/10.30482/jhyd.2021.271045.1507

[16] Grinshpan, M., Turkeltaub, T., Furman, A., Raveh, E., & Weisbrod, N. (2022). On the use of orchards to support soil aquifer treatment systems. *Agricultural water management*, *260*, 107315. https://doi.org/10.1016/j.agwat.2021.107315

[17] Ramak, Z., Zeidali, N. N., & others. (2021). A review on the artificial recharge of the aquifers as a process against groundwater stresses. *Journal of rainwater catchment systems*, *9*(2), 35-56. (**In Persian**). https://www.sid.ir/paper/958631/en

[18] Casanova, J., Devau, N., & Pettenati, M. (2016). Managed aquifer recharge: An overview of issues and options. *Integrated groundwater management: Concepts, approaches and challenges*, 413–434. https://doi.org/10.1007/978-3-319-23576-9_16

[19] Fakhreddine, S., Prommer, H., Scanlon, B. R., Ying, S. C., & Nicot, J. P. (2021). Mobilization of arsenic and other naturally occurring contaminants during managed aquifer recharge: A critical review. *Environmental science and technology*, *55*(4), 2208–2223. https://doi.org/10.1021/acs.est.0c07492

[20] Maréchal, J. C., Bouzit, M., Rinaudo, J. D., Moiroux, F., Desprats, J. F., & Caballero, Y. (2020). Mapping economic feasibility of managed aquifer recharge. *Water (Switzerland)*, *12*(3), 1–13. https://doi.org/10.3390/w12030680

[21] Alam, S., Borthakur, A., Ravi, S., Gebremichael, M., & Mohanty, S. K. (2021). Managed aquifer recharge implementation criteria to achieve water sustainability. *Science of the total environment*, *768*, 144992. https://doi.org/10.1016/j.scitotenv.2021.144992

[22] Kniffin, M., Bradbury, K. R., Fienen, M., & Genskow, K. (2020). Groundwater model simulations of stakeholder-identified scenarios in a high-conflict irrigated area. *Groundwater*, *58*(6), 973–986. https://doi.org/10.1111/gwat.12989

[23] Salehi-Shafa, N., Babazadeh, H., Aghayari, F., & Saremi, A. (2022). Artificial recharge management of Shahriar Plain aquifer with multi-objective simulation-optimization model. *Water and irrigation management*, *12*(1), 99-119. (**In Persian**). https://doi.org/10.22059/jwim.2022.333952.944

[24] Ulibarri, N., Escobedo Garcia, N., Nelson, R. L., Cravens, A. E., & McCarty, R. J. (2021). Assessing the feasibility of managed aquifer recharge in California. *Water resources research*, *57*(3), e2020WR029292. https://doi.org/10.1029/2020WR029292

[25] Dillon, P., & Arshad, M. (2016). Managed aquifer recharge in integrated water resource management. In *Integrated groundwater management: Concepts, approaches and challenges* (pp. 435–452). Springer international publishing Cham. https://doi.org/10.1007/978-3-319-23576-9_17