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Original Article

Effects of Surface Water on Artificial Recharge of Coastal Aquifers by GIS Zoning Maps: A Case Study in Ghaemshahr, Iran

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Abstract
Background: The study aimed to assess surface water resources for potential use during non-irrigation seasons to boost groundwater aquifers. This method also helps reduce aquifer depletion, mitigate land subsidence, and enhance groundwater quality.
Methods: In this study, artificial feeding methods were used to determine the appropriate location for the Ghaemshahr plain. Water resources were tested in terms of quantity and quality through field and laboratory studies. Based on the findings, geographic information system (GIS) mapping was utilized to create maps and select the best location and feeding method.
Results: The most important source of nutrition for recharging the aquifer in terms of quantity and quality was the Talar River. The study area's conditions like aquifer thickness, permeability, topographic slope, and land use were analyzed using GIS and thematic maps. The results indicated that by using these methods, it is possible to store 5 million cubic meters of surface water in the aquifer for 6 months.
Conclusion: This study demonstrated the feasibility of using surface waters in the area for artificial feeding, employing the pond method1. Additionally, it is recommended to dig measuring wells to monitor the water level rise at the bottom of the pond 1. It also suggests the use of simulation software like PMVIN, Mod flow, and GMS to optimize the artificial replenishment process and select the most suitable approach from the defined scenarios before taking any actions.
Keywords: Artificial recharge location, Basin, Coastal aquifer, Infiltration

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Introduction

In recent years, several factors have contributed to fluctuations in groundwater levels. These include reduced rainfall and prolonged drought, population growth, expansion of industrial and agricultural areas, unsustainable groundwater extraction practices, and inadequate management of groundwater resources. Over time, these factors have led to fluctuations in groundwater withdrawals, with periods of increase and decrease. As the aquifer's storage capacity diminishes, it exerts greater pressure on the sediments above it. This heightened pressure results in the compression of smaller sediments among the larger ones, leading to land subsidence and, in certain instances, the sinking of plains. Efficient management of groundwater resources hinges on two primary aspects: reducing the extraction of water from the aquifer and increasing its replenishment. Replenishing groundwater in plains can be achieved through various methods, including flood spreading, the utilization of recharge wells, and the implementation of recharge basins. A critical determinant for the success of recharge efforts, particularly using the basin method, is the careful selection of optimal locations. Groundwater resources hold significant importance in regions characterized by arid and semi-arid climates, such as Iran. The critical state of groundwater resources can be attributed to a range of factors, including unregulated and excessive consumption of both surface and groundwater, declining precipitation, a mismatch between supply and demand, inappropriate agricultural practices and irrigation methods, extensive well drilling, and their improper use. These challenges are particularly prevalent in some of Iran's plains.[1] Artificial recharge is defined as the process of deliberately introducing water into a permeable geological formation to replenish the groundwater aquifer. This is done with the goal of improving both the quantity and quality of the groundwater. Artificial recharge methods involve the construction of specific facilities and may also include alterations to the natural environmental conditions of the region to facilitate this process.[2] The selection of a suitable location for artificial recharge depends upon a range of factors, including the region's climatic conditions, available water resources (both surface and groundwater), hydrogeological and geological characteristics, existing infrastructure, and the chosen method and quantity of artificial replenishment. In plains, artificial replenishment is accomplished through diverse methods, including flood spreading, the utilization of recharge basins, and the installation of recharge wells. In a separate study focused on the Hashtgerd plain, the primary source of artificial replenishment is identified as the Kordan River, taking into account the specific conditions of the study area. This source is utilized during the period from November to May. River water is channeled into infiltration ponds through an existing diversion channel. Employing the Todd, Hantoush, and Houisman methods and conducting the necessary calculations, it is estimated that approximately 21 million cubic meters of water can be replenished into the aquifer over a six-month period. To maintain a balanced water table and prevent swampy conditions downstream, precautions must be taken to avoid excessive elevation of the water table. Given the direction and velocity of the flow, practical solutions may involve designing channels perpendicular to the flow or excavating pumping wells to manage and regulate the water table effectively.[3] The selection of locations for artificial groundwater replenishment operations was carried out using multi-criteria decision-making methods in conjunction with a geographic information system (GIS). This was demonstrated through a case study conducted in the Hormozgan province, specifically focusing on the Shamil and Ashkara plain. The study's objective was to optimize the utilization of floods and ensure the stability of the groundwater aquifer. Two straightforward cumulative weighting methods were employed, along with a hierarchical analysis process that utilized a specialized vector method within the GIS framework to pinpoint suitable areas for artificial groundwater recharge. A comparative analysis of the outcomes of these two methods revealed that the hierarchical analysis approach yields more precise and accurate results.[4]

In a separate study conducted in the western Medinapur region, remote sensing, GIS, and multi-criteria decision-making techniques were applied to identify suitable areas for artificial groundwater replenishment. The findings underscore the effectiveness of employing multi-criteria decision-making techniques in conjunction with GIS for determining suitable locations for artificial groundwater recharge.[5] In a specific region of Sri Lanka, the identification of suitable sites for artificial groundwater replenishment was conducted using GIS. This approach involved integrating various layers of data related to factors such as slope, land use, drainage density, land cover, geology, geomorphology, and soil cover. The study's findings demonstrated that this GIS-based technique effectively establishes optimal locations for artificial groundwater replenishment. This approach not only saves time but also proves to be cost-effective in the process of pinpointing suitable sites for these operations.[6] This study aimed to assess the impact of artificial groundwater replenishment on the water quantity within the Dibdibba unconfined aquifer in Karbala, Iraq, using a groundwater modeling system. The primary source of untreated water used in this artificial replenishment process was the output of treated water (third treatment) from the primary Waste Water Treatment Plant in Karbala, and it involved the use of 20 injection wells. The results showed that the injection of treated water through 20 wells increased the water table for 5000 and 10 000 m^3/day by more than 91 and 136 km^2, respectively. In addition, increasing the volume of water added to the aquifer can lead to the creation of new agricultural areas with an area of more than 62 km^2 and a length of about 20 km along the river. The treatment of wastewater plays a pivotal role in comprehensive water management planning strategies, particularly in the context of artificial groundwater replenishment and the sustainable development of agricultural resources.[7]

Numerous researchers have employed GIS-based methodologies to identify appropriate regions for artificial groundwater aquifer replenishment. Notable studies in this domain include the works of Zaidi et al in 2015,[8] Mahdavi et al in 2020,[9] Lachaal et al in 2022,[10] Chitsazan et al in 2018,[11] Ben Khelifa and Charugui in 2021,[12] and García-Menéndez et al in 2018.[13] Consequently, the utilization of recycled effluent proves to be an effective approach for enhancing both the quantity and quality of groundwater within an aquifer. Numerous studies have demonstrated the viability of these alternatives, particularly in situations where conventional freshwater resources are severely constrained.[14]

Climate change, along with a decrease in rainfall and temperature, has been increasing the extraction of groundwater resources and decreasing the water table. To prevent this problem, there are several ways to strengthen the aquifer, one of which is artificial feeding.

Summary of the goals of an artificial feeding scheme:

1. Flood control and management: This aims to regulate and manage floods while conserving their excess water.
2. Aquifer stabilization: The goal is to maintain equilibrium in aquifers located in regions with a negative water balance.
3. Mitigating saline water intrusion: This involves strategies to combat the intrusion of saline water into freshwater aquifers.
4. Removal of microbial and bacteriological contaminants: The scheme aims to eliminate microbial and bacteriological contaminants by

considering the effects of fluid flow in porous media.

5. Leakage prevention: The objective is to prevent the leakage of groundwater from aquifers.
6. Seasonal water storage: This involves utilizing the underground reservoir's potential to store excess water during non-crop seasons.

Materials and Methods

In this study, a comprehensive dataset was compiled from various sources, including the Meteorological Organization, the Mazandaran Regional Water Organization, the Geological Survey of Iran, the Statistics Office, and the Agricultural Jihad Office. This dataset encompassed a range of information, including meteorological data (such as rainfall, temperature, and evapotranspiration), river discharge records, and geological maps. Additionally, statistics related to soil tests, well logs, pumping tests, and well discharges within the study area were collected from these departments. All of this data was subjected to analysis using Arc Geographic Information System software, enabling the conversion of this information into thematic maps for further assessment and interpretation.

GIS Software

A GIS is a system for recording, storing, controlling, integrating, utilizing, analyzing, and displaying data that spatially reference land. GIS is a computer-based system that provides four basic capabilities concerning reference ground data: data input, data management, data processing and analysis, and data output. In general, the capabilities of GIS over similar information systems and manual methods can be described as follows:

- Ability to collect, store, retrieve and analyze large volumes of information.
- Ability to communicate between geographic information (map) and non-geographic information (information tables) and create facilities for analyzing geographic information using non-geographic information and vice versa.
- Ability to perform a wide range of analyses such as stacking layers, finding different objects using their proximity to a particular thing, simulation, calculating the number of times an incident occurs at a certain distance from a certain point or points.
- Accuracy, efficiency, high speed, and ease of updating data.
- Ability to perform statistical calculations such as calculating the area and environment of specified phenomena.
- Ability to track and examine changes in geographical locations over time.
- Ability to use to locate different projects.[15]

Area of Study

The study area in Ghaemshahr is situated within the geographical coordinates of approximately 52°– 23’ to 52°- 35’ east longitude and 44°- 35’ to 47°-36′ north latitude. It is located between the Sari-Neka region to the east and the Babol-Amol region to the west, covering an area of approximately 3348 km^2. Within this area, about 935 km^2 consist of flat terrain, while the remaining 2413 km^2 encompass elevated areas. The highest point within this region reaches an elevation of 3929 m, while the lowest point, at minus 26 m, is situated below sea level at the basin's exit (Figure 1).

In the Ghaemshahr study area, the average annual rainfalls in the highlands and plains are 622.1 and 778.2 mm, respectively. The highest monthly rainfall in the highlands in January is 84 mm and in the Ghaemshahr plain in November is 124.6 mm. According to the statistics from the 25-year period, the annual evaporation rate from the water pan and the open water surface at higher elevations stands at 939.8 and 771.2 millimeters (mm), respectively. In contrast, at lower elevations (the plain), the estimated annual evaporation rates from the water pan and the open water surface are 1050.4 and 1014.4 mm, respectively. The climate of the Ghaemshahr study area has been calculated based on the Embereger classification from temperate to very humid type.[16]

Geology of the Study Area

According to the geological division of Iran as proposed by Stoecklin in 1968, the study area is situated within the Alborz zone.[17] The Alborz mountain range is considered a continuation of the Alpine-Himalayan belt. In its central areas, there is a complex geological structure characterized by several anticlines and smaller synclines, all of which generally follow the main east-west geological formation. According to Iran's division of construction units, the Ghaemshahr plain falls within the Gorgan-Rasht zone. This zone encompasses the coastal area along the Caspian Sea, and a significant portion of this zone is characterized by sedimentary deposits from the current geological era. With reference to the metamorphic schists found in Gorgan, the origins of this zone's formation are attributed to the Precambrian era, as depicted in Figure 2.[18]

Hydrology and Hydrogeology of the Study Area

The Ghaemshahr study area is comprised of two primary

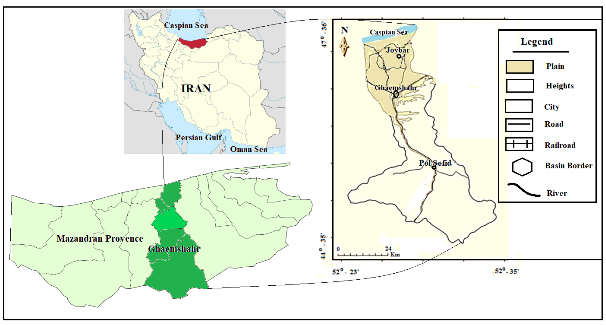

Figure 1. The Geographical Location of Ghaemshahr Catchment Area in Mazandaran Province, Iran

catchments, which direct surface flows in a south-to-north direction, ultimately emptying into the Caspian Sea (as depicted in Figure 3). These basins, categorized as the Talar and Siahrud catchments, gather surface water flows and channel them towards the sea. The alluvial aquifer of the Ghaemshahr plain, with an area of 575 km^2 (62% of the total area of the plain), is located between the Caspian Sea and the heights overlooking it. In order to obtain a more precise understanding of the aquifer's condition, drilling logs, exploratory wells, and geological surveys have been employed in the region. Across the majority of the study area, extensive marine sediments originating from both ancient and recent Caspian deposits, measuring more than 1500 m in thickness, are prevalent. These sediments consist of diverse components, including vibrant marls, sandstones, sandy layers intermixed with silt and clay, all containing bivalve and Gastropoda fossils, which were deposited under saline seawater conditions. Atop this layer, alluvial river sediments are found, distributed according to the behavior and force of surface currents emerging from the elevated regions, exhibiting varying thicknesses and extents.[18]

In general, from the south of the plain, due to the reduction of riverbed slope at the entrance to the plain and the reduction of River Kinetic Energy, larger grain sediments are deposited at the beginning of the route, and smaller grain sediments are deposited towards the plain outlet. The presence of fine-grained and coarse-grained horizons in the alluvium of the area has led to the formation of free alluvial aquifers and confined aquifers (middle part of the plain) in the range.

Identification of bottom (bed) rocks (Figure 4) in the coastal plains of Mazandaran through geophysical studies is rugged due to the close resistance of alluvial and lake sediments, as well as changes in groundwater salinity. Therefore, geophysical studies and exploratory drilling been used to estimate the thickness of the freshwater aquifer. According to geoelectric sections, the maximum aquifer thickness in the southwest of the plain in the alluvial fan and the minimum aquifer thickness is in the coastal areas of the Caspian Sea. Variations in aquifer saturation thickness range from less than 10 m in the northern part of the range to more than 100 m in the central position of the alluvial fan (Figure 5a). On the other hand, the thickness of the unsaturated position of the Ghaemshahr plain aquifer in the foothills is 20 to 30 m (Figure 5b). As we progress northward and approach the Caspian Sea, the thickness of these sedimentary layers diminishes to less than 3 m. This poses a challenge for artificial recharge efforts in the coastal area.[16]

Factors Influencing the Selection of Suitable Places for Artificial Recharge

To identify suitable sites for artificial groundwater recharge, it is necessary to identify the practical factors and use them as indicators to determine susceptible areas. These factors include:

The geology of the area, as well as the geological section, exhibit favorable permeability characteristics. Both surface and subsurface Earth formations should not introduce any factors that would degrade water quality. Additionally, there should be no intermittent presence of impermeable formations at the recharge site. Ideally, the location for recharge and discharge (utilization) should be kept as close together as possible. Efforts should focus on utilizing low-value land to minimize or eliminate acquisition costs. Recharge operations should aim to align with groundwater level contours to ensure even water distribution. The selection of the artificial recharge site should prioritize the use of local materials for project implementation, minimizing the need for extensive

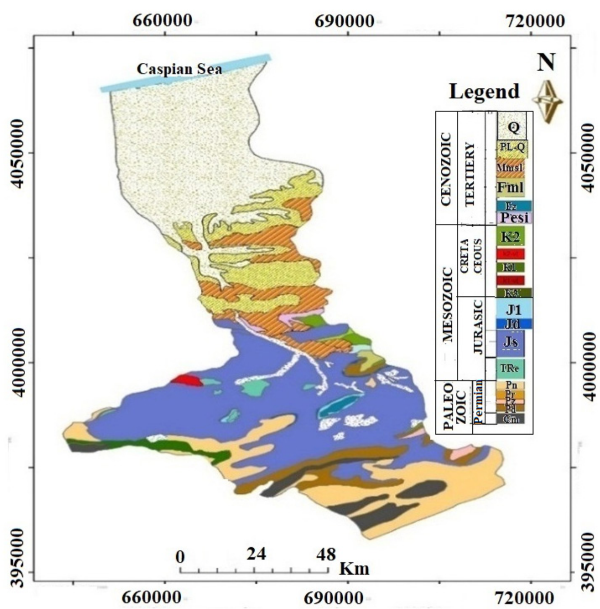

Figure 2. The geological Map of the Study Area

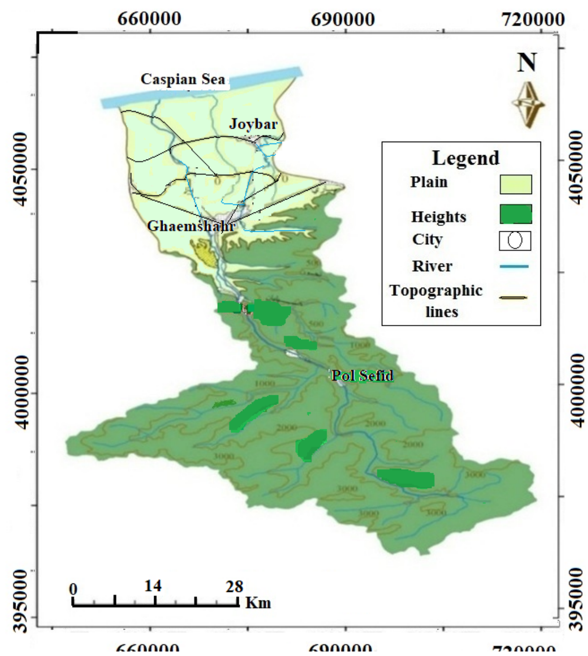

Figure 3. The Hydrographic Network of the Ghaemshahr Study Area

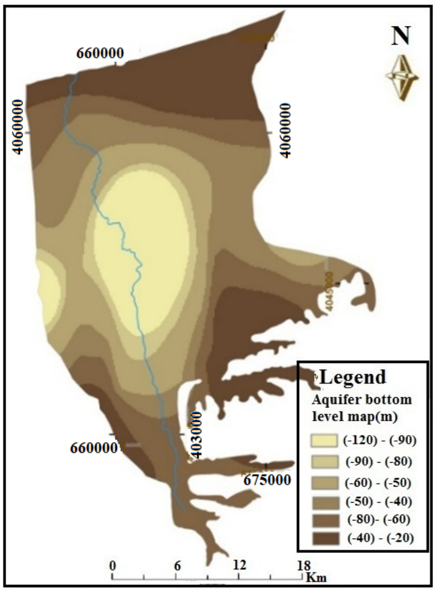

Figure 4. The Bedrock of the Ghaemshahr Plain Aquifer

material transport. Furthermore, the unsaturated layer should have a minimal thickness.

In this research, indices of slope value, surface permeability, alluvial dry layer thickness, land use, and waterway network and permeability coefficient were applied. The classification of the indicators was based on the proper perspective for artificial nutrition, expert theories, and the use of various sources in this field. Moreover, maps were prepared and classified in the Arc GIS environment.

Appropriate Methods for Performing Artificial Recharge

Calculation of Surface Soil Penetration

Surface permeability is critical at the construction site of the infiltration pond. In this study, after determining the appropriate location for the construction of the infiltration pond, a water infiltration test was performed on the soil at several points. An infiltration meter was used to measure cumulative infiltration and infiltration rate in the desert. The findings were analyzed employing the methodologies developed by Horton and the Soil Conservation Service (SCS). Through these equations, cumulative infiltration and the rate of water infiltration into the soil were computed.[19] Within the study area, ten infiltration tests were conducted in the designated areas intended for the construction of infiltration ponds, specifically located at the onset of the plain near the Talar River (see Table 1). From the collected data of 10 samples, three samples have been presented in Table 1 to show the selection and data. Based on the data presented in Table 1, time-versus-cumulative penetration curves were plotted on logarithmic paper using the SCS method. The infiltration equation was derived from these plotted curves, enabling the calculation of infiltration rates in units of millimeters per minute (mm/min) or meters per day (m/day). As a result of this analysis, the calculated infiltration values fell within the range of 0.5 to 2 m/day, with an average value of 0.7 m/day. The results of several penetration tests performed are presented in Table 1 and Figure 6.

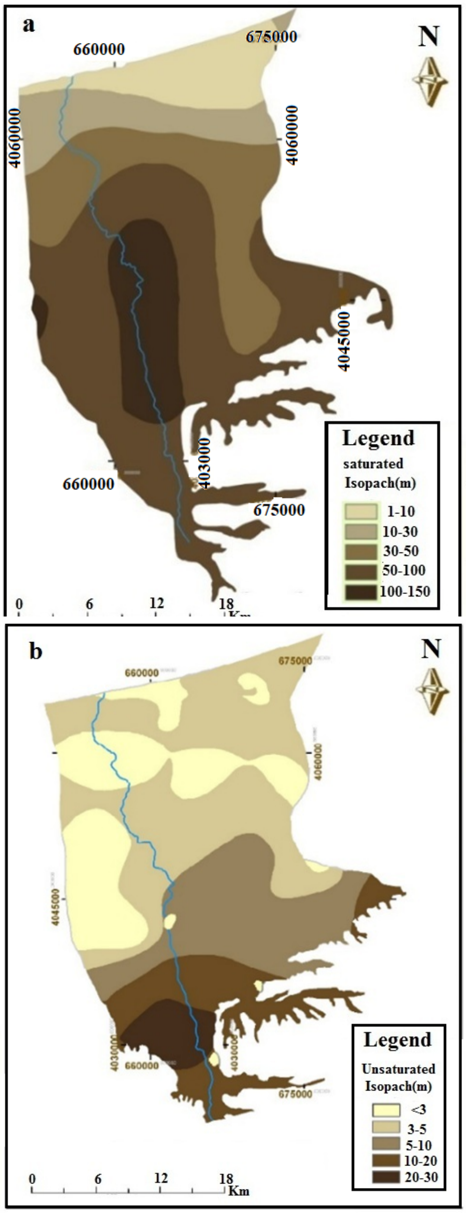

Figure 5. Saturated (a) and Unsaturated (b) Isopack Map of the Ghaemshahr Plain Aquifer

Optimal Width for Infiltration Basin in the Study Area

The optimal width for the pond should be determined based on the thickness of the aquifer to ensure hydraulic efficiency. In cases of uniform and homogeneous soil, these two dimensions are typically quite similar. For a homogeneous but heterogeneous soil, the required width should be multiplied by $\sqrt{K_h / K_v}$ (equation 1).[20]

$$W = z \times \sqrt{K_h / K_v} \quad (1)$$

where, W = optimal width for the pond, Z = average alluvial thickness, K_h = horizontal permeability, and K_v = vertical permeability.

Table 1. The Surface Penetration Measurements of Three Soil Samples Taken From the Designated Site for Artificial Recharge in Ghaemshahr Plain

T (min)	Cumulative Penetration Height (mm) (1)
0	0
4	42
8	75
12	95
25	148
35	195
50	229
130	524
270	690
300	830
0	0
2	20
4	42
8	75
15	113
25	148
40	195
0	0
6	10
15	18
25	24
35	30
60	49
90	68

Average Infiltration Basin Yield (Infiltrated Volume)

The average infiltration rate depends on the infiltration capacity and dimensions of the pond. If we consider the infiltration capacity constant, to increase the infiltration rate, several ponds with the same width can be built in succession along the groundwater flow. Huisman in 1982 provided Equation 2 to determine the volume of infiltrated water[21]:

$$\begin{aligned} &Penetration\,volume\,in\,the\,basin = Optimal\;wid \\ &Basin\,length \times Penetration\,capacity \end{aligned} \tag{2}$$

Calculation of Water Table Rise During Artificial Recharge

Elevation of groundwater level can be expressed by mathematical relations, but simplistic assumptions such as Dupuit flow hypotheses should be used. In the case of circular basins, the elevation h in the center of the dome is calculated by equations 3, 4 and 5[22]:

$$h = \frac{i}{R}t\left[1 - e^{-u1} + u1\int_{u1}^{\infty}\frac{e^{-u}du}{u}\right] \tag{3}$$

i = Constant infiltration discharge (L/T) and R = Filling coefficient

$$\propto = \frac{K.Hs}{R}\;,\;U1 = \frac{a^2}{4 \propto t} \tag{4}$$

a = Radius equivalent to the basin, K = Horizontal permeability, and Hs = Average saturation thickness (thickness of aquifer)

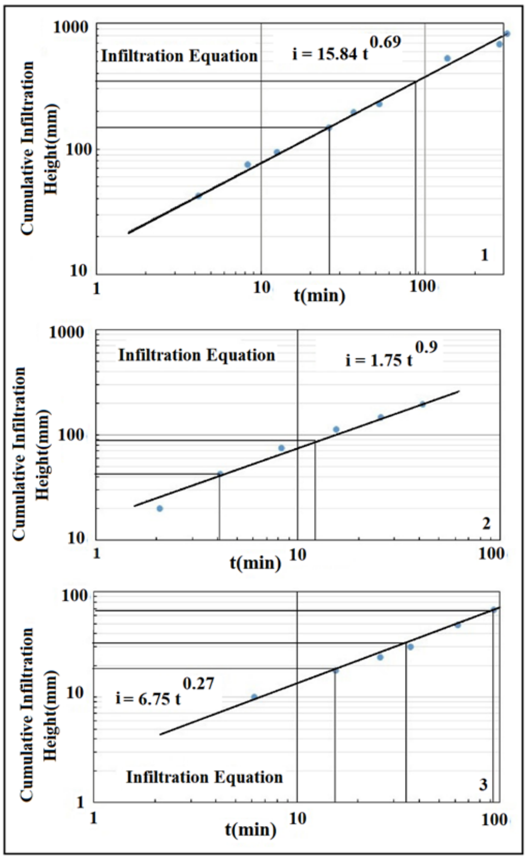

Figure 6. Cumulative Infiltration Curve – Time

$$V = \pi r^2 \times h \times R \tag{5}$$

V = Volume of stored water (m^3), r = Nutrition impact radius (m), h = Average rising in impact radius (m) and R = Aquifer filling coefficient.

Calculation of Radius of Impact Effect During Artificial Recharge

In this study area, if a pond with an area of up to 2 hectares for six months of recharge was designate, the radius of influence (the distance from the center of recharge to the point where the water table reaches zero elevation) would be estimated to be approximately 5000 meters, as determined by the equation 6[14]:

$$Hc - Hn = \frac{iR^2}{4T}\left(1 + 2Ln\frac{Rn}{R}\right) \tag{6}$$

Hc = Saturation thickness and rising height (m), Hn = Primary saturation thickness of the aquifer (m), i = Surface penetration, Rn = Radius of influence (m), R = Radius of basin (m) and T = Transmissivity (m^2/day)

Use of Furrow and Ditch Systems

This method involves the creation of parallel channels with contour alignment to facilitate the infiltration of diverted water into the aquifer. To optimize this process and minimize the required ground level adjustments, the aquifer can be excavated in a spiral configuration. It is essential that the water entering these channels remains nearly transparent. To achieve this, sand pits can be strategically constructed along the water path to store and settle the water. Additionally, it is worth noting that existing channels along the designated route can be utilized. This allows for both the drainage of a portion of the transferred water and the construction of reservoirs to store excess water, meeting the needs of previously established reservoirs. In areas with relatively steep land slopes, such as the beginning of the Ghaemshahr plain near the Talar River (notably because Talar River carries more suspended matter than Siahrud), the method of feeding through the construction of streams or canals is recommended. For regions where the incoming water has a high suspended load, a ditch and groove system, including side systems, branches, and alignments, is suitable. During the design phase, it is crucial to consider optimal conditions, account for the land slope, and adhere to land availability constraints. This involves determining the volume of water entering the creek, as well as designing the dimensions, shape, number, and spacing of the streams accordingly.[23]

Flooding Method

To implement this approach effectively, it's necessary to divert the water flow from the riverbed and distribute it across a substantial area. However, in cases where the land has significant topographic variations, floods can form new channels, merge, and flow as a single stream. In areas with houses and a resident population nearby, it might be challenging to find a sufficiently large space to disperse floodwaters, rendering this method impractical.

Pit and Infiltration Basin Method

The pit beds, due to their proximity to the river and the presence of large-grain alluvial deposits, exhibit high permeability, making them well-suited for artificial recharge. However, the excavation of these pits over a vast area can be cost-prohibitive. Fortunately, there are numerous pits located closely together near the river. If it is possible and permitted to utilize these existing pits, it could provide a very cost-effective and highly efficient recharge method. Considering the hydrological characteristics of the Ghaemshahr alluvial fan, it appears that either the west or east side of the fan is well-suited for constructing infiltration basins. By diverting water from the Talar or Siahrud River and directing it into the basins excavated in the Ghaemshahr alluvial fan and areas with significant land depressions, we can achieve an effective recharge method similar in efficiency to the pit method. However, it's important to note that the infiltration basin approach may be somewhat more expensive due to the planning and construction of these basins, making it one of the noteworthy methods to consider.

Results and Discussion

In this study, the parameter of unsaturated alluvial thickness was determined using depth maps and by calculating the difference between the topographic layer and the water level layer (Figure 7). The examination of drilling logs for both drinking and agricultural purposes reveals that the aquifer in the Ghaemshahr plain is unconfined at higher elevations, transitioning to semi-pressurized conditions at greater depths and within the central plateau region, with variable pressure levels. Notably, most of the water level changes in the Ghaemshahr plain are concentrated in the southwestern part at the plain's beginning and the central section between Ghaemshahr and Kiakla. Slope is identified as a critical factor in site selection due to its significant influence on various factors, including runoff, erosion, material transport, and permeability. Steep slopes are unsuitable due to erosion concerns, while shallow slopes (at zero percent) hinder water flow. Research suggests that the optimal slope for artificial replenishment falls within the range of zero to 2%. In this study, a 1/25 000 topographic map was employed to generate the slope map (Figure 8).

In an aquifer, higher permeability enables a greater capacity for groundwater replenishment. The choice of the optimal pond width for hydraulic efficiency is also contingent on the aquifer's thickness and its hydraulic conductivity.[20] Within the alluvial fans in the southwestern part of the plain, the maximum transmissivity reaches around 1000 m^2/day. It is important to note that in the southern regions of the plain, specifically within the alluvial fans of the Talar and Siahrud rivers, the hydraulic conductivity is significantly higher compared to the northern areas of the plain. Within the Ghaemshahr plain, the transmissivity rate in the alluvial fans near the elevated areas surpasses that in the northern outlet regions of the plain, which are close to the sea, at approximately

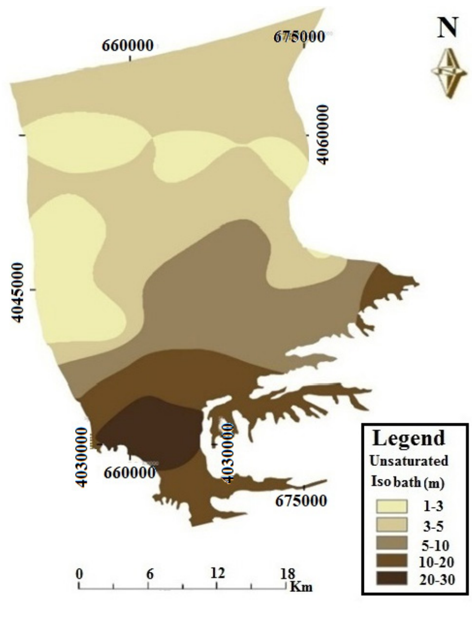

Figure 7. Unsaturated Thickness in the Study Area

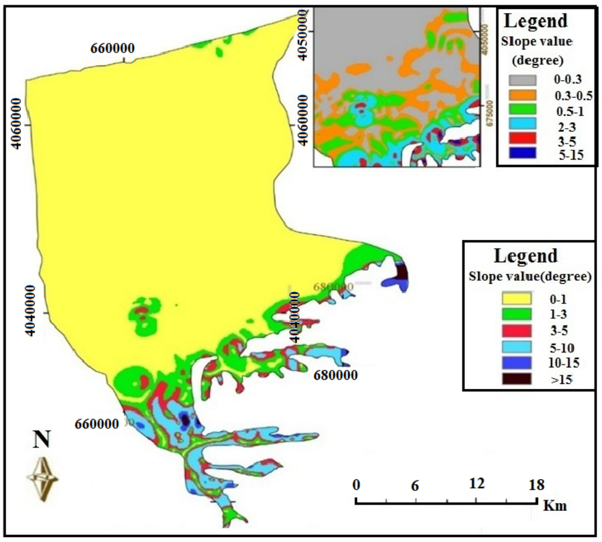

Figure 8. Topographic Slope Map in the Study Area

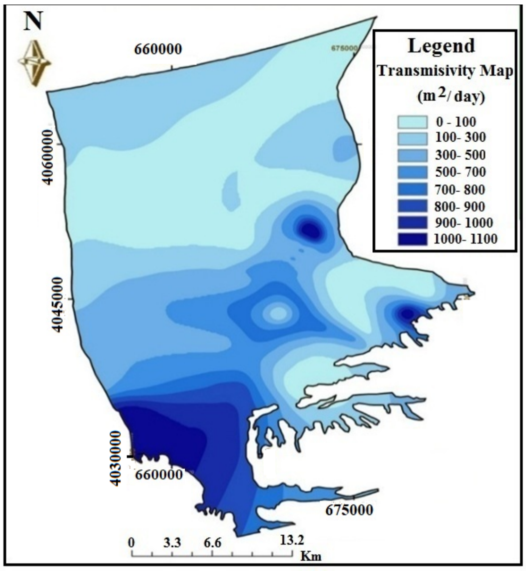

Figure 9. Alluvial Aquifer Transmissivity Map

100 m²/day (see Figure 9). It is crucial for soil permeability to meet acceptable standards for both economic viability and effective treatment. To determine the rate of water infiltration in the surface layers, soil sampling and hydraulic conductivity tests can be conducted. Alternatively, one can prepare a soil texture map and determine the infiltration rate using relevant standard tables or a simple device known as an infiltrometer. In this study, soil texture maps (Figure 10) and a two-point method were employed to calculate soil permeability. In the research area, after identifying suitable sites for artificial groundwater replenishment, we utilized a double ring infiltration tester to assess the rate of infiltration. Subsequently, these findings were incorporated into the soil conservation service (SCS) equation to compute the final infiltration rate.[24]

When evaluating potential sites for artificial groundwater replenishment, it's important to factor in their proximity to permanent or seasonal rivers, provided that other significant criteria are met within the area. If there is no nearby waterway available, or if the distance to transfer water from the river to the replenishment site is too extensive to be economically feasible, then implementing the project in that particular location may not be practical. In this research, the areas surrounding the river were assessed based on their distance from the river and were subsequently categorized. These classifications were then integrated with other relevant layers, taking into account their respective levels of significance (Figure 11).

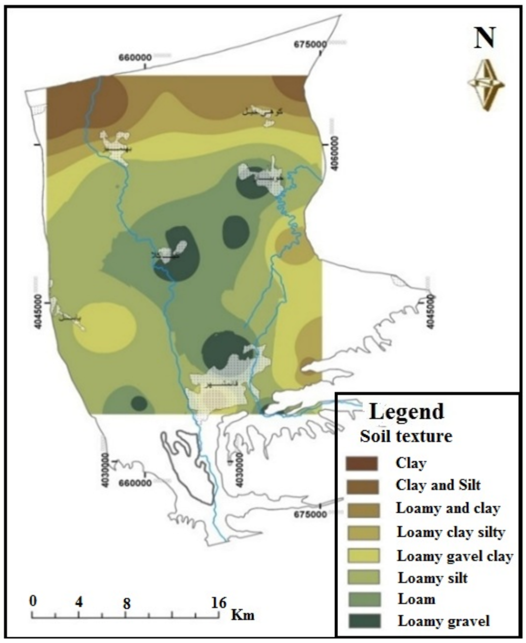

Figure 10. Soil Texture Map

Land Use

Taking into account the project's significance and economic factors, the choice of location and groundwater replenishment method can be influential. In this research, we integrated multiple layers to create a location map, which was then overlaid with the land use data to produce the final map. Land use in the study area encompasses a range of categories, including agriculture (mainly rice fields), orchards, fruit cultivation, shrubbery, forests, wetlands, coastal plains, sandy areas, residential zones, and diverse industrial facilities such as dairy production, battery manufacturing, and textiles. Various types of topographic maps and scales were utilized in this study.[18]

Weighting and Classification of Layers

After undergoing the internalization process, each layer was assigned appropriate ratings in accordance with established standards and the unique characteristics of the study area. The results were then categorized into distinct layers. Subsequently, these layers were assigned weights based on their significance in the context of artificial groundwater replenishment in the study area and were merged accordingly. The essential layers for determining suitable locations for groundwater replenishment

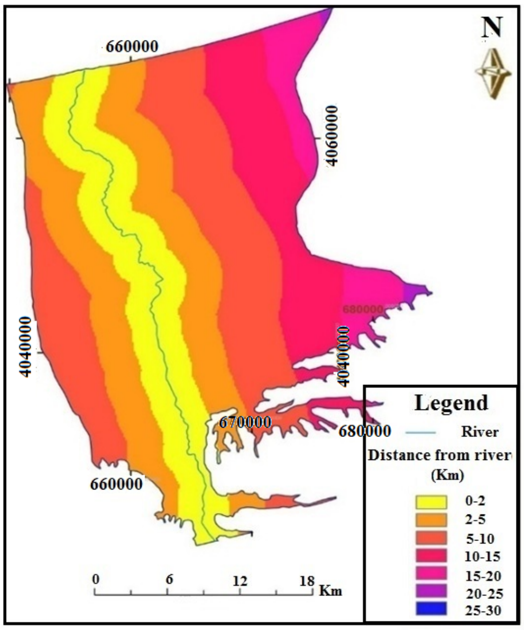

Figure 11. Distance From the Talar River in the Ghaemshahr Plain

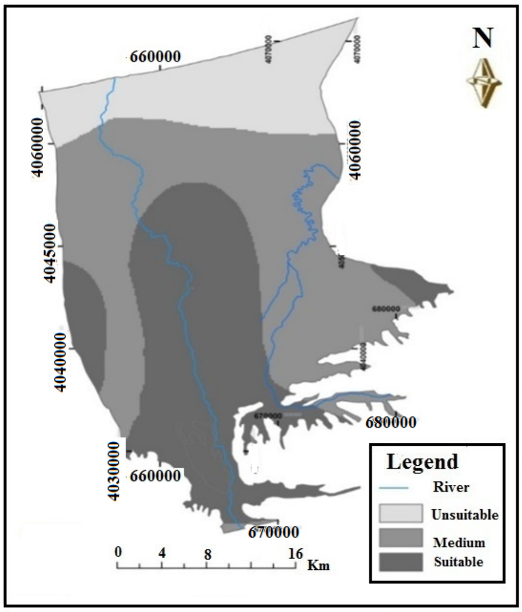

Figure 12- Classified Map of Aquifer Thickness

encompassed aquifer saturation, unsaturated thickness, permeability coefficient, topographic slope, surface permeability, waterway network, and land use, each of which underwent separate classification. Digital data was organized into point, linear, and polygon files and represented in both raster and vector formats. The maps illustrating these crucial layers for artificial groundwater replenishment within the study area can be seen in Figures 12 to 17.

Compilation and Composition Layers

In this study, spatial analysis was employed to merge layers, utilizing one of the most powerful analytical tools available in ArcGIS software. These tools facilitate the examination and modeling of both raster and vector data. Ultimately, classified maps were amalgamated based on their respective levels of significance, aided by the weighted sum tool.

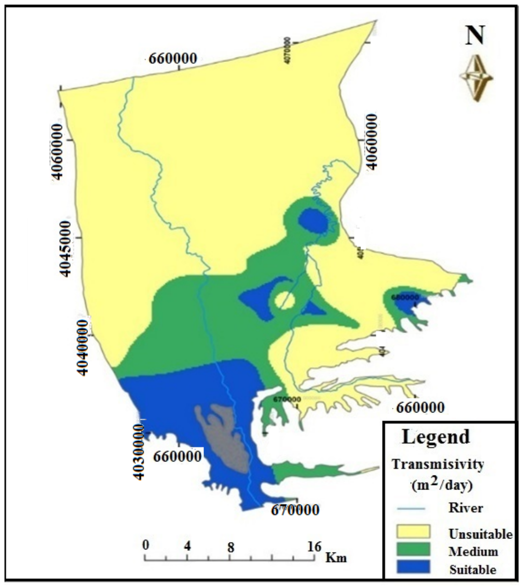

Figure 13. Classified Map of Aquifer Transmissivity

Suitable Location for Artificial Recharge

When determining suitable sites for artificial groundwater replenishment, aside from physical parameters, it's crucial to take into account the objectives of the replenishment efforts. There are two significant factors:

1. Proper position of water source.
2. Recognizing the location of the feeding area and its characteristics. In this research, the primary source for groundwater replenishment, aligned with the study objectives, was determined to be the Talar River, with occasional consideration of the Siahrud River. To identify suitable locations in the Ghaemshahr plain, we integrated several critical factors, including water transfer capacity, unsaturated thickness, aquifer saturation thickness, topographic slope, surface permeability, waterway network, and land use, weighted by their significance. We then created a location map based on these considerations. We also accounted for various conditions within the study area. For instance, site selection took into consideration factors such as evaporative and non-evaporative characteristics, proximity to power sources, and the presence or absence of land use. In the northern part of the study area, excessive groundwater extraction during agricultural seasons resulted in a decline in the water table. This led to the intrusion of saline seawater and a subsequent decline in water quality. However, measures such as creating a hydraulic barrier can prevent saltwater intrusion and improve water quality (Figures 18 and 19).

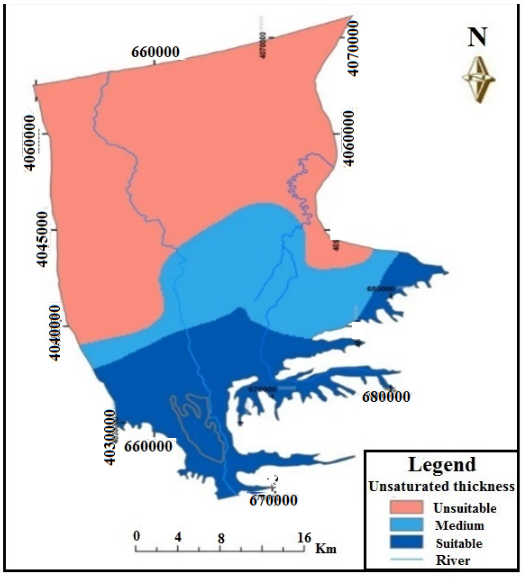

Figure 14. Classified Map of the Unsaturated Thickness

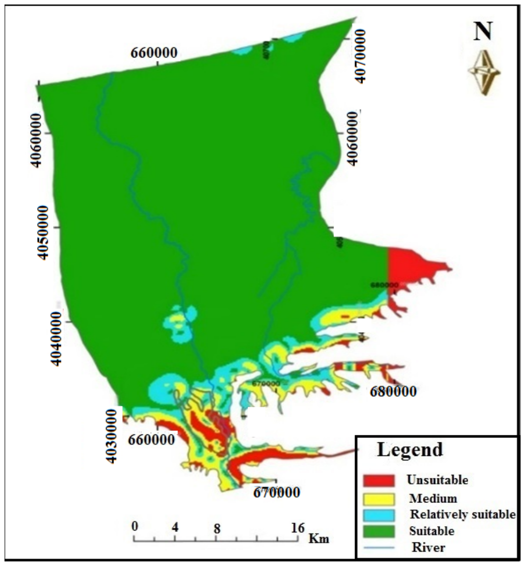

Figure 16. Classified Map of the Slope

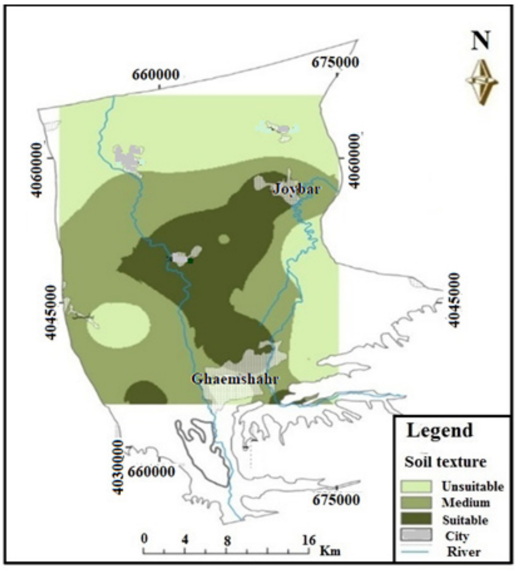

Figure 15. Classified Map of Soil Texture of the Study Area

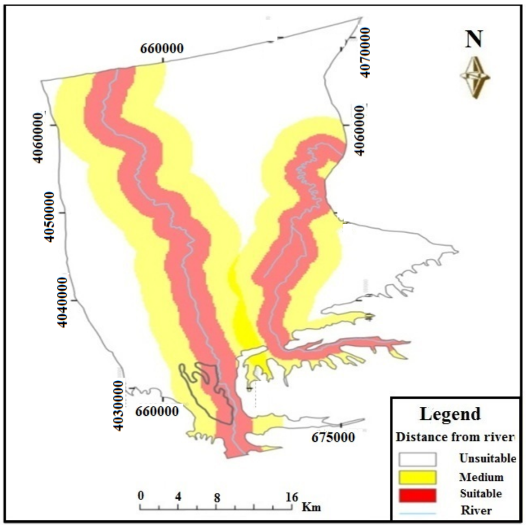

Figure 17. Classified Map of Distance From the River

Amount of Storage Volume in Case of Using Artificial Feeding Methods

In the study area, considering the natural characteristics of the site and the research conducted, three methods of artificial groundwater recharge were identified as suitable: infiltration basins, riverbed enhancement, and the use of ditches and furrow systems. In the event of implementing these methods, the calculated storage capacities for six months and one year are provided in Table 2.

Groundwater Balance Concerning Artificial Recharge Operations

In the Ghaemshahr plain, employing all three methods allows for 4.5 MCM of water to recharge the aquifer within a six-month feeding period. Approximately 0.22 MCM per year is deducted from this recharge amount due to river drainage and evaporation. Thus, based on the expression equation ($\Delta s = \text{output} - \text{input}$), the change in reserves (Δs) amounts to + 4.33 MCM. Assuming a constant harvest amount, the plain's balance is as shown in Table 3.

Conclusion

In conclusion, this study utilized GIS to identify suitable locations for artificial groundwater replenishment based on factors such as aquifer thickness, permeability, topography, waterway networks, and land use. Employing three methods for six months during non-irrigation seasons could potentially store 5 MCM of water in the alluvial aquifer. The design of infiltration basins and leveling systems should account for groundwater level fluctuations, ensuring effective control and management. Permeability values were determined through soil texture analysis and infiltrometer tests. Given the area's size and soil texture variations, it's advisable to conduct at least three on-site soil penetration tests for pond construction. The study highlights the need for environmental investigations due

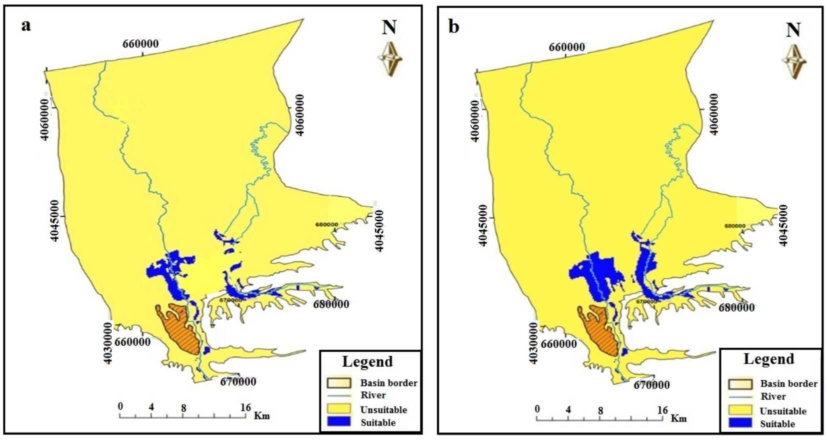

Figure 18. Map Resulting From Integration. (a) Without land use limitation, (b) With land use limitation

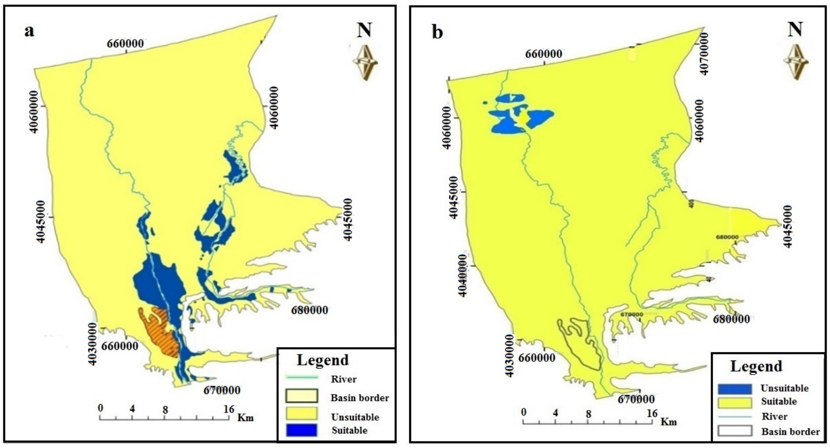

Figure 19. Map of the Combination. (a) regardless of evaporation zones and land use limitations, (b) for the northern areas of the plain in exceptional cases (over-withdrawal, water level decreases, the influx of salty sea water)

Table 2. The Amount of Storage Volume Using Artificial Feeding Methods (MCM)

Amount of Water Received From the River for Six Months\	Storage Volume in One Year (MCM), Methods Used (in Artificial Nutrition)	Storage Volume in 6 Months (MCM)
2% of the Talar River (0.15 m^3/s)	5 (infiltration basin)	2.5
1% of the Siahrud and Talar Rivers (0.11 m^3/s)	1.6 (Improving the riverbed)	0.8
1.5% of the Talar River (0.12 m^3/s)	2.4 (Trench and furrow systems)	1.2
Sum (MCM)	9	4.5

Table 3. Groundwater balance considering artificial feeding operations in the Ghaemshahr plain (Values in MCM)

Input Parameters						Output Parameters					Changes in Aquifer Storage Volume
Groundwater Input Flow	Infiltration Of Precipitation	Infiltration of Surface Flow After Improving the Riverbed	Infiltration of Artificial Recharge (Surface)	Infiltration of Wastewater (Drinking, Agricultural, Industrial)	Sum	Groundwater Output Flow	Discharge and Withdrawal (Wells, Springs, Aqueducts)	Aquifer Drainage by River	Evaporation From the Aquifer	Sum	
53.19	40.89	58.82	3.7	72.71	229.31	2.33	202.14	15.5	5.01	224.98	+4.33

to extensive rice cultivation, fertilizer use, and potential contamination from industrial wastewater and mining activities. Considering global water scarcity, expanding artificial groundwater replenishment schemes can play a crucial role in sustainable water resource development and mitigating water shortages. Recommendations from previous studies and this research include utilizing long-term meteorological data, conducting field studies, determining mixed water sources, drilling exploratory wells, and addressing saline water intrusion. The choice of artificial replenishment method (e.g., Todd, Hantush, or Houisman) can yield similar results, with the basin method being favored due to its sediment pond capabilities. Furthermore, simulation software like PMVIN, MODFLOW, or GMS can aid in selecting the best alternative among defined scenarios.

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Methodology: Homayoun Moghimi, Esfandyar Abbas Novinpour.
Project administration: Homayoun Moghimi.
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Software: Homayoun Moghimi.
Supervision: Homayoun Moghimi.
Validation: Homayoun Moghimi, Esfandyar Abbas Novinpour.
Visualization: Homayoun Moghimi.
Writing–original draft: Homayoun Moghimi.
Writing–review & editing: Homayoun Moghimi, Esfandyar Abbas Novinpour.

Competing Interests

The authors declared no conflict of interest.

Ethical Approval

There were no ethical considerations to be considered in this research.

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