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Evaluating Groundwater Quality to Determine the Feasibility of Modern Irrigation Techniques (Case Study: Bam-Narmashir Plain)

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Abstract

Groundwater in the Bam-Narmashir plain serves as a crucial water source for various purposes, including agriculture, drinking, and industry. Today, advancements in irrigation science have led to the development of new methods to enhance irrigation efficiency. In the new methods, such as drip irrigation, it is important to examine the EC, the pH level of the water, and the presence of cations and anions, as these factors can contribute to the clogging of drippers. Therefore, understanding the quality of this groundwater and evaluating the feasibility of modern irrigation methods is essential. In this study, the groundwater quality parameters of the region were obtained from 55 wells, and the Langiller index was calculated. Additionally, layers for each parameter were created using the IDW interpolation method through the Spatial Analyst tool in ArcGIS 10.6 Software. The semivariance diagram for 55 wells was made using GS^+ software. The semivariance diagram for the pH parameter, which showed a correlation coefficient of 0.913 with the spherical model, was identified as the most suitable model. Following this, all parameters were assessed based on FAO and ISIRI standard values to determine the implementation of drip and sprinkler irrigation systems. The results indicated that 94.54 percent wells had sodium levels exceeding three, 92.72 percent of wells had bicarbonate levels above eight and a half, 16 wells had a pH greater than eight, 78.18 percent of wells had chlorine levels over three, eight wells had water-soluble salts above 2,000, and 69.09 percent of wells had EC between 3 and 8. These findings highlight significant sodium, chlorine, and EC limitations for most of the study area. Given the constraints on groundwater resources in this region, it is important to consider management solutions to preserve and sustain the land.

Keywords: Inverse Distance weighting (IDW), Optimal exploitation, Semivariable graph, Water crisis, Water resources management.

1. Introduction

Groundwater plays a critical role in the Earth's hydrological cycle, serving as a vital reservoir that supports ecosystems, agriculture, and human consumption (Megahed et al., 2025). Across the globe, the pressure on water resources and infrastructure has reached a critical point, with many countries finding it increasingly challenging to satisfy the soaring demand driven by a rapidly growing population (Matarneh et al., 2024). Agriculture plays a crucial role in global water consumption, being one of the largest users of freshwater resources. Approximately 43% of the irrigated agricultural land relies on groundwater drawn from underground aquifers and reservoirs. This method is essential, especially in regions with scarce or seasonal surface water sources (Abd-Elaty et al., 2021). But, in an increasingly water-scarce and climate-vulnerable global context (Areosa et al., 2024), as civilizations have progressed, water use has evolved, making access to sufficient, high-quality water at the right time and place increasingly important. Hyper-arid and arid water resources are limited compared to humid and wet regions (Abd-Elaty et al., 2021; Benmarce et al., 2024).

Today, any water shortage is viewed as a significant barrier to sustainable development. As a result, managing water for agriculture is the most important and sensitive aspect of any integrated water conservation project (Mohammadi et al., 2023). By implementing appropriate management strategies for existing water resources, we can optimize their usage (Yazdani et al., 2009). A decline in water levels within groundwater aquifers results in various problems, such as decreased discharge from rivers and wells, lower water quality, changes in soil properties, and insufficient water supply for plants. These issues can lead to land subsidence, which further restricts access to water and diminishes agricultural productivity for farmers (Renger et al., 2002; Zimmermann et al., 2017). Consequently, the optimal use of water has become a central focus of government development programs. Given the quantitative and qualitative limitations of water resources, it is essential to adopt comprehensive water resource management methods.

This approach is necessary to minimize the adverse effects of the water crisis in the country. Water resource management is seen as a key solution to address the issues arising from the decline in both the quantity and quality of water. Before allocating or withdrawing existing resources, it is essential to assess the quantity and quality of water for sustainable agriculture (Ahmadi et al., 2015). Increasing agricultural production through the expansion of farmland encounters significant challenges due to water shortages. Therefore, the most viable approach to meet the rising demand for food is to enhance the productivity of agricultural water resources, allowing for more output with reduced water consumption (Ingrao et al., 2023). Given the challenges of water management in Iran, it is crucial to optimize agricultural water use by improving management practices (Dehghan and Galdavia, 2024). Among the most effective solutions proposed, new irrigation methods not only optimize water use for crops but also help prevent soil erosion.

Modern irrigation systems offer a significant opportunity to bridge the disparity between water supply and demand (Abd-Elaty et al., 2021). By utilizing advanced technologies and efficient water management practices, these systems can optimize water usage, ensuring that crops receive the precise amount of moisture needed for healthy growth. This not only helps in conserving water resources but also enhances agricultural productivity, making it possible to meet the increasing demands for food sustainably. In recent years, the advancement of irrigation science has led to the development of new methods to improve irrigation efficiency. These methods represent viable options for the sustainable management of water resources in agriculture. However, their effective and principled application is essential for aligning with sustainable agricultural practices (Behbahani et al., 2017).

Moursy et al. (2023) investigated the productivity and profitability of modern irrigation methods by applying on-farm drip irrigation to various crops in the Northern Nile Delta of Egypt. The study found that the overall cost of a drip irrigation system was lower compared to a surface irrigation system. Additionally, drip irrigation demonstrated more efficient water usage and savings across different summer and winter crops. Yazdanpanah et al. (2023) conducted a detailed investigation into the socio-economic factors, innovative traits, and social capital values associated with the implementation of various modern irrigation systems in the Khuzestan province of southwest Iran. Their research revealed that the farmers in this region were slow to adopt drip irrigation technologies. This delay was attributed to the intricate nature of the application process involved in these technologies, as well as the influence of available social capital, both from family connections and work networks. The findings underscore the challenges farmers face when navigating new agricultural practices, highlighting the importance of support systems in fostering technology uptake.

Galdavi et al (2024) conducted research aimed at identifying factors influencing the adoption of New Irrigation Systems (NIS) among farmers in the Torshiz region using a questionnaire survey. Analysis was conducted using SPSS 21 and Smart PLS software, revealing that all factors had a significant impact on the acceptance of NIS. Attitudinal factors were the most influential, followed by economic and social factors. Key findings included that the "suitable cultivation pattern for the region" was the most significant educational factor, while "various cultivation abilities" was the primary economic factor. Additionally, leveraging positive experiences of others was crucial socially. The study concluded that encouraging technology acceptance through identifying suitable cultivation methods and offering training can enhance agricultural production and improve water efficiency in a hot and dry climate.

Wael et al. (2024) undertook an in-depth comparative analysis of contemporary irrigation systems versus traditional flood irrigation practices, focusing on their respective impacts on groundwater potential within the unique context of ancient clayey soils found in the Qalyubia Governorate of the Nile Delta in Egypt. Their comprehensive study revealed significant insights into the relationship between irrigation methods and groundwater dynamics. The researchers discovered that the implementation of water-efficient irrigation techniques, while beneficial for water conservation, led to a marked reduction in recharge intensity of the groundwater. This phenomenon resulted in a notable decline in groundwater levels, with measurements indicating a decrease of between 10 and 50 cm in the groundwater table. In a study conducted by Hakami et al. in 2024, the quality of groundwater for irrigation purposes was assessed using various indicators through Geographic Information System (GIS) software, implementing the Inverse Distance Weighting (IDW) interpolation process.

The indicators evaluated included salinity (electrical conductivity), sodium hazard (sodium absorption ratio and permeability index), a combined salinity and sodium hazard index (based on electrical conductivity and sodium percentage), magnesium hazard index, and chloride content index. The results indicated that 24.14% of the samples exhibited high salinity, while 75.86% were classified as very high salinity based on electrical conductivity indices. Regarding sodium hazards, 79.3% of the samples posed a moderate risk to soil permeability in the long term, as indicated by the permeability index. When assessing the combined salinity and sodium hazard, 69% of the samples were found to be unsuitable for irrigation in terms of quality. For magnesium hazards, 55.17% of the groundwater samples were deemed unsuitable for irrigation.

Additionally, concerning chloride content, 72.41% of the samples exceeded the permissible limit set by Yemeni and international standards (350 mg/L). The interpolation results also highlighted areas in critical condition. Consequently, using groundwater from the study area for irrigation can hinder crop growth and productivity, lead to soil salinization, and/or result in physical degradation due to increased alkalinity. This situation may necessitate costly soil rehabilitation operations to restore productivity. Nevertheless, given all the factors affecting the use of poor-quality groundwater for irrigation, it can be conditionally utilized for that purpose in the study area.

In many arid regions, particularly those close to coastlines, the scarcity of water resources poses a significant challenge to agriculture and overall sustainability. This is exacerbated by the increasing water demands of crops, which have risen dramatically due to the impacts of climate change, higher temperatures, and shifting precipitation patterns. As a result, the need for effective and modern irrigation systems has become critical. Implementing advanced irrigation techniques, such as drip irrigation or automated systems, can optimize water usage, ensuring that every drop is utilized efficiently. These systems not only help in conserving precious water resources but also enhance crop yield and resilience, allowing farmers to adapt to the changing climate while maintaining food production in these vulnerable regions. Addressing the water crisis through innovative irrigation practices is vital for securing the future of agriculture and supporting the livelihoods of communities dependent on these ecosystems.

Drip irrigation has emerged as a particularly suitable solution for optimizing water resource use, thanks to its high distribution efficiency (Piri, 2012). Research findings indicate that approximately 98.3 percent of the land in the study area is well-suited for implementing drip irrigation methods (Seyedmohammadi et al., 2016). Key objectives for adopting modern irrigation practices include increasing irrigation efficiency, reducing overall water consumption compared to traditional surface irrigation, preventing surface runoff, minimizing soil erosion, promoting adequate soil ventilation, ensuring uniform water distribution across the field, and enhancing yield per unit area (Ghaemizadeh and Akhavan, 2014). To achieve the desired goals, the conditions and characteristics of the region must align with the features of the proposed system. If they do not, the implementation of modern methods may not only be ineffective but can also decrease yield per unit area, lower productivity, and create inconsistencies in water distribution.

Therefore, conducting a thorough and appropriate feasibility assessment before applying modern methods on a regional scale is crucial. The quality and quantity of surface and groundwater resources can vary significantly across different regions, making it essential to evaluate these factors. Conducting a feasibility assessment that considers water quality before implementing modern techniques helps prevent the waste of energy, capital, and resources. In fact, it is essential to assess the groundwater's (GW) quality to guarantee that it is suitable and to design sustainable management methods to meet the demands for drinking water and irrigation that exist now and in the future (Hossain et al., 2024).

This study aims to utilize a Geographic Information System (GIS) to identify areas that are suitable for implementing pressurized irrigation methods, based on the indicators and standards for irrigation water quality. Additionally, the potential risks associated with each parameter have been considered.

2. Materials and Methods

2.1. Study area

The study area is within the Lut Desert watershed, characterized by a hot desert climate. Its average altitude is 960 meters above sea level, covering an area of 9,921 square kilometers, of which 4,357 square kilometers consists of plains. This region contains the main groundwater reservoirs. The average depth of piezometer wells that tap into the water table (static level) ranges from 150 to 200 meters (Kerman Province Regional Water Joint Stock Company). Fig. 1 illustrates the study area's location and the wells used for evaluating and zoning the parameters. Data from 55 wells, collected by the Kerman Province Water Resources Studies Department in 2017, were utilized for this study.

The study area is located between longitudes 57°15' and 59°30' and latitudes 28°30' and 29°45'. It has an average altitude of 960 meters above sea level and covers an area of 9,921 km^2, of which 4,357 km^2 are plains. The main groundwater reserves in the region are situated in this area. The average depth of piezometer wells in contact with the water table (static level) ranging from 150 to 200 meters (Regional Water Company of Kerman Province).

The region experiences a hot and dry climate, with vegetation primarily composed of drought- and salinity-resistant plants, such as palm and mulberry trees, which historically played a role in silk production. The Bam Plain features seasonal rivers such as the Nisa, Fashkoh, Telango, and Tahrud, which originate from the Barez and Rhine Mountains. Rainfall in this region is low, and there is a significant temperature difference between day and night. The average annual rainfall measures 60 mm, primarily occurring in the form of showers. The Plain is made up of alluvial deposits that date back to the Quaternary period. This area consists of low-lying plains along with sedimentary and clay terraces, which are important reservoirs for groundwater.

The predominant land use in this plain is fallow land, followed by saline areas and agricultural fields. The plain to the south is bordered by the Jabalbarez Mountains, which are among the highest peaks in Kerman Province. Mount Keshit is located to the northwest and west, while Loot Zangi Ahmad lies to the north of the plain.

2.2. Research method

This research seeks to comprehensively assess the quality of groundwater to evaluate the feasibility and effectiveness of modern irrigation methods. By analyzing various parameters such as pH levels and mineral content, the study aims to determine how suitable the groundwater is for irrigation purposes. Understanding the groundwater quality is crucial for optimizing irrigation practices, enhancing agricultural productivity, and promoting sustainable water management in farming communities. Through this evaluation, we aim to provide valuable insights that can guide the implementation of advanced irrigation techniques that are both efficient and environmentally responsible.

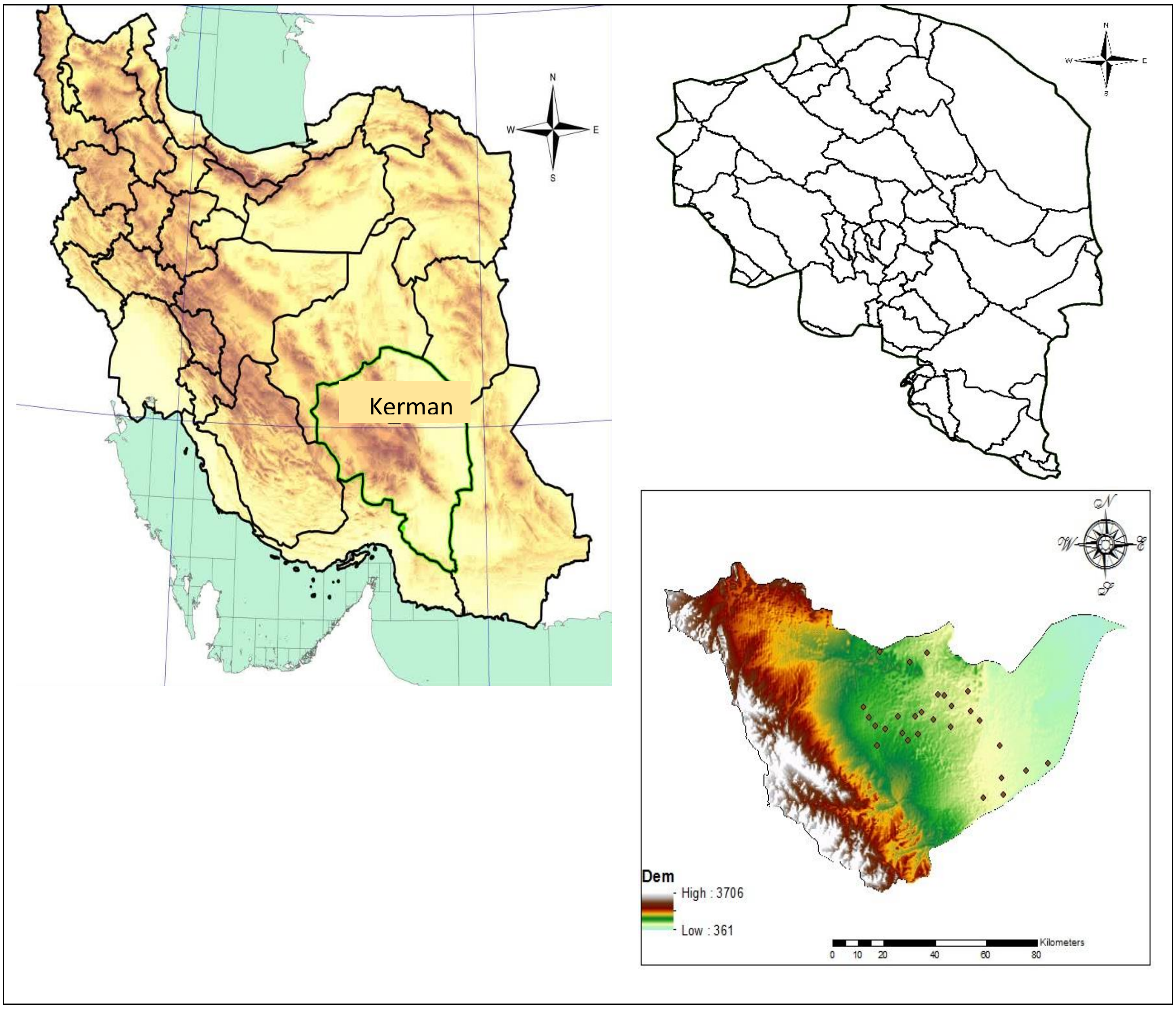

Fig. 1. Study area with the location of the wells used

2.2.1. Assessment of groundwater quality

The significance of groundwater quality assessment lies in its role in determining the suitability of groundwater for various purposes (Benmarce et al., 2024), such as the use of modern irrigation techniques. Groundwater chemical constituents can serve as indicators of water quality attributes and provide insight into the chemical composition of groundwater (Megahed et al., 2025). In sprinkler irrigation, the distribution of water on the leaves is significant, making the salinity, bicarbonate, sodium, and chloride content in the irrigation water crucial. According to the standards provided (FAO, 1994), the water quality restrictions for the sprinkler irrigation method are presented in Table 1.

Table 1. Degree of irrigation water quality restriction for the sprinkler irrigation method

Ion (meq/l)	No restrictions	Low to moderate restrictions	Severe restrictions
Sodium	Less than 3	More than 3	-
Chlorine	Less than 3	More than 4	-
Bicarbonate	Less than 1.5	1.5 to 5.8	More than 8.5

In drip irrigation, it is important to examine the EC, the pH level of the water, and the presence of cations and anions, as these factors can contribute to the clogging of drippers. EC serves as an indicator of the total dissolved salts in the water, making it a valuable parameter for assessing the suitability of drip irrigation. Additionally, measuring the pH of the water is crucial as it influences the amount of sediment that may accumulate in the drippers. The tendency of the water to precipitate calcium carbonate within the drip irrigation system is evaluated using an index known as the Langelier Saturation Index (LSI).

The LSI is initially calculated based on laboratory results from the chemical analysis of water. A positive LSI value indicates a tendency for calcium carbonate to precipitate in the water, while a negative value suggests that carbonate precipitation will not occur. The LSI was calculated and analyzed following the guidelines in Table 25 of FAO Publication 29, using Equations 1 and 2 (FAO, 1994).

$$LSI = pH - pHs \quad (1)$$

$$pHs = p(Ca+Mg+Na+K) + p(Ca+Mg) + p\,(CO_3 + HCO_3) \quad (2)$$

In this formula, p (Ca + Mg + Na + K) represents the index of water cations, which is based on the total concentration of cations present in the water. The value p (Ca + Mg) specifically denotes the index of calcium and magnesium, relying solely on the total concentrations of these two cations. Similarly, p (CO_3 + HCO_3) indicates the index of carbonate and bicarbonate, depending on the total concentrations of these components in the water. All concentrations are measured in milliequivalents per liter.

The standards for important water quality parameters for drip irrigation, based on the FAO standard (FAO, 1994) and the Study Methodology for Justifying Modern Irrigation Methods (ISIRI, 2008), are presented in Table 3. In this study, GS^+ software was utilized to create a semi-variable map for each water quality parameter. Then, layers for each parameter were generated using interpolation methods through the Spatial Analyst tool in ArcGIS software.

In this study, the inverse distance weighting method was employed for interpolation. This technique calculates the unknown value by assigning weights to the data points surrounding the desired location, allowing for effective interpolation. It is based on the principle that points that are closer together are more similar than those that are farther apart, meaning that closer points hold more weight in the calculation (Johnston et al., 2001). Zoning maps were created for the chemical parameters of sodium, chlorine, and bicarbonate (HCO_3^-) for sprinkler irrigation, as well as for pH levels and total dissolved solids (TDS) for drip irrigation.

2.2.2. Interpolation method

Geographic Information Systems (GIS) create a comprehensive representation of groundwater quality (Mohamaden et al., 2024). Using a Geographic information system to distribute data from water sample results spatially can assist in determining water quality and preserving and managing groundwater resources (Gintamo et al., 2021). Efficient and modern computer-based technologies for managing water have developed and Geographic Information Systems (GIS) are now very important. In order to manage water resources on a regional basis, comprehend the natural environment, avoid flooding, determine water availability, and assess water quality, GIS may be an important tool (Dandge and Patil, 2022).

To map the quality of groundwater, researchers employed several interpolations using GIS. For instance, the geographical distribution of physicochemical characteristics was extensively studied using the Inverse Distance Weighted (IDW) interpolation. IDW is an algorithm for estimating measurement values or spatially interpolating data. Weights are computed in the opposite direction from the observation location to the predicted point site (Shankar et al., 2022). This study employed the inverse distance weighted (IDW) interpolation method, which will be elaborated on in the following sections.

The analysis of the spatial correlation of groundwater quality data was conducted using an empirical semivariance graph. This graph is a crucial tool in Geostatistics, as it provides a visual representation of how data points relate to one another over varying distances. The semivariance graph illustrates the degree of correlation or lack thereof between changes in variable values, based on the distances separating the measured points. Essentially, it quantifies the relationship between pairs of observations by calculating the square of the differences in their values. This calculation not only accounts for the distance between each pair of points but also considers their directional orientation, allowing for a nuanced understanding of spatial trends. By plotting these correlations, the semivariance graph helps researchers identify patterns in groundwater quality and can reveal important insights into environmental factors influencing these variations (Davoudi et al., 2016).

$$\hat{\gamma}(\mathrm{h}) = \frac{1}{2N(h)} + \sum_{i=1}^{N(h)} [Z(u_i) - Z(u_i + h)]^2 \qquad (3)$$

In Equation 3, the empirical variogram is represented, where ($N_{(h)}$) denotes the number of pairs of points that are separated by a distance (h). $Z(u_i)$ and $Z(u_i + h)$ are the observed values of the variable at the points (u_i) and ($u_i + h$), respectively. After calculating the empirical semi-variogram, the best theoretical model is fitted to the data. In the inverse distance weighting method, the estimation distance is the same as that used in the ordinary Kriging estimator. However, the weights are determined solely based on the distance of each known point to the unknown point, without considering the distribution of the points around the estimated location (Mostafazadeh and Moeidinai, 2000 and Dehghanisanij et al., 2005). Consequently, closer points are assigned more weight, while farther points receive less weight.

3. Results and Discussion

The statistical descriptions of water quality parameters, including mean, maximum, standard deviation, and others, are summarized in Table 2 for 10 years from 2007 to 2017. This table indicates that the coefficients of variation for chloride (Cl), EC, and sodium (Na) are the highest among the parameters measured. Conversely, bicarbonate (HCO_3, log) and pH exhibit the lowest coefficients of variation. To assess the normality of the data distribution, the Kolmogorov-Smirnov test was conducted using SPSS software. Additionally, a spatial correlation analysis of the water quality data was performed through semivariogram modeling, with the specifications for the semivariogram model related to water quality parameters in 2017 outlined in Table 3.

To assess the degree of spatial correlation, the ratio of the piecewise effect (C0) to the semivariable peak (C0 + C) was used. If this ratio is less than 0.25, it indicates a strong spatial correlation between the data. A ratio between 0.25 and 0.75 suggests a moderate spatial correlation, while a ratio greater than 0.75 indicates a low spatial correlation or no correlation (Cambardella and Karlen, 1999). Based on the parameters obtained from the fitted semi-variograms, the spherical model for the pH parameter, with a piecewise effect ratio of 0.30 (indicating medium spatial correlation) and a correlation coefficient (R^2) of 0.913, was determined to be the best spatial structure model. According to the results presented in Table 2, all parameters exhibit a strong spatial correlation. The semi-variogram model that best fits the pH parameter is illustrated in Fig. 2.

Table 2. Statistical summary of water quality data for the Bam Plain for 2007-2017

Parameter	Mean (mm)	Standard deviation (mm)	Variance (mm^2)	Minimum (mm)	Maximum (mm)	Skewness	Elongation	Coefficient of variation
Cl	11.64	15.94	254.13	1	76	2.76	7.88	1.37
Cl (log)	1.85	1.1	1.2	0	4.33	0.24	-0.31	0.59
EC (mmhos/cm)	1906.82	1728.22	2986762.2	384	8200	2.29	5.12	0.9
EC (mmhos/cm) (log)	7.28	0.72	0.51	5.95	9.01	0.48	0.12	0.098
EC (ds/m)	1.91	1.73	2.98	0.38	8.2	2.29	5.13	0.9
EC (ds/m) (log)	0.37	0.71	0.51	-0.97	2.1	0.48	0.13	1.91
PH	7.99	0.33	0.11	7.3	8.7	-0.14	-0.48	0.041
TDS	1239.53	1123.37	1261959.4	250	5330	2.29	5.12	0.91
TDS (log)	6.85	0.72	0.51	5.52	8.58	0.48	0.12	0.1
HCO_3	3.82	2.32	5.39	1.4	13.4	2.73	8.57	0.61
HCO_3 (log)	1.22	0.46	0.21	0.34	2.6	0.78	1.4	0.38
Na	13.7	15.15	229.51	1.5	70	2.46	5.8	1.11
Na (log)	2.22	0.88	0.77	0.41	4.25	0.26	0.07	0.4

Table 3. Characteristics of models fitted to the semivariogram of water quality parameters

Parameter	Spatial Structure Model	Piece Effect (C0)	Threshold (C+C0)	Radius of Effect	$\frac{C0}{C+C_0}$	Correlation Coefficient (R^2)	RSS
Cl	Spherical	0.001	1.67	34640	0.0006	0.68	1.42
EC (mmhos/cm)	Spherical	0.001	0.72	35420	0.001	0.66	0.33
PH	Spherical	0.04	0.14	32660	0.30	0.91	7.301e-04
TDS	Spherical	0.001	0.72	35440	0.001	0.66	0.33
HCO_3	Spherical	0.08	0.41	91100	0.20	0.68	0.01
Na	Spherical	0.001	1.06	33770	0.0009	0.64	0.71

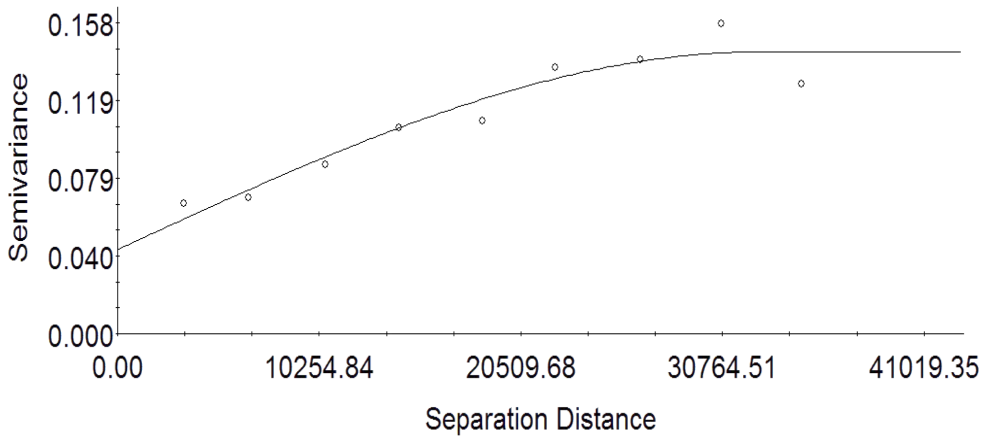

Fig. 2. Experimental semi-variogram and fitted model (solid line) of the PH parameter

The quality of the parameters for implementing sprinkler irrigation in the study area was evaluated. The investigation revealed that the chlorine content of 21.81 percent of wells is within the unrestricted range, measuring less than 3 milliequivalents per liter. In contrast, 78.18 percent of wells have chlorine levels above 3, placing them in the moderate to serious restriction category. It is important to note that the permissible concentration of sodium and chloride ions for a sprinkler irrigation system is set at 3 milliequivalents per liter (as shown in Table 1). According to the sodium and chlorine zoning maps, a small area in the southern part of the region has sodium and chloride levels below 3, while most of the central and northern parts of the region exhibit sodium and chloride levels exceeding 3, indicating severe restrictions.

Out of the wells studied, 3 have sodium content below 3 and are without any restrictions. Conversely, 94.54 percent of wells have sodium levels above three and come with moderate to serious restrictions. Additionally, for most of the studied area, the concentration of these elements exceeds permissible limits.

Therefore, if groundwater is to be used, it is recommended to limit usage to a small portion of the allowable amount. High levels of chlorine and sodium are toxic to most fruit trees and some crops, leading to plant poisoning. Furthermore, using water containing excessive sodium can negatively impact soil permeability (Pirmoradian et al., 2014). These include salt-sensitive plants (fruit trees, grain corn, peas, oranges, peaches, tangerines, mung beans, lentils, chickpeas, peanuts, etc.), semi-resistant plants (carrots, lettuce, sugarcane, rice, onions, etc.), and salt-resistant plants (alfalfa, barley, sugar beet, cotton, etc.) (Ayers and Wescot, 1985).

Also, considering the zoning of chlorine and sodium, based on the cultivation pattern of the region, the cultivation of tomato and corn crops is limited according to the standards provided by FAO (1994) and the implementation of sprinkler irrigation causes damage to the leaves of the plants, which is consistent with the results of (Ghaemizadeh and Akhavan, 2014).

In most study areas, significant limitations related to bicarbonate (HCO_3) have been observed when implementing the sprinkler irrigation method. According to the bicarbonate zoning map, most locations show bicarbonate levels ranging from 1.5 to 5.8 and have low to moderate limitations, and a small part of the northern part of the region has bicarbonate levels of more than eight and serious limitations, so most of the points in the study area have limitations. The amount of bicarbonate (HCO_3) in two wells is less than 1.5 (no limitations), two wells have bicarbonate of 1.5-5.8 (low to moderate limitations), and 92.72 of wells have bicarbonate of more than 5.8 (serious limitations).

Irrigation with water containing bicarbonate causes soils that are rich in calcium to gradually turn into sodic soils and ultimately affects the soil structure in the long term, destroys the environment around the roots, and makes the soil sodic (Seifi and Riahi Madvar, 2017; Zia Tabar Ahmadi and Aghajani Mazandarani, 2009). Using water that contains bicarbonate for sprinkler irrigation can lead to deficiencies in zinc and iron in plants, such as lettuce and soybeans.

This can impair plant growth, cause leaf chlorosis (yellowing of leaves), and ultimately reduce crop yields (Seifi and Riahi Madvar, 2017). To effectively implement pressurized irrigation, it is important to assess the water quality in terms of EC, TDS, and pH levels. The table below outlines four levels of restrictions for irrigation water quality, specifically for drip irrigation.

Table 4. Level of Restriction of Water Quality for Drip Irrigation Water Quality

Parameter	No restrictions	Low to moderate restrictions	Severe restrictions
EC (ds/m)	Less than 0.8	0.3-8	More than 3
TDS (mg/l)	Less than 500	2000-500	More than 2000
PH	Less than 7	7-8	More than 8

Fig. 3 shows the interpolation maps of water quality parameters using the IDW method. The EC values of 18.18 percent of wells are below 0.8, indicating no limitations. 69.09 percent of wells have EC values ranging from 0.8 to 3, which suggests low to moderate limitations. In contrast, 12.72 percent of wells exhibit EC values greater than 3, indicating severe limitations. According to the TDS zoning map, a small portion of the southern regions has TDS values below 500, while most areas fall within the range of 500 to 2000, reflecting low to moderate limitations.

Additionally, a small portion of the northern regions of the plain experiences severe limitations, with TDS values exceeding 2000. In a study of 55 wells, the total dissolved salts in the water of 18.18 percent of wells were found to be less than 500 mg/L, while 67.27 percent of wells had dissolved salt levels ranging from 500 to 2000 mg/L, indicating low to moderate limitations. Additionally, 14.54 percent of wells had dissolved salts exceeding 2000 mg/L, which is considered a severe limitation. Most areas studied showed salinity levels within the low to moderate limitation range.

The salinity of irrigation water plays a crucial role in irrigation practices and its effects on plants and soil. When discussing drip irrigation methods, it's important to recognize the variety of dripper types available. Selecting the appropriate drippers, such as flexible flow drippers or high-flow options like bubblers and mini bubblers, can help mitigate issues such as sedimentation caused by water salinity.

This approach aligns with findings from previous research (Gholami Sefid Koohi and Barzegar Akhtekhaneh, 2014). Furthermore, the EC (salinity) of irrigation water can be managed by adjusting the distance and depth at which the water is applied, thereby reducing the negative impacts of salinity. According to the zoning map, the EC in the northern regions of the plain has significant limitations, with values exceeding three. As a result, cultivating salinity-sensitive crops in these northern areas is not recommended. In contrast, the southern regions and central parts of the plain exhibit low to medium limitations, allowing for unrestricted cultivation. It is important to note that the pH (salinity) of irrigation water will be a limiting factor for plants.

However, this parameter does not significantly influence the assessment of water suitability for implementing the drip irrigation method. In many chemical processes, either water or soil plays an active role and can affect the precipitation of iron salts and calcium carbonate in drippers. Additionally, the absorption of various soil nutrients by plants is dependent on the pH of the soil solution resulting from the irrigation water.

According to the standard presented in Table 4, the results indicated that 70.90 percent of the samples fell within the pH range of seven to eight (low to medium limitation), while 29.1 percent had a pH level greater than three (severe limitation). Specifically, in the study area, 70.90 percent of wells had pH values between seven and eight (low to medium limitation), and 29.09 percent of wells exhibited pH levels above eight (serious limitation) for the drip irrigation method. Consequently, pH emerges as a limiting factor for the clogging of drippers when implementing this irrigation method. Additionally, the pH band zone map reveals that most of the flat areas have a pH between seven and eight, indicating that the water in this region is primarily alkaline and poses no pH-related limitations.

Increasing the pH value has an adverse effect on the LSI index by affecting the dissolution of minerals in the formations (Seifi and Riahi Madvar, 2017). For this reason, the LSI index does not allow the implementation of the drip irrigation method except in a small part of the north of the study area. It should be noted that although the LSI showed that it did not cause the problem of calcium carbonate precipitation in any of the wells, considering that this index is negative in most places, the corrosiveness of the water can have negative effects on the equipment used in sprinkler irrigation methods (Seifi and Riahi Madvar, 2017).

The components of water impurities (such as calcium carbonate and sulfate, barium sulfate, silica, etc.) can precipitate due to various conditions such as pressure drop, temperature change, flow change, pH change, etc. (Yazdani et al., 2009; Davoudi et al., 2016). In bodies of water with high hardness levels, primarily due to the presence of calcium (Ca^{2+}) and magnesium (Mg^{2+}), heating can cause the release of associated carbon dioxide, leading to the formation of sediment on the pipe walls.

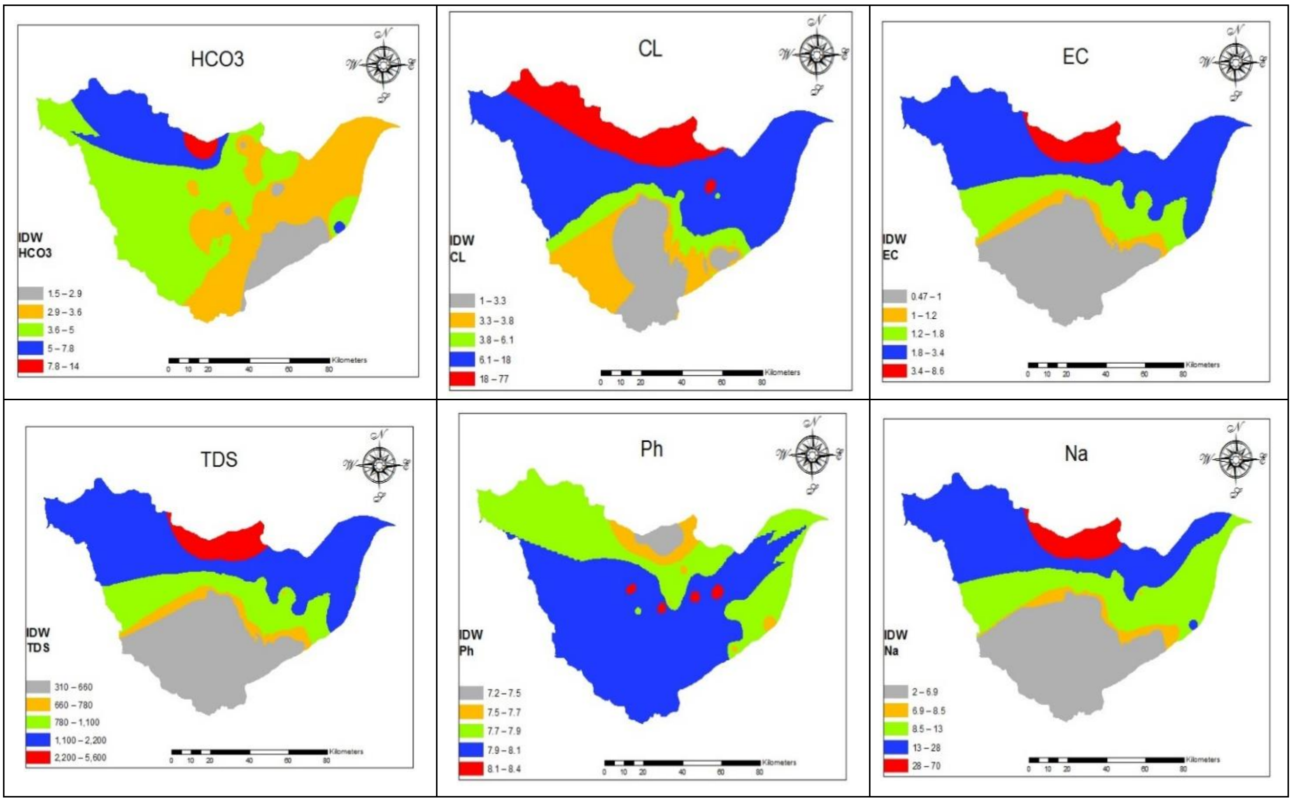

Fig. 3. Interpolation maps of water quality parameters using the IDW method

This sedimentation reduces the pipes' transfer capacity. Therefore, selecting the right drippers and pipes is essential for increasing the facility's lifespan and reducing pumping costs. Given the limitations posed by groundwater resources in the study area, it is crucial to implement effective management solutions to preserve and stabilize the land. To address the issue of corrosion, transferring water to a pool and aerating it can eliminate low acidity levels, ensuring that the quality of irrigation water does not pose a significant limitation for the drip irrigation method. However, long-term management and control of salinity in the field can be challenging. In sprinkler irrigation, a considerable amount of water is wasted due to evaporation and wind drift. These losses are inevitable in sprinkler irrigation methods and can significantly reduce the system's efficiency.

Increased evaporation at the surface of the field raises the ambient humidity and lowers the temperature, which subsequently reduces the rate of evaporation. However, if wind causes moisture to be carried away from the field surface and replaced by dry air, evaporation will continue (Rahmatabadi et al., 2012). In sprinkler irrigation, evaporation losses are difficult to control. However, by managing irrigation timing, such as watering during off-peak evaporation hours (from evening to morning), especially in warmer months when air temperatures are cooler, these double evaporation losses can be minimized (Karimi et al., 2016; Yacoubi et al., 2010). To further reduce other types of losses, such as runoff, deep penetration, and wind drift, it is essential to take measures like selecting the appropriate type of sprinkler, adjusting the operating pressure, and ensuring proper sprinkler base height (Rostamian et al., 2014; Seifi and Riahi Madvar, 2017).

4. Conclusion

Water is a precious blessing and one of the most fundamental resources in the agricultural sector. It is essential not only to explore and develop new water sources but also to implement measures for their optimal use. Constructing irrigation networks, utilizing traditional rivers, and employing pipes and other common solutions can significantly reduce water losses during transmission and distribution. Furthermore, declining water quality for irrigation raises concerns and poses risks to sustainable agriculture. Thus, it is crucial to monitor the quality of irrigation water resources carefully. The study of maps and results obtained in this study showed that in most of the studied areas, there are limitations for implementing drip irrigation due to the quality of groundwater in terms of pH, and a small part of the studied areas is without limitations.

Also, in terms of TDS and EC, most of the studied area has moderate and serious limitations. And there are serious limitations to implementing drip irrigation. Of course, drip irrigation methods solve problems such as sedimentation caused by water salinity to some extent by using various types of drippers with flexible orifices or with high water flow. By managing the irrigation interval and irrigation depth, it is possible to control water salinity. However, based on the results concerning HCO_3, Cl, and Na levels, most of the studied area faces significant limitations regarding Na and Cl for sprinkler irrigation. Given the critical conditions in the region, if the current exploitation practices continue, it is essential to implement optimal management strategies to preserve the aquifer and prevent the degradation of water quality. This management approach should replace the current practices.

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6. Conflict of Interest

No potential conflict of interest was reported by the authors.

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