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Investigating temporal and spatial changes in the quality of underground water in Marvast plain

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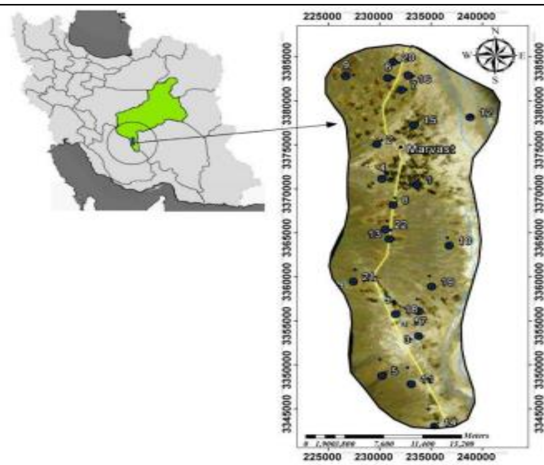
GRAPHICAL ABSTRACT



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ABSTRACT

This research was conducted with the aim of investigating temporal and spatial changes in the quality of underground water in Marvast plain in order to be used in planning for these resources. For this reason, the underground water quality data of Marvast Plain was prepared and selected for the research through the review and test of Run Test and Makos for the statistical period of 21 years (2001 to 2021). By performing trend analysis, the presence of trend in all data was determined and during the implementation of geostatistical methods, the trend was removed. Also, for the implementation of geostatistical methods, half-variable and half-variable cross-plot were chosen and due to the higher R2, lower RSS and stronger spatial structure, the best model was selected, and the exponential model was found to be suitable for most of the parameters. Then RBF, IDW with powers of 1 and 2, normal kriging and normal cokriging were used to perform interpolation. The most accurate method was selected for each parameter with the mutual evaluation method and three error estimation indices MAE, MBE and RMSE. The results showed that the normal cokriging method is the best method for most parameters (cation, anion, Ec, Cl, Ca, K, Mg, Na and TH). For the SAR, So4 and pH parameters, the normal kriging method and for the Na percentage parameter, the radial basis function was found to be the most suitable method. The results showed that the concentration of most parameters has an upward trend from west to east and south to north. Also, with the passage of time, the trend of reducing the quality of underground water was observed.

1. Introduction

Groundwater resources are one of the most important water resources, especially in dry and desert regions of the world. In these areas, due to the lack of water resources, their quality is more important. Managing these limited resources regardless of their quantitative and qualitative changes leads to incorrect and sometimes destructive decisions (Noori *et al.*, 2020). The increase in population in recent years, followed by the increase in the need for food resources, has led to more harvesting of these resources, which unfortunately, due to wrong management, has caused a decrease in quality and even permanent destruction of these resources (Beiranvandi and Jahdi, 2020). The severe drop in the level of underground water tables, the influx of salt water to fresh water tables, land subsidence and the increase in the concentration of soluble

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salts in these sources are among the results of excessive exploitation of underground water (Pourkhosravani *et al.*, 2021). Groundwater is more important than surface water due to its advantages such as less pollution and better quality, availability in most areas, and this issue in dry and desert areas where access to sufficient surface water sources is not always possible. It is more important (Noori, Ranjbari and Bonakdari, 2023). One of the main characteristics of underground water is its quality. The quality of water resources has changed due to human activities and the introduction of various pollutants into them, which ultimately has a bad effect on human health and severely limits its use in various sectors of development, including agriculture, industry, and drinking (Noori, Ranjbari and Bonakdari, 2023). Therefore, knowing and studying water quality and providing the necessary guidelines in this regard in order to maintain public health is of special importance (Radfard *et al.*, 2018). Among the water quality parameters, sodium, chlorine, bicarbonate, total cations, PH, SAR, EC and TDS parameters can be mentioned. Managing water resources and maintaining and improving their quality requires data on the location, amount and distribution of chemical factors of water in a certain geographical area (Marjan Nouri; Amirsalar Montazer Faraj, 2022). Considering the software advances in the last decades and the instability of underground water quality characteristics in space and time, it is possible to obtain good information about the trends of these changes by examining these changes over time and space and planning accordingly. and had proper management of the mentioned resources (Badeenezhad *et al.*, 2020). The available statistics in the field of quality parameters of underground water are in point form and do not provide accurate information about changes in the distance between points. Knowing how the process of spatial and temporal changes requires finding accurate methods to investigate the process of these changes in the distance between the sampled points (Adhikary *et al.*, 2011; Marjan Nouri; Amirsalar Montazer Faraj, 2022). Timely identification and preparation of a map of quality changes and identification of its cause by observational and traditional methods is a difficult, time-consuming and expensive task. Geostatistical methods, as methods that reduce costs by reducing sampling and increase the accuracy of estimates to a considerable amount, are widely used in various environmental sciences, including soil science, weather and climatology, and biology. have been paid attention (Alsaaran, 2000). According to the mentioned cases, in this research, it has been tried to investigate the temporal and spatial changes of underground water quality in Marvast plain in Yazd province by using GIS and the status of changes using groundwater quality zoning maps.

Talebi and Fatemi (2020) in evaluating the quality and quantity of underground waters of Bahadran Plain stated that the most important formations in terms of reservoir rock and the supply source of alluvium of the plain and the quality of groundwater are the Lower Cretaceous limestone sediments of Bahadran (Talebi and Fatemi, 2020). Talebi (2022) has studied one of the methods of water supply in Iran in the research of the water crisis in Iran and the resulting security consequences, and if it is desirable, the use of karst resources has been stated (Sadegh Talebi, 2022). In connection with the quality of underground water, several studies and researches have been conducted in Iran and other countries, as an example of the study by Dehghan Rahimabadi et al. (Rahimabadi *et al.*, 2022). Mentioned in relation to the chemical characteristics of groundwater, Anayah & Almasri (2009) (Anayah and Almasri, 2009) in the West Bank of Palestine and Adhikary et al (2011) (Adhikary *et al.*, 2011) in Delhi, India. It should be mentioned that no study has been done on the investigation of temporal and spatial changes in the quality of underground water in Marvast Plain, so it is considered a new research in this respect.

2.2. Materials and methods
2.2.1. The study area

Khatam city with an area of 7931 square kilometers is located in the coordinates of 31 degrees and 30 minutes to 39 degrees and 32 minutes north latitude and 53 degrees and 50 minutes to 54 degrees and 40 minutes east longitude. Khatam city consists of two cities, Herat and Marvast, and four villages named Fateh Abad, Chahek, Harabarjan and Isar. The studied area is a part of the Marvast plain and has an area of 528.83 square kilometers and is located in the geographical range of 54 degrees and 8 minutes to 54 degrees and 18 minutes of east longitude and 30 degrees and 11 minutes to 30 degrees and 35 min of north latitude (Ardestani et al, 2016).

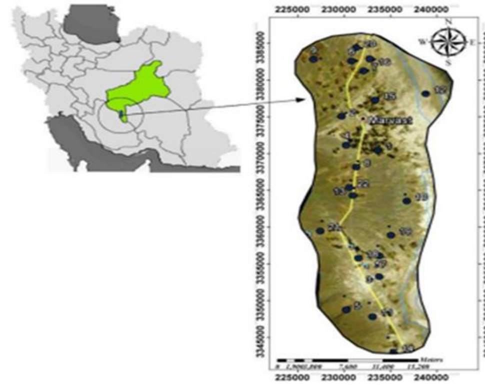


Fig.1. Location of the study area.

2.2. Data collection and preparation

To carry out this research, the data of underground water quality parameters of Marvast plain including pH, Na, Mg, K, HCO_3, EC, Cl, Ca, SAR, 4SO and TH in a period of 14 years (2008-2021) and from 22 wells available from It was collected by the regional water organization and used after preparation. Correlation methods between wells and SPSS software were used to reconstruct the data. Considering that the data of some wells in the correlation coefficient test did not show any correlation with other wells, the differences method was used to reconstruct these data. Kolmograph-Smirnov test was used to check the data distribution. In this research, the methods of RBF, IDW with powers of one and two, geostatistics, normal cokriging and normal kriging and ArcGIS software were used.

3. The results of the data distribution check

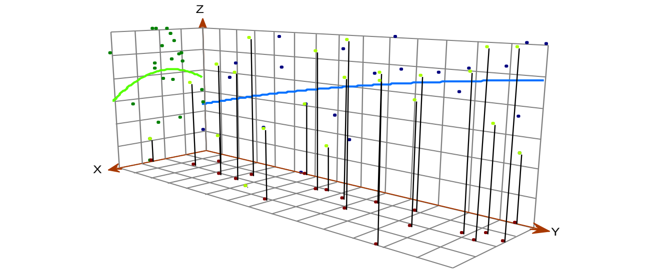
The distribution of data was checked through SPSS software and Kolmograph-Smirnov method, the results of which are shown in Table (1). Based on the Table 1, it can be seen that all the parameters are normal except the Na parameter. Log x method was used to normalize the Na parameter during the execution of kriging and cokriging methods.

Table 1. Results of data distribution analysis using Kolmograph-Smirnov method.

Parameter	TH	SAR	Na %	K	Na	Mg
Data value	0.051	0.157	0.935	0.166	0.034	0.169
Parameter	Ca	So_4	Cl	Hco_3	pH	EC
Data value	0.255	0.179	0.057	0.385	0.620	0.121

3. Results and discussion
3.1. Trend analysis

ArcGIS software was used to check the presence or absence of trends in groundwater quality data. In this software, trend analysis is done through the Geostatistical Analyst plugin and the Data Explorer section and the Trend Analysis option. In the Trend Analysis dialog box, each of the vertical bars show the location and value of each of the sampled points. These points are depicted in the north-south and east-west planes, and across each of them (planes), a line corresponding to the trend in them is drawn (green line, east-west trend, and blue line). show the north-south trend. If the line corresponding to any of the directions is straight, it indicates that there is no trend in the data in that direction. The bent or so-called U-shaped state indicates the presence of a trend in the data of that direction (Anayah and Almasri, 2009). The results of trend analysis are as described in Fig. 2a-m.



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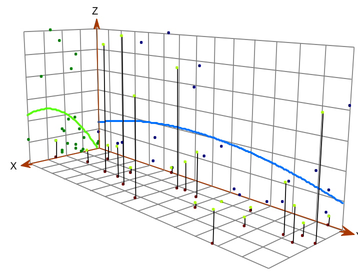

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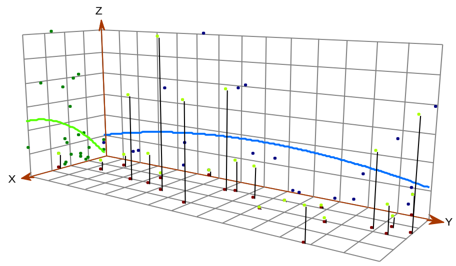

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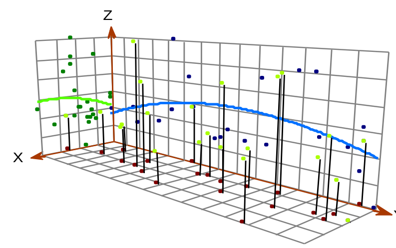

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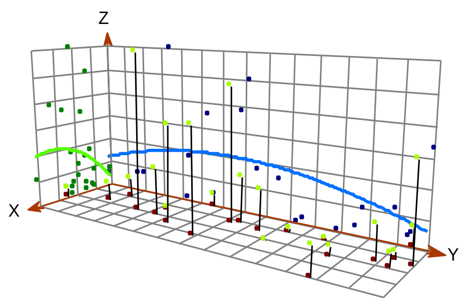

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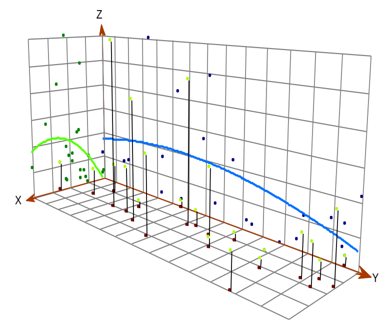

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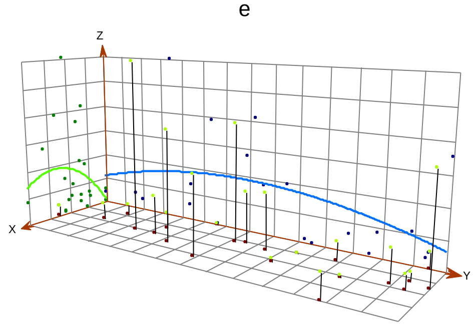

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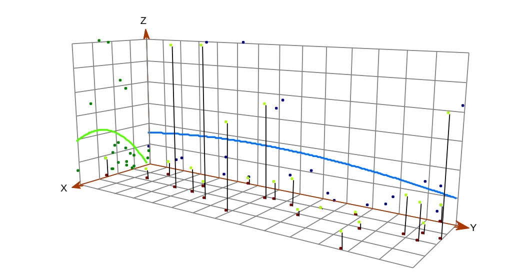

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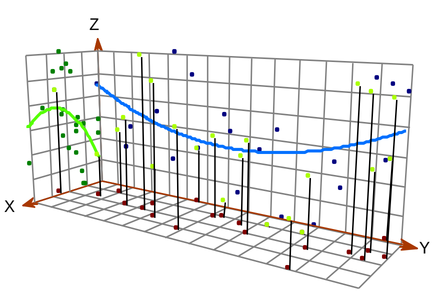

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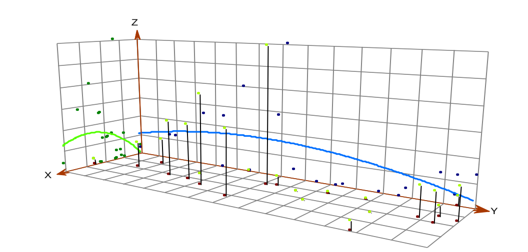

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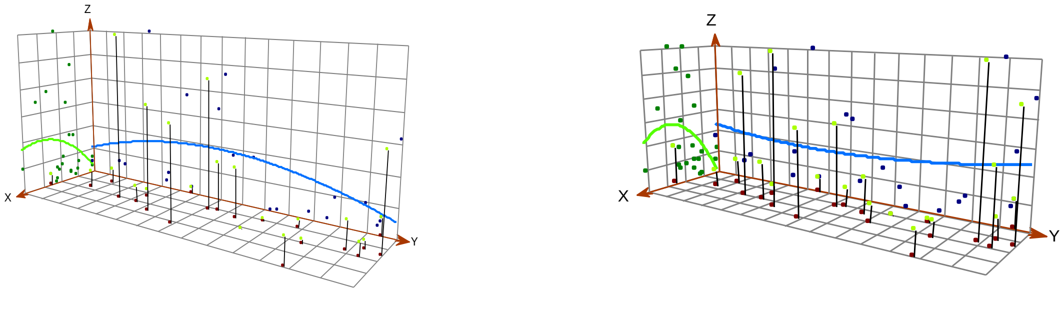

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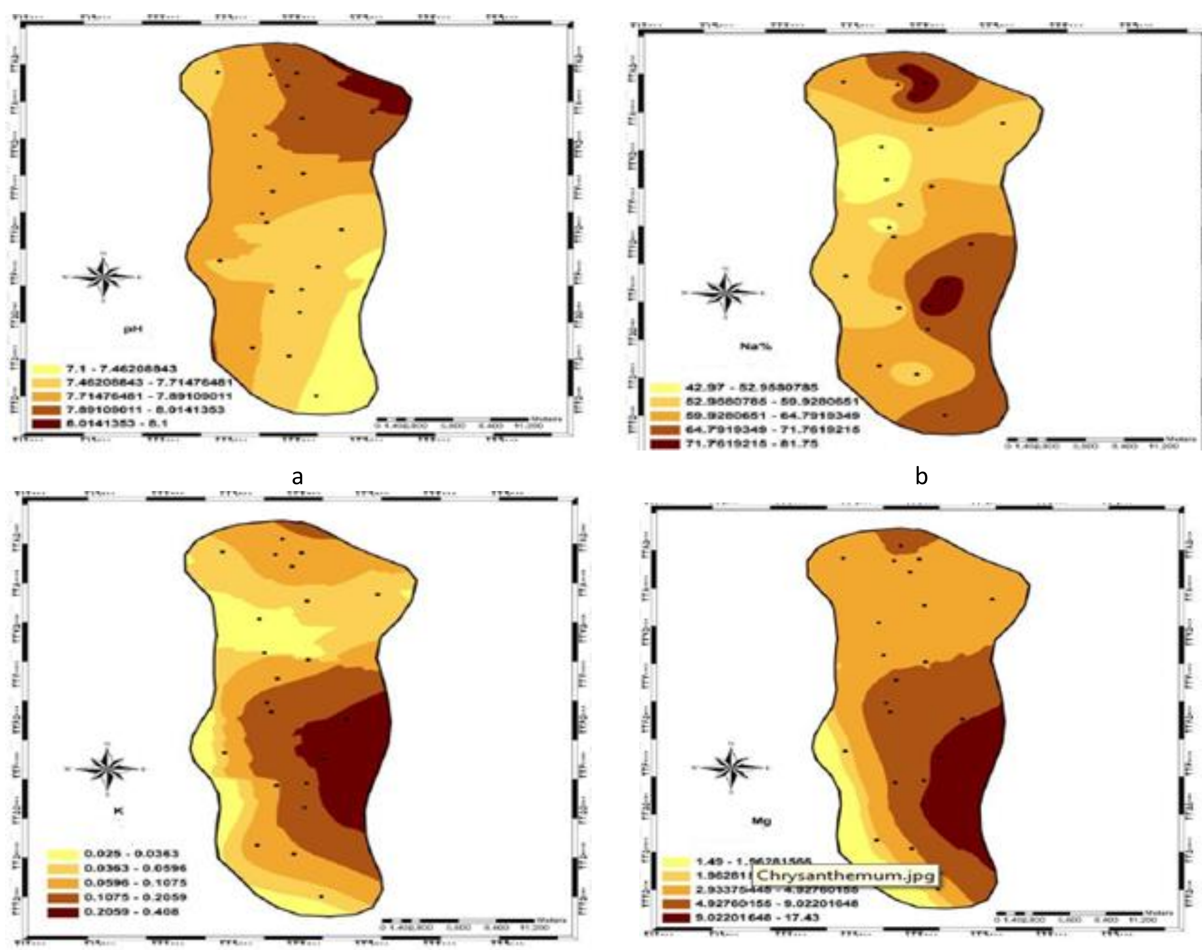
Fig. 2. Results of trend analysis of water quality parameters as (a) pH, (b) EC, (c) Cl, (d) HCO_3^-, (e) Ca, (f) SO_4^{-2}, (g) Mg, (h) Na, (k) Na%, (j) K, (m) TH, (l) SAR.

3.2. Variogram analysis (semi Variogram)

The results of variogram analysis and selection of the best model for each groundwater quality parameter based on higher R2, lower RSS and stronger spatial structure are presented in Table 2. Table (2): The results of the semi variable analysis of the parameter. After calculating the variogram and mutual variogram and fitting the most appropriate model, different interpolation methods were implemented for each parameter and after checking the results, the most accurate method was selected for each parameter and the groundwater quality map of the area was drawn. In this research, five interpolation methods were used: distance image weighting with powers of 1 and 2, radial basis function, normal kriging and normal cokriging. Mutual evaluation was used to check the results of interpolation methods. Three methods of mean absolute error (MAE), mean skew error or standard deviation (MBE) and root mean square error (RMSE) were used to check the error of estimated values. The results of mutual evaluation for each method can be seen in Table 3.



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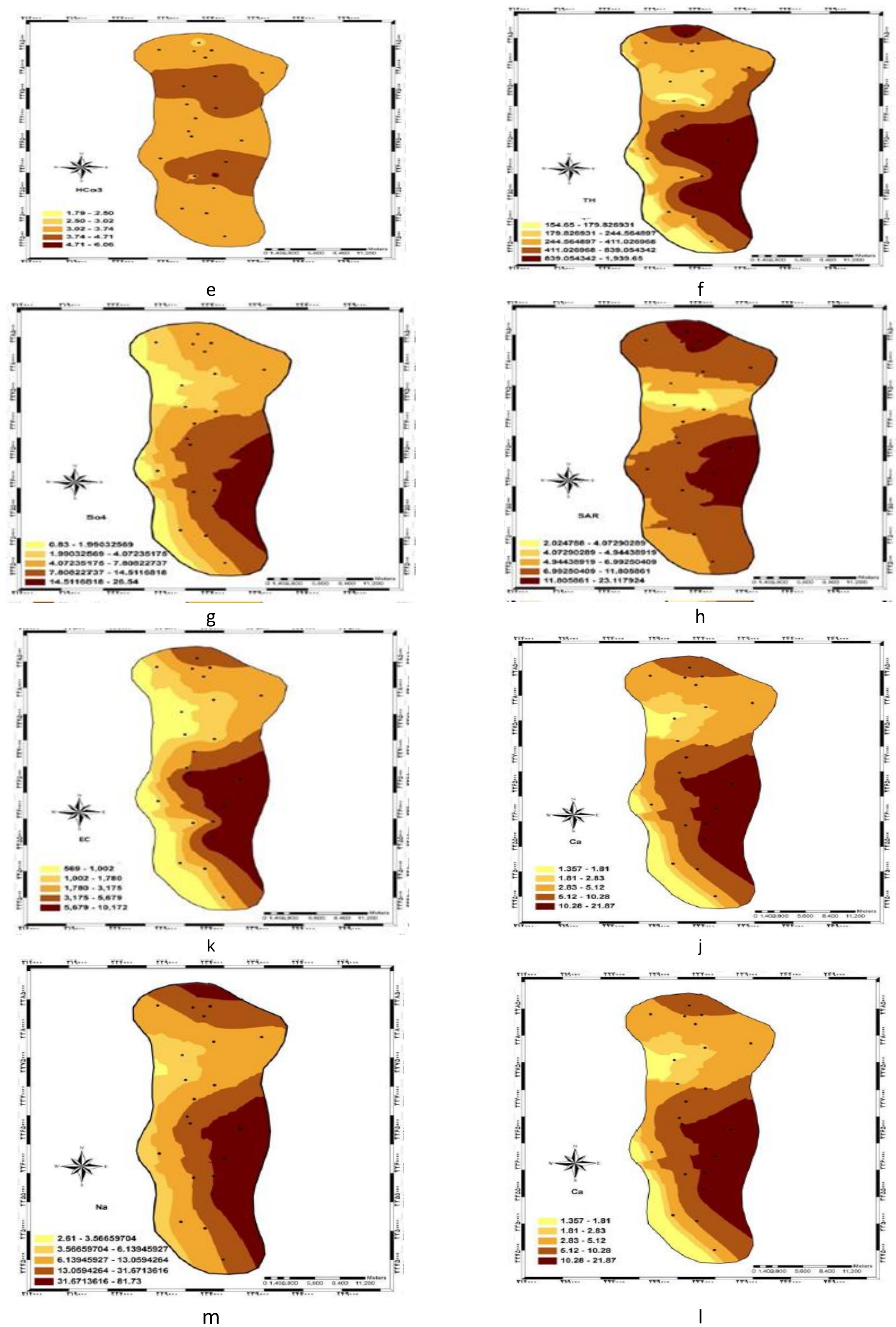

Fig. 3. Changes in water quality parameters in the study area as (a) pH, (b) Na%, (c) k, (d) mg^{-}, (e) HCO$_3$, (f)TH, (g) SO$_4$, (h) SAR, (k) EC, (j) Cl, (m) Na, (l) Ca**.**

To check the distribution of data, SPSS software was used, and Kolmogorov Smirnov method was used among different methods. Table 1 shows the normality of the studied parameters. Some researchers also used the Kolmogorov Smirnov method in their research to check data distribution (Noori *et al.*, 2021).

In the trend analysis stage, as seen in Fig. 2a-m, the data has a U-shape in the north-south, east-west, or both directions, which indicates the existence of a trend in the data. Considering that in geostatistical methods, the data should have no trend, the existing trend was removed during the implementation of interpolation methods (Noori *et al.*, 2021). For the implementation of geostatistical methods, semi-variance is an important part, the semi-variance was calculated for all parameters and the best model was selected for each parameter. This method has been used by others (Chang, 2008; Fang and Ding, 2010; Noori *et al.*, 2021). By examining the three indices R2, RSS and spatial structure for the semivariables, the best semivariable model and reciprocal semivariable model were selected for each parameter. Most of the parameters had an average or weak spatial structure. Due to the importance of spatial structure in geostatistical interpolators, first the spatial structure index was investigated and then two other indices R2 (higher value) and RSS (lower value) were used. In this research, the exponential model showed the most agreement with the groundwater quality data of Marvast Plain. Gaussian and spherical models were ranked second and third in interpolation.

In this research, the exponential model showed the most agreement with the groundwater quality data of Marvast Plain. Gaussian and spherical models were ranked second and third in interpolation by examining different methods of interpolation and evaluating the results, chose the most accurate method for drawing underground water quality maps (Noori *et al.*, 2020). According to Table 3, it can be concluded that the conventional cokriging method is the most accurate method for drawing maps of spatial changes of Ec, Cl, Ca, K, Mg, Na and TH parameters. By examining the results of mutual evaluation and the error indices of different methods given in Table 3, for each parameter, the method that had the lowest error value in at least two of the three indices of the error evaluation of the methods as the most accurate method for interpolation and Preparation of distribution map was selected. For example, in the SAR parameter, the MAE and MBE indices had the lowest values in the normal kriging method with a slight difference. Noori et al. (2020) also obtained similar results for all or part of the quality parameters in their research on groundwater quality stratification, and the cokriging method is the most appropriate method (Noori *et al.*, 2020). They recognized Due to the fact that the cokriging method is suitable for interpolating most of the groundwater quality parameters, it can indicate the existence of a significant relationship between most of the groundwater quality parameters.

For SAR, So4 and pH parameters, the normal kriging method was found to be the best interpolation method, which is consistent with the research results of (Kistemann *et al.*, 2008; Salimi *et al.*, 2020). Here, like the previous parameters, the normal kriging method was chosen as the appropriate method due to having the lowest error in at least two error indices.

For the Na percentage parameter (Na%) of the radial basis function, the most appropriate method was found, and in this regard, we can refer to the similar results obtained from the literature (Talebi and Fatemi, 2020).

The HCO_3 parameter was interpolated by the distance photo weighting method, which is consistent with other work (Sethi *et al.*, 2012). The mentioned people introduced distance photo weighting method for some parameters or all of them as a suitable method. According to the above results and researchers' opinion, geostatistical methods are in most cases the most appropriate interpolation method for groundwater quality parameters. Geostatistical methods with the same number of samples as certain methods showed higher accuracy in most cases. This shows that in geostatistical methods, good accuracy can be obtained with a smaller number of samples, and as a result, time and cost of sampling can be saved. The obtained results are consistent with literature (Marjan Nouri; Amirsalar Montazer Faraj, 2022).

Examining the spatial changes of groundwater quality parameters using the resulting maps shows that except for the pH parameter, the rest of the parameters in the plain have an increasing trend from west to east and from south to north, which can be attributed to geomorphological characteristics. found area Looking at the satellite image of Marvast region shown in Fig. 1, white dots can be seen on the northeast to southeast edge of the plain, which indicates the presence of desert in these areas. The presence of the desert belt in the mentioned areas has a significant effect on the quality of underground water in this area, which can be attributed to the general slope of the areas towards the desert. This causes the groundwater to move towards the desert. By increasing the length of the movement path, the contact time of water with different formations increases and increases the concentration of its solutes in these areas, which is consistent with the findings of (Sethi *et al.*, 2012; Noori, Ranjbari and Bonakdari, 2023).

4. Conclusions

According to the findings of this research, geostatistical methods are among the most accurate interpolation methods that save time and money by reducing the number of sampling times and provide acceptable results. In order to implement these methods, the assumption of normality and absence of trend in the data is required, and most of the data are normal, but all of them have a trend, for which the trend was removed. Also, calculating the semivariable, interpreting its results and choosing the most suitable model is the main part of these interpolators, which must be done carefully. It should be noted that geostatistical methods are not always the most accurate method for interpolation and other methods should be implemented and the error of each measurement method should be selected. As seen, distance image weighting methods and radial basis function were recognized as suitable methods for Hco3 and Na percentage data. In order to evaluate the changes in the quality of underground water, which is the main goal of this research, maps of underground water quality were drawn and it was observed that there is a trend of increasing the concentration of parameters and decreasing the quality of underground water from west to east and from south to north. This is the opposite for the pH parameter and its decrease was observed in the eastern and northern regions. The reason for the increase in the concentration of parameters can be found in the existence of the desert in the eastern and northern margins of the plain. The hydraulic gradient of the region, which is towards the desert, causes leaching of salts from other regions and their accumulation on the edge of the desert. The reason for this finding is the nature of underground waters, which are faced with a decrease in quality and an increase in the concentration of pollutants as they move away from the feeding place and closer to the discharge place. In the Marvast region, feeding is mostly done in the western regions. The results of the maps show the better quality of underground water in the western areas of the plain, which can be planned for new harvests in these areas. Due to the decrease in quality in the eastern regions, the exploitation of these regions should be reconsidered. Examining the maps of parameter changes in the last 22 years showed an increase in the concentration of most pollutants. The decrease in quality in recent years can be due to the increase in extraction from underground water tables, the decrease in rainfall in the region and finally the advance of the desert.

Author Contributions

The whole process of research has been done by myself as the corresponding author.

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Conflict of Interest

No financial aid or cost was received from any person or organization to conduct this research.

Data Availability Statement

The data required for this research was obtained from Yazd Region Water (Yazd, Iran) and is available.

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