Desalination and Water Treatment
www.deswater.com

doi:10.5004/dwt.2019.23780

148 (2019) 119–127
April

Assessment of water quality changes during climate change using the GIS software in a plain in the southwest of Tehran province, Iran

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Received 28 June 2018; Accepted 12 January 2019

ABSTRACT

Climate change is a continuous phenomenon that in some conditions it may lead to drought which substantially affects drinking water resources. Also, there may be other associated impacts, such as seawater interruption, water quality deterioration, drinking water deficiency, etc. While climate change affects surface water resources straight over changes in the significant long-lasting climate variables such as rainfall, evapotranspiration, and air temperature, the relationship between groundwater and climate variables is more complicated. The current study aimed to investigate the special effects of different climatic factors including temperature, precipitation, evaporation, and transpiration on the quality of groundwater resources of Varamin plain, Iran. In this study, out of 80 wells with specific spatial information, sampling was done. In the following, the water samples quality were assessed by considering different parameters including pH, electrical conductivity, total dissolved solids, anions and cations concentrations, and total hardness. Finally, the raw data mapped by Arc GIS 10.3 software. The results showed that these parameters (except pH) along the plain are highly variable and the spatial distribution of the data is not normal, and the frequency of pixels with fewer values is higher than the spatial mean of the region. Spatial distribution of pH was about 0.05 in all the plain. According to our findings, Correlation analysis showed that water resources quality is influenced by climatic factors. Also, it should be noted that the maximum temperature had the highest impact.

Keywords: Water resources; Chemical quality; Climatic change; Varamin Plain; Iran

1. Introduction

The chemical quality of groundwaters is one of the most critical issues in the use of these resources for supplying freshwater in the world [1–8]. Today, the climate change phenomenon and its consequences are among the significant crises for the management of water resources [9,10]. Groundwater resources are affected by climate change through direct interaction with surface water resources and also, indirect interaction through the feeding trend [11,12]. In some areas, climate changes and excessive water withdrawal in recent years have caused groundwater levels to diminish significantly. The sub-surface flow of freshwater has also declined, and thus salty water has penetrated lands [13]. Thus, given the reliance of humans upon groundwater as a sustainable resource, investigation of the quality of these resources and their affectability by climatic conditions especially in warm and dry regions of the country is crucial [14].

As the long-term meteorological average of a region, which is indeed a complicated interaction between all geographical and ecological factors of the environment, climatic conditions play a significant role in determining

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the quality and quantity of water resources in general and groundwater resources. Climate changes can cause variate and modify the distribution and the partitioning of contaminants in water bodies through several factors (e.g., the increase in temperature, reduction in oxygen through water shortage, acidification, and remobilization of contaminants in sediments due to flooding). Further unforeseen effects can be related to climate changes (e.g., enlarged use of pesticides due to the increase of plant syndromes caused by new vectors and erosion of coastal areas due to rise in sea level). Also, it should be noted that climate change affects surface water resources straight over changes in the significant long-lasting climate variables such as rainfall, evapotranspiration, and air temperature, but the relationship between groundwater and climate variables is more complex and is not well understood [15,16]. Awareness of how groundwaters of a region are affected by quantitatively and qualitatively by climatic conditions can offer a suitable criterion suggesting the status of groundwaters in different regions. It also provides the possibility of planning for controlling and managing the withdrawal of groundwaters [5,17–19].

In this regard, Abbaspour et al. [20] examined the effect of climate change and especially global warming on the water resources of the country. In their study, they described climate change as a phenomenon affected by factors such as solar activities, volcanoes, atmosphere, and percentage of greenhouse gases in the earth's atmosphere. The effects resulting from their changes lead to the transformation of the meteorological status, altered spatiotemporal distribution of precipitation, superficial flows, evaporation, feeding of groundwater aquifers, and water quality of these resources. They considered the earth's warming as the most important influential factor affecting climate change. By investigating different scenarios, they concluded that this phenomenon would eventually result in the diminished chemical quality of surface and groundwaters.

Furthermore, Rasouli et al. [21] evaluated the effect of climate change in qualitative and quantitative changes of groundwater resources of Urmia and Kahriz aquifers. They found that drought and overdraft from the local wells have resulted in diminished groundwater level and quality. In their study, they considered the reduced level of Urmia Lake water and drying of some of its areas as one of the climatic factors affecting diminished groundwater quality of the region. In investigations, it was observed that the level of groundwaters declined between 1984 and 2011, while the extent of its salinity and electric conductivity increased. Najafzadeh et al. [21] investigated the effect of climatic and geological factors on the quality and quantity of groundwater resources in Mahvelat Plain. They evaluated the data related to water level, electric conductivity, and the total concentration of soluble salts within three statistical periods related to 2001, 2007, and 2012 in Arc GIS software using geostatistical methods. To determine the factors affecting the qualitative and quantitative changes in groundwater, they studied factors including diminished level of precipitation and drought, geological conditions, sedimentology, and progression of salty waters from the adjacent deserts.

Further, for monitoring the chemical quality of water resources, Dindarloo et al. [22] in BandarAbbas, Yousefi et al. [2] in jolfa City, Khastou [23] in Eslamshahr city, Ritesh Vijay et al. [24] in India, and Abbasnia et al. [25] in Chabahar town investigated physiochemical parameters of water in these regions, and then compared the results with standard indices. Also, Kolahkaj et al. [26] in Ramhormoz Plain evaluated the effects of drought on the chemical quality of water extracted from the wells in these plains. Zehtabian et al. [27] in Isfahan town used geostatistical interpolation methods to compare this method and other assessment factors. They concluded that the geostatistical methods have high accuracy.

Although the greatest obvious impacts of climate change could be variabilities in surface water levels and quality, the most important worry of water managers and the government is the possible decrease and quality of groundwater resources, as it is the main existing drinking water supply for human consumption and irrigation of agriculture production worldwide. Since groundwater aquifers are feed mainly by rainfall or through interaction with surface water bodies, the direct impact of climate change on rainfall and surface water finally affects groundwater resources. It is increasingly known that groundwater cannot be considered in isolation from the landscape above, the society with it interacts, or from the local hydrological cycle, but requires to be managed generally. Inconsiderate the likely consequences of possible future (climate and non-climate) changes on groundwater systems and the local hydrological cycle, a significant (but not exclusive) component to understand is the influence that these factors exert on recharge and runoff. It is essential to consider the potential effects of climate change on groundwater resources. As part of the hydrologic cycle, it is estimated that groundwater system will be affected by alterations in recharge (which encompasses changes in precipitation and evapotranspiration), potentially by changes like the relations among the groundwater and surface water systems, and variations in use related to irrigation.

This study aimed to investigate the effect of climatic factors on the chemical quality of Varamin Plain aquifer to understand the situation of the region and for proper planning in line with it for optimal exploitation of the current water resources in the region. In this study, out of 80 wells with specific spatial information, sampling was done, and the monitoring was also performed based on groundwater quality index. Finally, the zonings of interest were done by ArcGIS software 10.3.

2. Materials and methods

2.1. Study area

Varamin plain is located in 45 km^2 southwest of Tehran city in the latitude of 51º.40′N and latitude of 35º.30′E, encompassing an area of about 139,700 ha and the average altitude of the plain is 1000 m above sea level. It has to be noted that more than 60,000 ha of this plain are considered as agricultural land.

Varamin plain has a dry climate, and among its characteristics are low precipitation, high heat levels, and extended dry periods. The northern areas of this region with the mean annual temperature of 11°C have the minimum regional temperature, while its southern areas with the mean annual temperature of 18°C have the maximum temperature. The spatial distribution of precipitation in this region suggests that from north to south and from west to east, the precipitation in the region declines. The changes in the precipitation of Varamin station indicate that the mean annual precipitation level is 173 mm in this region [28].

2.2. Sample collection

In this study, to investigate the climatic effects on the chemical quality of waters extracted from the wells in Varamin Plain, after doing the necessary coordination, Universal Transfer Mercator (UTM) and the information associated with the chemical quality of the water of regional wells from Water and Wastewater Company of Varamin and Tehran University of Medical Sciences within 2003–2016 were collected. Further, the specifications of the active meteorological stations and rain gauge stations of this town and the information related to the level of precipitation and the mean temperature related to the region were taken from Iranian Meteorology Organization within the mentioned period.

2.3. The experiments

All qualitative analyses of water resources were performed in Water and Wastewater Laboratory at Tehran University of Medical Sciences, according to the standard method for examination of water and wastewater. Calibrated devices measured electric conductivity and pH. A summary of these examinations is providing in Table 1 [29].

2.3.1. Statistical and geostatistical analysis methods

In this study, Ordinary Kriging geostatistical model was used with Gaussian semi-variogram with a pixel size of 213 m. Kriging is a method in which to estimate an unknown point; a weight is assigned to each measured sample. Kriging is a linear estimator as follows:

$$Z^* = \sum_{i=1}^{n} \lambda_i z_{(xi)}$$

In this relation, Z^* is the value of the spatial variable estimated, $Z_{(xi)}$ shows the value of the spatial variable observed at point xi, and λ_i denotes the statistical weight attributed to xi sample, which represents the importance of the i_{th} point in estimation. Given the quality of correlation and manner of spatial changes of the phenomena as well as the relationship between the studied variable and other explanatory variables, the kriging interpolation method is categorized into different types. In ordinary kriging method, assuming dominance of the spatial correlation component and directly employing the semi-variogram, Z value at a point like Z_0 is obtained from the following relation:

$$z_0 = \sum_{i=1}^{s} w_\chi z_x$$

In these relations, the weights are obtained through concurrently solving a set of equations by minimizing the variance $\mathrm{Var}\left\{\sum w_i z(x_i y_i) - z(x_0 y_0)\right\}$ [30,31].

2.4.2. Data analysis

The qualitative and chemical information of each well has been incorporated spatially in their related points and presented in Arc GIS10.3 software as zoning maps.

3. Results

3.1. The wells information

As mentioned previously, in this study, the information related to 80 wells in Varamin Plain was assessed. A statistical summary of the analysis of the wells is indicated in Table 2.

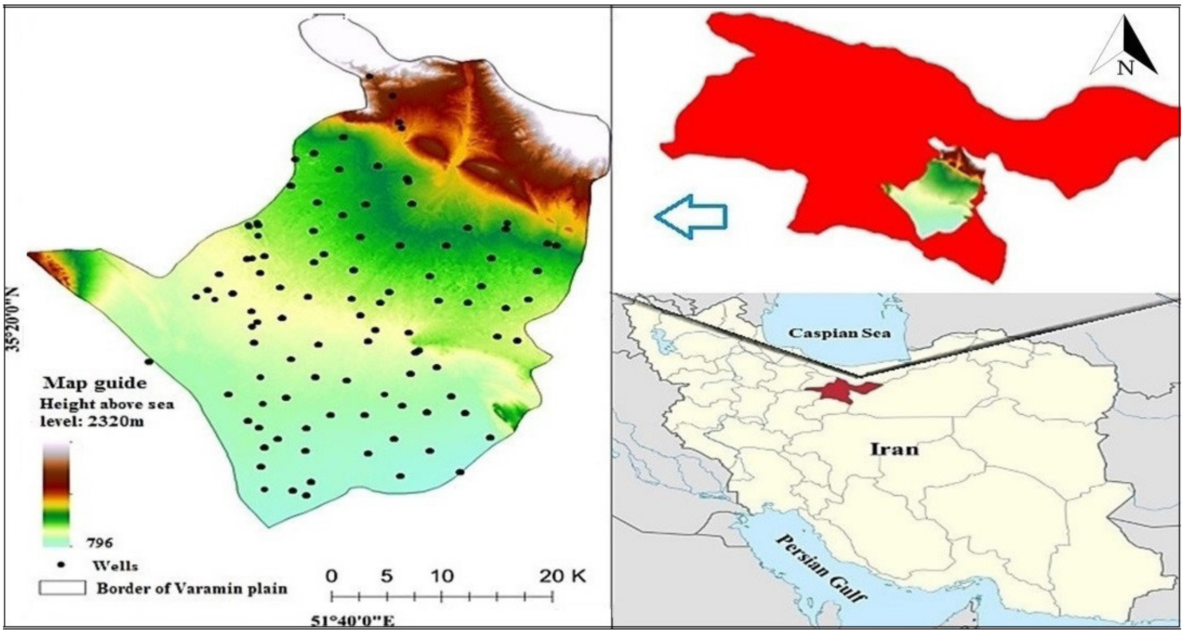

Fig. 1. Location of studied area and spatial distribution of investigated wells.

Table 1
Summary of the test methods

Parameter		Summary of test method
TDS (mg/L)		The filtered samples are poured into a crucible and placed in a steam bath to dry. The samples are then placed in the fore and after drying the weight is calculated according to the formula.
Total hardness (mg/L as $CaCO_3$)		The titration with standard EDTA solution in the presence of a reagent of Eriochrome Black T and Ammonia tampons
The number of anions (mg/L)	Chlorine (Cl)	The argentometric method in the presence of the reagent of potassium chromate and titration with silver nitrate
	Sulfate (SO_4^{-2})	Spectrophotometric method
	Nitrate (NO_3^-)	Spectrophotometric method
The number of cations(mg/L)	Calcium (Ca)	The titration with standard EDTA solution in the presence of a reagent of Murexide and Sodium hydroxide
	Magnesium (Mg)	Flame Photometer
	Sodium (Na)	Flame Photometer
	Potassium (K)	Using the difference in total hardness and calcium hardness

Table 2
Data obtained from the analysis of the waters extracted from 80 wells in the Varamin plain

Parameter	Min	Max	Mean	Standard deviation	Coefficient of variation
TDS (mg/L)	216	9163	1287.5	1616.2	%125.5
Total hardness (mg/L as $CaCO_3$)	171	3950	659.7	742	% 112.4
Cations (mg/L)	4.1	130.86	22.33	27	% 121
Anions (mg/L)	4.31	121.21	22.48	26.68	% 118.68
EC (µs/cm)	423	12400	2237.4	2667	% 119.2
pH	7.03	8.9	7.78	0.37	% 4.8

3.2. Data normalization

In the presentation of the estimated map of spatial distribution related to the six studied features, Q-Q PLOT was used to investigate normality or pseudo-normality of the data. The data related to the spatial distribution of all parameters (except for pH) were not standard, and to return to normal them, normal logarithm function was used.

3.3. Spatial distribution of the parameters

Figs. 2a–g display the spatial distribution of the main studied parameters in Varamin Plain. As can be seen, in the spatial distribution related to the features of the concentration of cations and anions, total dissolved solids, total hardness, and electric conductivity, the western and northwestern areas of the plain have the most significant values.

The maximum value of spatial distribution for these parameters is 28–118 mg/L for the concentration of cations, and 29–135 mg/L for anions, 1820–9163 mg/L for total dissolved solids, 882–3950 mg/L of calcium carbonate for total hardness, and 2554–13360 µs/cm for electric conductivity. Furthermore, for pH, it can be stated that the spatial distribution of this parameter has been almost uniform across the entire area, and reaches its maximum value at around 8–8.6 in a small part of the northwest of the plain.

Comparison of the spatial mean and spatial standard deviation suggests a very dramatic variability for all of these factors in this region. Furthermore, by dividing the standard deviation index by the spatial mean, the coefficient of spatial changes of distribution was obtained for these parameters. These numbers suggest that the spatial distribution of these parameters in the groundwater of the studied region is highly variable. However, for pH, the variability is low.

The spatial skewness of the distribution obtained for cations, anions, total dissolved solids, total hardness, and electric conductivity indicates that the spatial distribution of data in the studied region around the mean is not normal. The frequency of pixels with values lower than the spatial mean is significantly higher. The obtained spatial skewness of distribution as 0.5 for pH suggests that the spatial distribution of this variable around the man is healthy and symmetrical.

The studies related to the general spatial trend of parameters in groundwater of Varamin Plain were performed from south to north and west to east. The results indicated that with movement from west to east, the value of these parameters except for pH has a considerably descending trend in the groundwater of the region. Thus, these factors have a significantly descending western-to-eastern trend. Further, the spatial trend of pH in the groundwater of the region showed that from west to east, there is a relatively

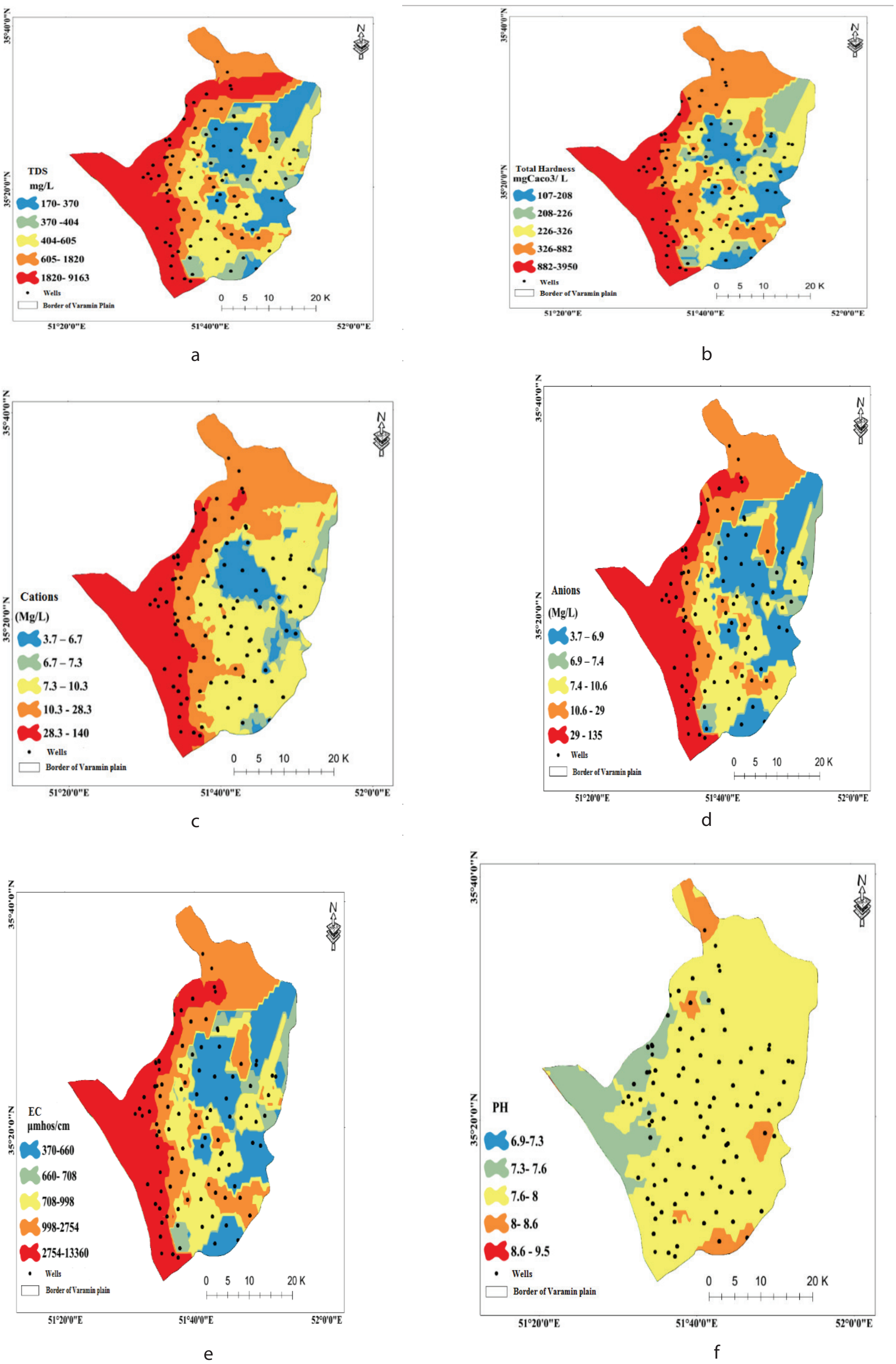

Fig. 2. a. Spatial distribution of TDS parameter. b. Spatial distribution of total hardness parameter. c. Spatial distribution of cation parameter. d. Spatial distribution of anion parameter, e: Spatial distribution of electric conductivity(EC) parameter. f. Spatial distribution of pH parameter.

Table 3
Statistics of physicochemical characteristics related to the studied parameters

Parameter	Spatial min	Spatial max	Spatial mean of concentration	Spatial standard deviation of distribution	Coefficient of variation	Skewness
TDS (mg/L)	235	7278	2439	2185	0.89	2.02
Total hardness (mg/L as $CaCO_3$)	130	3274	1029	870	0.85	1.8
Cation (mg/L)	5	118	37.3	30	0.78	1.9
Anion (mg/L)	4.5	119	39.5	34	0.87	2.02
EC (µs/cm)	435	11612	3732	3293	0.88	2.02
pH	7.3	8.4	7.8	0.2	0.02	0.5

tangible ascending trend in pH for the groundwaters of the region.

However, in the studies related to the south-to-north direction of Varamin Plain, no particular spatial trend is observed for all parameters. It is only observed that the groundwater around the northern and southern margins of the plain have higher values when compared with the central areas.

3.4. Spatial correlation analysis

In order to detect the relationship between climatic conditions and each of the six factors, Pearson spatial correlation analysis was used at a confidence level of 0.95 (p-value = 0.05). Spatial correlation analysis was done based on 213-m pixel structure of water quality variables and climatic variables. The results were obtained as correlation matrices, as presented in Table 4. In this table the correlation is calculated based on a 213-m pixel structure in GIS. According to this table, the six studied factors have all a significant relationship with the parameters of mean temperature, maximum temperature, minimum temperature, total precipitation, evaporation, and perspiration. The only exception is pH and its relationship with the minimum temperature, for which their relationship was not significant. The results of the analysis also revealed that the relationship between all factors and the NDVI index is not significant.

The positive correlation coefficients suggest a direct relationship between that factor and the studied factor, while a negative relationship represents an inverse relationship between them.

3.5. Discussion

To evaluate the qualitative characteristics of groundwater in Varamin Plain, the standards presented by the Iranian Standard and Industrial Research Institute (5th Edition). This evaluation was done based on three qualitative indices of water, i.e., pH, the total dissolved solids content in water, and total hardness.

According to the standard, the desirable level of pH for drinking water is 6.5–8.5, and the maximum allowable level is 6.5–9. Since all of the groundwaters in Varamin Plain region lying within the permissible pH range, thus no particular limitation was observed regarding this index.

About the standard, the maximum allowable and desirable total hardness (as the second factor) levels in drinking water are 500 and 200 mg of calcium carbonate per liter, respectively. Thus, use of waters of parts of the region located in the west and northwest of the plain, accounting for around 39% of the entire region, which has a total hardness of higher than 500 mg of calcium carbonate per liter.

Evaluation of the total dissolved solids index in water revealed that the maximum allowable limit of TDS index for drinking waters is around 1500 mg/L. Based on the assessments, the western and northwestern areas of the plain cannot be used for drinking purposes, as the values of TDS in this part of the plain are above the maximum allowable limit.

The results were presented as correlation matrices, which were observed for other factors except for pH, where the qualitative parameters of groundwater had a significant direct relationship with the thermal factors of the climate (mean temperature, maximum temperature, and minimum temperature) at a confidence level of 0.95. Thus, the thermal factors of the environment have a significant direct effect on the qualitative factors of groundwaters in Varamin Plain (except for pH). Precipitation, evaporation, and perspiration also had a significant effect on the water quality factors taken from the local wells. Compared with other studies, in a case study, the climatic changes and their impact on groundwater resources (2012) were studied in Souss-Masa water basin in Morocco. Based on the results obtained by Bouchaou et al. [32], the mean precipitation over the past three decades has declined in this region, due to climatic changes and global warming. The external and sub-superficial water resources have declined in this region. Also, the results of the chemical analysis indicate that the water quality of these resources has diminished, while their salinity has increased. In a review study, DE Nicola et al. [33] examined the relationship between climate change and the scarcity of water resources (case study: Saudi Arabia). In this research, is has been projected that climate change would enhance the average global temperature by 4.1–8.5°C by 2100, significantly affecting water accessibility and quality. In this paper, it has also been emphasized that the increased mean global temperature will result in decreased precipitation and thus reduced feeding of groundwater resources.

On the other hand, with the reduction of surface water resources, exploitation from groundwater resources has increased, causing further reduction in the water level of these resources, increased salinity, and lowered quality of water extracted from them. Moghimi et al. [34] studied the effect of hydrogeochemical factors on the qualitative indices of groundwater in the Qazvin plain. In this investiga-

Table 4
The spatial correlation matrix between 6 studied characteristics in the groundwater of the Varamin plain and climatic factors in this area at a confidence level of 0.95 (P-value = 0.05)

		Mean temperature	Maximum temperature	Minimum temperature	Total precipitation	Evaporation and perspiration	NDVI index
Spatial correlation analysis of cations and climate factors	Spatial correlation coefficient	0.37	0.44	0.31	0.42	0.53	–0.151
	Statistical significance	0.001	0.008	0.007	0.008	0.004	0.07
	Analysis result at 95% confidence level	Meaningful	Meaningful	Meaningful	Meaningful	Meaningful	Not meaningful
Spatial correlation analysis of anions and climate factors	Spatial correlation coefficient	0.31	0.45	0.28	0.49	0.54	–.013
	Statistical significance	0.004	0.009	0.02	0.008	0.004	0.08
	Analysis result at 95% confidence level	Meaningful	Meaningful	Meaningful	Meaningful	Meaningful	Not meaningful
Spatial correlation analysis of TDS and climate factors	Spatial correlation coefficient	0.481	0.57	0.31	0.59	0.52	–0.12
	Statistical significance	0.004	0.009	0.02	0.008	0.004	0.08
	Analysis result at 95% confidence level	Meaningful	Meaningful	Meaningful	Meaningful	Meaningful	Not meaningful
Spatial correlation analysis of pH and climate factors	Spatial correlation coefficient	–0.25	–0.29	–0.23	–0.51	–0.27	–0.12
	Statistical significance	0.04	0.03	0.06	0.008	0.04	0.09
	Analysis result at 95% confidence level	Meaningful	Meaningful	Meaningful	Meaningful	Meaningful	Not meaningful
Spatial correlation analysis of EC and climate factors	Spatial correlation coefficient	0.43	0.46	0.37	0.41	0.46	–0.10
	Statistical significance	0.007	0.005	0.007	0.009	0.005	0.12
	Analysis result at 95% confidence level	Meaningful	Meaningful	Meaningful	Meaningful	Meaningful	Not meaningful
Spatial correlation analysis of total hardness and climate factors	Spatial correlation coefficient	0.44	0.52	0.34	0.57	0.48	–0.17
	Statistical significance	0.004	0.0009	0.02	0.0008	0.0004	0.08
	Analysis result at 95% confidence level	Meaningful	Meaningful	Meaningful	Meaningful	Meaningful	Not meaningful

tion, the chemical parameters of 42 wells under exploitation for ten years have been used. Comparison of the parameters with the standards of Iranian Industrial Standard Institute as well as those of Ministry of Energy suggested a qualitative drop of groundwater resources in Qazvin Plain. The most important reasons for this diminished quality alongside the effect of geological formations can be climate change and drought, indiscriminate withdrawal, groundwater drop, and diminished reservoir volume.

Moreover, the importance of annual precipitation and mean summer temperature was examined as the most critical controlling climatic factors affecting the changes in the water quality. The results obtained from Pearson spatial correlation matrices in GIS indicated that among the climatic factors of the environment (minimum temperature, maximum temperature, and mean temperature), the maximum temperature had the maximum impact on the qualitative parameters of the water extracted from groundwater resource.

4. Conclusion

The major problem that the studied area of this paper is facing is the earth's subsidence phenomenon, which is likely to be due to climate change and groundwater scarcity, and requires further studies. The study of the relationship between climate change and loss of fresh groundwater resources is essential to find outing the characteristics of the different areas. The effects of future climatic change may be felt more severely in developing countries such as Iran, whose economy is mainly dependent on agriculture and demands for energy, freshwater, and food. Although climate change has been widely recognized, research on the special effects of climate change on the groundwater resources is relatively limited. The reasons may be that extensive historical data are required to analyze the characteristics of climate change. These data are not always available. Also, the driving forces that cause such changes are yet undefined. The climatic anomaly may occur frequently and last for some period.

Monitoring the chemical quality of groundwater resources and studying the factors affecting it to provide a sustainable source for proper usage and exploitation are crucial for proper management. Based on the results of this study, generally it can be stated that using geostatistical methods, one can well plot the spatial distribution of the main parameters affecting the chemical quality of groundwater resources of a region, so that one can benefit from them for management of water resources and supplying healthy drinking water in line with standards for citizens. Also, using climatic data, it is possible to study the effects of this factor on groundwater resources both qualitatively and quantitatively in order to be able to do the essential planning. Nowadays, the rapid growth of population and in turn, the greater need to water resources, global warming, climate change, and enhancement of qualitative standards are the limitations that compel managers to use novel methods in the management of water resources. The results of this study indicated that geostatistical methods could be an essential step in this regard.

Conflict of Interest

The author declared that there was no conflict of interest in this study.

Acknowledgment

This research was supported by Islamic Azad University, North Tehran Branch Services grant.

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