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Research Article

MONITORING THE SPATIO-TEMPORAL TRENDS OF GROUNDWATER QUALITATIVE PARAMETERS THROUGH GEOSTATISTICAL TOOLS

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ABSTRACT

Groundwater resources are among the most important water supplies for human beings especially in arid and semi-arid regions where precipitation is scarce. These blessings are also vital for life sustenance as well as sustainable development in industry and agriculture. The quality of groundwater bears a great concern due to its key role in human health and safety therefore studying and monitoring the qualitative parameters of these resources is a useful and effective approach to tackle the related challenges. In this study, all the available data of Marand Plain's aquifer were collected from the Regional Water Company. Checking the available dataset, a temporal range of 12 years (2002-2013) was chosen to be integrated into GIS. In ArcGIS, the map layers of the qualitative parameters were produced applying the Geostatistical Analyst tool and an appropriate interpolation method of the Ordinary Kriging model was selected to produce the interpolated surfaces for qualitative parameters. Finally, the change detection layer of each parameter was extracted. The change detection layers show the spatial fluctuations of groundwater quality over time. The temporal trends of the quality indices of the study area were also drawn. Based on the results the quality of Marand aquifer varies in different patterns spatially over the plain. The temporal analysis results suggest that in general, the water quality of the aquifer is in an inappropriate situation in which the groundwater quality has been deteriorated gradually during the study period.

Keywords: Geostatistical analysis, GIS, groundwater quality, marand plain.

1. INTRODUCTION

Groundwater is defined as water beneath the ground surface which flows through soli particles and accumulates in the saturated layers. These blessings are considered as one of the most important water supplies for human beings especially in arid and semi-arid regions of the world where precipitation is scarce. More than about 90% of the world's drinking water is supplied via groundwater aquifers [1] thus the water quality bears great concern due to its key role in human health and safety. Groundwater can become contaminated naturally or because of numerous types of human activities; residential, municipal, commercial, industrial, and agricultural activities can all affect groundwater quality [2]. Water quality changes in time and varies from region to region and also in different parts of a specific region, therefore, studying groundwater quality variation is a key step for monitoring and managing these vital resources which deal with human life.

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Geographic Information System dubbed GIS, “has vast applications in water sciences such as estimation of rainfall-runoff, mapping flood risk zones, assessment of groundwater quality and so forth” [3]. Benefiting from a wide range of analyzing tools and opportunities, GIS is known as a robust means for studying and solving environmental problems including groundwater-related issues. Typical examples of GIS applications in groundwater studies are site suitability analyses, managing site inventory data, estimating vulnerability of groundwater to pollution potential from nonpoint sources of pollution, modeling groundwater movement, modeling solute transport and leaching, and integrating groundwater quality assessment models with spatial data to create spatial decision support systems [4]. Nohegar et al [5] studied the temporal and spatial characteristics of groundwater quality in Minab Plain, Iran. Applying GIS and analyzing the quality data of the region’s groundwater for a period of 10 years. they found that in the middle part of the study area, the water quality of well water has a better situation regarding Electrical conductivity and TDS. In another study, Nas & Berktay [4], used GIS to map urban groundwater quality in Konya city, Turkey. They analyzed groundwater hydro-chemical parameters and concluded that the southwest of the city has optimum groundwater quality, and, in general, the groundwater quality decreases south to north of the city. Rao [6] studied seasonal variations of groundwater quality in Andhra Pradesh, India. He analyzed the quality data for both pre and post-monsoon periods and found that the majority of the groundwater samples are not good for irrigation in post-monsoon compared to that in pre-monsoon. Jeihouni et al [7] in a study made an assessment of groundwater quality for drinking purposes in Tabriz, Iran. They analyzed 70 sample wells of the region and used the kriging method for creating map layers in GIS. The results of the study indicated that the groundwater quality increases from North to South and from West to East of the study area. Nwankwoala et al [8] used GIS for groundwater quality assessment and monitoring in Port Harcourt, Nigeria. They used the kriging interpolation method for map layer generation and assessed all the water quality parameters. The result showed that Cl had the highest concentration among the anions and Ca had the highest concentration among the cations. They also recommended that the use of GIS should be encouraged to periodically monitor and assess groundwater quality. Bilesavar [9] in his MSc dissertation, studied groundwater hydro-chemistry of Marand Plain aquifer. The results of analyzing all quality parameters suggested that groundwater quality for drinking purposes decreases from East to West. They also found that groundwater quality mimics its quantity over different years.

Iran is a country with a relatively hot and dry climate and is located in an arid and semi-arid region. The annual average rainfall of the country is 250 millimeters. Therefore, the lack of water has existed long ago [5]. Population growth and increased demand for water in recent decades in Iran have caused a severe water problem so that most of its water need for drinking and agricultural uses, is supplied from poor groundwater sources. Up to date Monitoring and mapping of groundwater, quality properties can be an effective pace for sustainable use of groundwater resources. The main objective of this research is to study and analyze the groundwater quality in Marand Plain, one of the most critical plains of the country [10] where its groundwater resources have been suffering mismanagement and overuse for years, to obtain an overall view of its quality fluctuations in recent years.

2. MATERIALS AND METHODS

2.1. Study Area

Marand county is located in North-West of provincial capital Tabriz, NW Iran, confined to the coordinates 38° 25' 58.44" N and 45° 46' 29.64" E. With an estimated area of 826 square Km, Marand Plain is located in the southern part of the region. It is known as a part of the catchment area in the Caspian Sea in northwest Iran [11]. Most of the region’s population lives in the plain and relies on the region’s agriculture-based economy [11]. Receiving a medium annually raining of 236mm and a medium temperature degree, annually 10.9C, Marand Plain is a member of semi-arid regions. Almost all of the area's water need is provided from groundwater sources. Based on the reports of the Regional Water Organization, Marand Palin is among the six critical regions in East Azerbaijan province in which any exploitation of groundwater sources is prohibited due to a severe decline in water level in recent decades [12]. The location of the study area has been manifested in Figure (1).

2.2. Data Preparation

In this study, a 12-year long dataset was used to assess groundwater quality changes over time. Qualitative data of groundwater of the study area were obtained from the East Azerbaijan branch of Regional Water Organization. All the data were analyzed and a useable database was created for the spatial analysis. From the 87 available well dataset, 45 wells with the same spatial coincidence and temporal resolution were selected. A number of qualitative parameters were selected to be studied according to their role in water quality. The description of the used parameters is shown in Table 1.

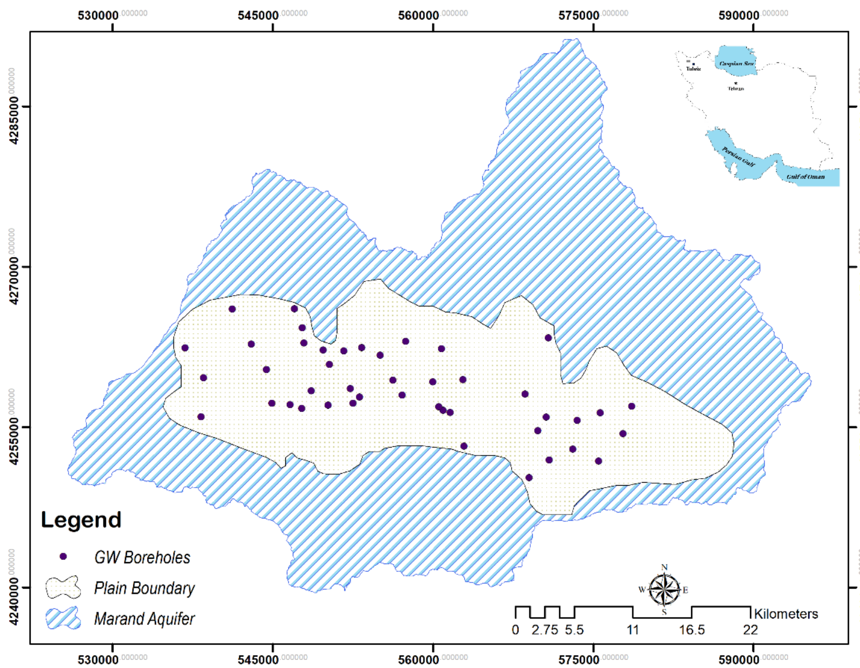

Figure 1. The Spatial Spread of the Groundwater Boreholes on Marand Plain, NW of Iran

Table 1. Description of the qualitative parameters used in the study.

Qualitative Parameter	Description
PH	PH shows the level of acidity and alkalinity of water thus is a very critical indicator of human health. Though PH usually has no direct effect on consumers, it is one of the most important quality parameters of water. Assessment of the water PH level requires careful attention at all stages of water treatment to guarantee satisfactory water clarification and disinfection [13].
CL	As a major anion detectable in all water bodies in nature, Chloride is not toxic for human beings but high levels diminish water suitability for both potable purposes [14] and cultivating activities due to the increased water salinity [3].
EC	Electrical conductivity measures the ability of water to pass the electrical current [15] which depends on the concentration and type of water ions as well as temperature. Since water EC goes hand in hand with TDS and water dissolved ions, its regular measurement is deemed as an important factor for water quality assessment.
TDS	Total Dissolved Solids, indicates the total mass of constituents dissolved in water [16]. The ratio of water ions increases as TDS increases and this will lead to high levels of water EC. Water is being saline as TDS levels increase in a given groundwater body making it inappropriate for human and plant consumptions.
SAR	SAR is a general quality index that represents the amount of sodium in the water [17]. High sodium levels affect the soil permeability and lead to infiltration problems and soil crusting and poor aeration [18].
SO_4	Sulfate is found at high concentrations in both surface and sub-surface water resources. Its high concentration deteriorates both the water taste and water odor [19] and can also cause diarrhea in humans, especially infants [20].
HCO_3	Bicarbonate has got fringe significance in public supplies but the higher ratios bring about unpleasant taste and corrosiveness of the water as a result of alkalinity.
TH	Total Hardness is the hardness of the mineral content of water. Hard water is not problematic for human health however; high levels of hardness could cause serious problems in industrial settings.
Ca Mg	Calcium and Magnesium are water TH index those high levels in water can cause the formation of scale in boilers, water heaters, and pipes [21] therefore they can affect the value of water for public and industrial uses.
Na K	Sodium and Potassium are important ions in groundwater and are used widely in water quality assessment and laboratory analysis. The presence of higher concentrations of sodium and potassium in groundwater suits it for drinking [19].

2.3. Spatial Analysis

2.3.1. Geostatistical Analysis

Geostatistics offers a way of describing the spatial continuity of natural phenomena and provide adaptations of classical regression techniques to take advantage of this continuity [22]. In the GIS world, the Geostatistics analysis provides an opportunity to create continuous surfaces from sample points of a phenomenon measured at different locations to predict the values of unsampled points. The interpolation techniques available in geostatistics are divided into two main types: deterministic and Geostatistical**.** The Geostatistical methods are based on statistical models that include autocorrelation.

2.3.2. Ordinary Kriging Interpolation Method

Aa a powerful statistical interpolation method used for diverse applications such as health sciences, geochemistry and pollution modeling, Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface [23]. Kriging technique is an exact interpolation estimator used to find the best linear unbiased estimate [24]. Ordinary Kriging is a spatial estimation method where the error variance is minimized [25]. Ordinary kriging assumes the model: $\mathbf{Z(s) = \mu + \varepsilon(s)}$**;**

Where μ is an unknown constant. To use this interpolation model, data must be normally distributed as well as being auto-correlated.

There are a variety of methods for each Kriging model to use in the Geostatistical Analyst but the best one is the method in which, the standardized mean error is close to 0, the root-mean-square error and average standard error are as small as possible (this is useful when comparing models), and the root-mean-square standardized error is close to 1 [4]. In the present study after exploring the dataset of each qualitative parameter, an appropriate method of Ordinary Kriging was used to create map layers of the parameters. Before using the interpolation techniques, it's necessary to explore data to check their spatial dependence and distribution. In the Geostatistical Analyst, Exploratory Spatial Data Analysis graphs (ESDA) are used for examining data prior to interpolation. The Histogram and Semivariogram tools were used to check the distribution and autocorrelation of the data respectively.

2.3.3. Checking Data Distribution

Checking data distribution is a preliminary step in the application of geostatistics such as Kriging in which it is assumed that the data are normally distributed over the study area. Distribution checking is done to guarantee this property for the data. In case the distribution is not normal, a data transformation method is applied to make the distribution normal. An ideal normal distribution should have 3 properties: 1) Mean and Median values of data should be as the same as possible, 2) Data Skewness should be close to 0 and 3) Data Kurtosis should be close to 3. In this study, the distributions are controlled using the Histogram tool and it's found that none of the parameters has a normal distribution, therefore, suitable Transformation methods were applied to the data. The results of the data checking process have been shown in Table 2.

Table 2. Normal Distribution Characteristics of the Parameters

Qualitative Parameter	Transformation	Mean	Median	Kurtosis	Skewness
PH	Box Cox	7.08	7.10	3.5	-0.82
CL	Log	1.73	1.68	2.90	-0.2
EC	Log	7.29	7.25	2.32	0.03
TDS	Log	6.78	6.74	2.32	0.03
SAR	Box Cox	2.90	2.70	3.5	0.61
SO_4	Log	0.7	0.9	4.1	-0.9
HCO_3	Log	1.59	1.49	4.02	0.78
TH	Log	5.94	5.94	3.4	-0.19
Ca	Log	1.25	1.21	2.8	0.06
Mg	Log	1.37	1.43	3.6	-0.54
K	Log	-2.06	-2.0.6	3.58	-0.4
Na	Log	1.82	2	3.52	-0.81

2.3.4. Examining Data Autocorrelation

Autocorrelation is the correlation or similarity of values, generally values that are nearby in a dataset. Spatial data is said to exhibit spatial autocorrelation when values measured nearby in space are more similar than values measured farther away from each other [26]. The Semivariogram Cloud was used to discover the spatial autocorrelation of the qualitative parameters of the study area. The Semivariogram/Covariance Cloud tool shows the empirical semivariogram and covariance values for all pairs of locations within a dataset and plots them as a function of the distance that separates the two locations [26]. After exploring the semivariograms of the data, an acceptable spatial correlation was discovered.

2.3.5. Creating Map Layers

Layers are the mechanism used to display geographic datasets in Arc Map [26]. Most geographic information systems (GISs) use map layers to organize geographic features [27]. The Ordinary Kriging model was applied to all the groundwater quality datasets to create the map layers. Ordinary Kriging uses different methods to create an interpolated surface including J-Bessel, Hole effect, Rational Quadratic, K-Bessel, Exponential, Spherical, Tetraspherical, Pentaspherical, and Circular. A method is selected which has the least RMSE[†] [3]. In this study, all the various methods of Ordinary Kriging were tested to choose the best fitting one (Table 3).

[†] -Root Mean Square Error

Table 3. Results of Semivariogram Modelling of the Qualitative Parameters

Qualitative Parameter	Fitted Model	Mean	Root Mean Square	Average Standard Error	Mean Standardized	Root Mean Square Standardized
PH	Hole Effect	0.007	0.365	0.425	0.016	0.870
CL	Hole Effect	0.451	6.82	9.56	0.049	0.760
EC	J- Bessel	-50.572	699.143	525.16	-0.162	1.545
TDS	Hole Effect	17.10	468.33	535.34	0.034	0.837
SAR	Hole Effect	0.0739	1.507	1.584	0.0309	0.93
SO_4	Circular	0.068	2.013	2.64	-0.0413	0.838
HCO_3	Hole Effect	0.011	2.83	2.69	0.093	0.96
TH	Hole Effect	4.65	239.95	274.5	0.025	0.805
Ca	Exponential	-0.254	3.018	2.514	-0.187	1.086
Mg	Hole Effect	-0.0435	2.559	3.026	-0.049	0.987
K	K-Bessel	-0.001	0.073	0.085	-0.043	1.077
Na	Hole Effect	-0.117	3.129	4.066	-0.076	1.152

2.3.6. Change Detection of Groundwater Quality

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different time [28]. In the GIS world, the term "Change Detection" refers to the method of comparing two raster images of a certain area to discover the changes which have taken place in a given period of time [29]. In this approach, two raster layers representing two different dates are used to create the change surface of the interested phenomena during that time period. It can be expressed as:

$$L_{\Delta T} = L_{Tj} - L_{Ti} \tag{1}$$

Where $L_{\Delta T}$ is the change detection layer, L_{Tj} and L_{Ti} are raster layers representing the second and the first time rasters respectively. The result of this function may have three values: positive and negative values respectively indicate the increase and decrease in the phenomenon under study while zero indicates no change areas.

2.4. Temporal Analyses

Temporal statistical analysis enables you to examine and model the behavior of a variable in a data set over time to determine whether and how concentrations are changing over time [30]. Time Series Plots were used to fathom the existing trends in groundwater quality in the study area.

3. RESULTS

The results of the study show the occurred changes in groundwater quality during the study period. Change detection maps which resulted from spatial analyses, illustrate the spatial variations while Time series plots show the temporal changes of the qualitative parameters of groundwater. According to the spatial fluctuations of the qualitative parameters (Figure 2), different parts of the Plain vary in amounts of each parameter. While some parts of the area show an increase in the amounts of parameters, other parts show a decreasing trend. For instance, the spatial distribution of Ca, Mg is very akin to that of TH in which the quality level increase is seen in a small portion of the north while the other parts show decreases. From the maps offered in Figure 2, the variations of the water quality of Marand aquifer during the limited time scale of this study can be detected as a means for any water-related monitoring and treatment activity.

The results of the temporal analyses led to graphs in which annual fluctuations of groundwater quality in the current time span are detectable. Based on these graphs it's found that except for some parameters which have descending trends like Na, K, $SO_{4,}$ and $HCO_{3,}$ most of them have an ascending trend. The ascending trend in the qualitative parameters was detected in PH, Cl, EC, TDS, TH, Ca, Mg, values which means the amount of these ions have been increased during the study period. The trend line of SAR remained pretty straight which indicates this parameter has had a fixed trend that is, there is no change in its temporal fluctuations. The temporal fluctuation of the parameters has been shown in Figure 3.

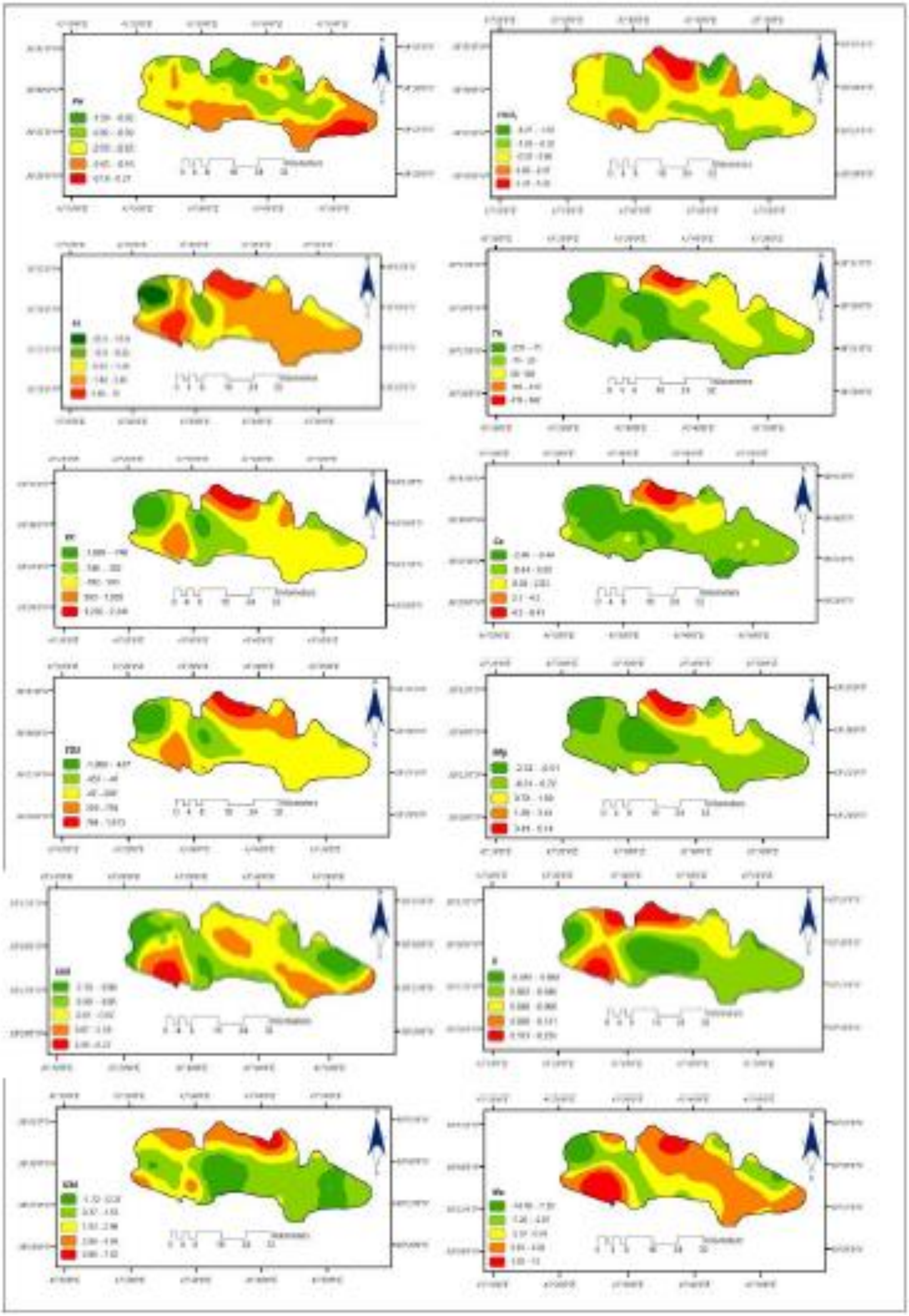

Figure 2. Spatial fluctuations of the qualitative parameters of Marand plain aquifer

Figure 3. Temporal fluctuations of the qualitative parameters

4. DISCUSSION OF THE RESULTS

In the present study, the map layers of qualitative parameters of Marand Plain aquifer were produced applying geostatistical analyses in the GIS environment and based on the change detection approach, quality change layers of each parameter were extracted. Each change detection layer illustrates the occurred rise and fall and their amount during the start and the end of the given period of time. The Time series plots also were drawn in Excel in order to trace the annual changes in the quality parameters. According to the spatial analysis results, the spatial variation of Cl, EC, Na, TDS and SAR parameters are approximately similar where the eastern parts show increase while west of the area shows a decrease in the concentration levels. The variations of Ca, Mg and TH are also similar to each other showing the ascending trends in the small portion of the central north of the area. The other parts found to have suffered decreases regarding these parameters. The other four quality parameters are different in the spatial pattern throughout the plain.

Referring to the temporal graphs, the ascending trend of Ca, Mg and TH and the descending trend of Na and K reveal that the hardness of the region's water has been increased during the past 12 years in the study area. The ascending trend of Cl, EC, and TDS is also a sign of the increased water salinity as a result of higher PH thus water alkalinity in the same period. The decreased amounts of HCO3 and SO4 are desirable according to water quality standards but since the temporal trends of these two in the study area are slightly descending it cannot be interpreted as water quality enhancement. The temporal analysis results suggest that in general, the water quality of the region's aquifer is in an inappropriate situation in which the groundwater quality has been deteriorated gradually during the study period. This could be due to both anthropogenic and natural factors such as harsh weather and dry climate of the region, excessive pumping of groundwater resources, growth of population and water level decline in the recent years.

5. CONCLUSION

Being used for different purposes, groundwater quality has a significant impact on both agricultural and industrial products, therefore, affects human life deeply. On the other hand, having up to date and reliable information about its quality in a given area is required for taking on-time managerial measures. Geographic Information System is a robust means to monitor groundwater quality over time taking benefit of its analytical tools to produce suitable maps. The results of this work showed the suitability of GIS and it's geostatistical tools for analyzing groundwater quality data and stresses the idea of benefiting more and more of GIS to monitor and manage aquifers around the world.

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