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Monitoring and Predicting the Groundwater-Level Fluctuations for better Management of Groundwater Resource in Lowlands Using Geographic Information System (GIS)

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Abstract

In order to be aware of groundwater-level fluctuations in arid and semi-arid regions, it is necessary to make an accurate forecast of the groundwater depth situation. The drying of Hamoon lake, severe water shortages and significant reduction in groundwater levels have led to critical environmental conditions in the Sistan plain. Spatial understanding of groundwater depth changes in the region and awareness of the severity of groundwater depletion are important for the development of water resources management strategies. Therefore, this study was conducted with the aim of zoning groundwater depth using geostatistics and GIS techniques in the agricultural lands of Sistan plain located in the east of Hamoon Lake, with an area of about 201000 ha. For this purpose, groundwater depth data were collected from 846 wells by field survey using piezometric wells in the study area. In this research, various geostatistical methods including deterministic interpolation method and geostatistical methods were evaluated to compare the prediction ability of groundwater depth spatial variations. The results showed that the intensity of groundwater depth changes in the study area with a coefficient of variation of 19.87% is moderate. The spherical model could better explain the spatial variation of the experimental variogram of the studied parameter in the region. Finally, the results related to the deterministic method of inverse distance weighted with power 2 estimates a better prediction for groundwater depth zoning than kriging and cokriging geostatistical methods.

***Keywords**:* Sistsn Plain, Geostatistics, Groundwater Depth, Hamoon Lake

1. Introduction

Sistan plain is one of the lowlands with ultra-arid climate in eastern Iran. This region has a fragile ecosystem due to the famous 120-day winds and dust storms and is facing a severe shortage of water

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resources because of the lack of water rights for the Helmand River from Afghanistan (Zoraghi et al., 2019). On the other hand, annual rainfall of less than 50 mm and evaporation of more than 5000 mm in the region, as well as the dryness of Lake Hamoon, have led the natives of the region to use groundwater. Over the past 20 years, the reasons mentioned above and the high use of water each year have led to a decrease in groundwater recharge in the region. If this trend continues, it will create water stress for plants in the region and may eventually lead to desertification and severe environmental damage in the area (Bazzi et al., 2021). Due to the lack of a permanent river in the region, the protection of groundwater resources should be a priority in Sistan plain water resources management programs. Management systems such as the management of Sistan's groundwater resources, which in recent years has faced a crisis of declining water levels and volume depletion, need a forecasting system to implement better management to prevent crisis in this region.

On the other hand, nowadays understanding the spatial variation of groundwater depth is a prerequisite for achieving sustainable use of water in various fields. It is easy to pointy measurement the water table, but achieving continuous groundwater levels based on this measurement is the main goal for monitoring water resources. In order to achieve such measurements, a strong and reliable interpolation method is required (Li et al., 2005). Among the various interpolation methods, no one method is uniquely optimal, and therefore the best interpolation method for a particular situation can only be obtained by comparing their results.

Some studies have been conducted to compare different interpolation methods in a variety of situations and the use of geographic information systems (GIS) has been an important tool in the analysis of groundwater characteristics in specific areas (Sun et al., 2009). In their study, Hu et al. (2005) prepared groundwater level maps for the North China Plain using ordinary kriging techniques. Their findings showed that a 6-meter drop in groundwater compared to 1990. Theodossiou and Latinopoulos (2007) interpolated groundwater levels in the Antontas basin in northern Greece using the Kriging method, and they estimated the accuracy of interpolation values by using cross-validation method.

In a study, Kambhammettu et al. (2011) evaluated the best level of groundwater depth of the CalSabad Plain in the US state of New Mexico using the Universal Kriging method. The results of this study showed that the difference between the surface estimated by this method and the observed water level is between 0.6 to 4.5 meters and the reliability coefficient was set at 90%. Shahzad et al. (2020) in Punjab, Pakistan predicted the depth of groundwater level by geostatistical methods. The results of this study showed that the best model expressing the spatial variation of groundwater depth in the study area is Gaussian and the spatial correlation class of this parameter with values less than 25% is strong.

However, there are few reports that can compare groundwater depth monitoring in ultra-arid areas with different interpolation methods. Therefore, the objectives of this study were to select the optimal interpolation method in this area from kriging (K), cokriging (CK) and inverse distance weighted (IDW) methods and to compare the accuracy of groundwater depth interpolation for each method and error analysis. Second, the best interpolation method is used to survey the spatial variation of groundwater depth and, finally, to analyze the trend of depth change.

2. Materials and Methods

Sistan plain is located on the delta of Helmand river (flood plain) in eastern Iran and in the north of Sistan and Baluchestan province. The average altitude of the region is 485 meters above sea level. The average annual rainfall and evapotranspiration in this region are 50 and 5000 mm, respectively. 120-day strong winds are unique in this region and this is one of the most important factors involved in the high amount of evapotranspiration in addition to the high temperature of the region. Land use in the area includes agriculture, rangeland as well as unusable land (Zoraghi et al., 2019).

The study area is part of the agricultural lands of Sistan plain located in the east of Hamoon lake with an area of about 201,000 ha, which is located between the geographical coordinates of 61° and 10´ to 61° and 45´ E and 30° and 50´ to 31° and 22´ N as shown in Figure 1.

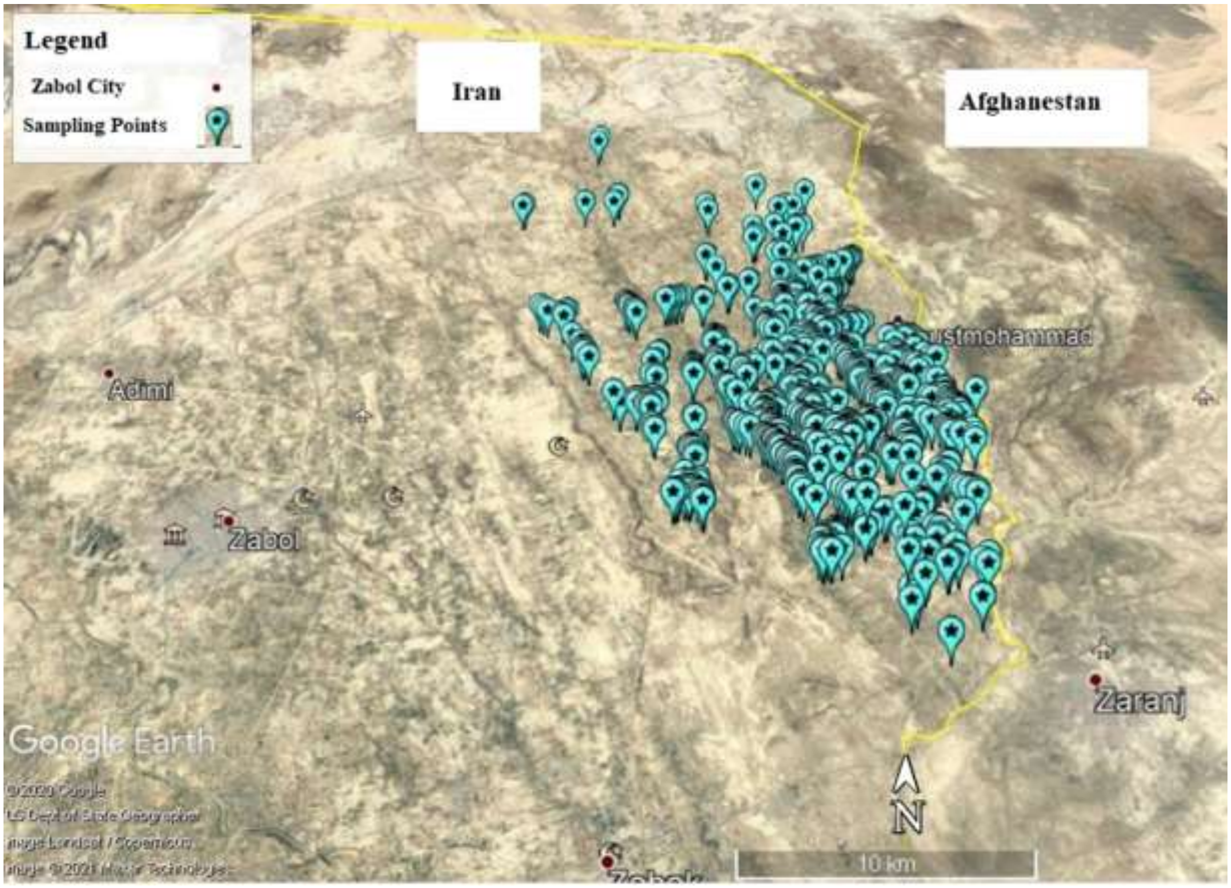

Figure 1. Geographical location of sampling points in the Sistan plain

For this research, groundwater depth data were collected from 846 wells in the area by field survey using piezometric wells in the area. After fitting the appropriate variogram model to the spatial structure of the data and determining its factors in the study area, the different geostatistical methods including deterministic interpolation methods (Inverse distance weighted (IDW) with powers 1 and 2) and geostatistical methods (Ordinary kriging method (OK)), Simple kriging (SK), Ordinary cokriging method (COK), simple cokriging (CSK)) was performed and results was compared. GS+ software was used to draw the semivariogram of the parameters. The most appropriate variogram model was selected based on the minimum sum of squares (RSS) and the maximum amount of R2. In order to compare the used methods in this study and select the most appropriate model for estimating groundwater depth, the cross-validation technique was applied. In this method, an observation point is removed at each stage and that point is estimated using the other points. This is repeated for all observation points. At the end, there will be an estimation of the number of observation points. In this study, the parameters of mean error (ME) and root mean square error (RMSE) were used.

$$ME = \frac{1}{N}\sum_{i=1}^{N}(Z^*(x_i) - Z(x_i)) \quad (1)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Z^*(x_i) - Z(x_i))} \quad (2)$$

That, Z * (xi) is the estimated value at point i and Z (xi) is the observational value for point i (Bameri et al., 2015). Also, in the cokriging method we need to use an auxiliary variable. For this purpose, the correlation of groundwater depth with the parameter of digital elevation model (DEM) was investigated. If the parameter has a positive and significant correlation with groundwater depth as auxiliary variable is entered in the cokriging modeling.

Due to the study area is located in lowlands and flat regions, the digital elevation model used in modeling and preparing the desired parameter map was obtained from ALOS PALSAR satellite information with an accuracy of 12.5 meters. In order to zoning and present the map according to the mentioned statistical values, a method with the lowest ME and RMSE values was selected. Data analysis was performed using SPSS 21 software. Arc GIS 10.6 software was also used for geostatistical analysis and mapping. After determining the best interpolated method for groundwater level prediction in Sistan plain, spatial zoning maps of the study area were produced in Arc GIS software.

3. Results and Discussion

The statistical summary of the studied features was shown in Table 1. According to Wilding et al. (1983), if the coefficient of variation of data is less than 15%, the data have low variability. If the value of this coefficient is between 15 and 35%, the class of variability is moderate. At the end, if the value of this coefficient is more than 35%, it indicates high variability of the data. Therefore, as shown in Table 1, the intensity of groundwater depth changes in the study area can be considered moderate.

Table 1. Statistical characteristics of the studied variables

Variables	N	Min	Max	Range	Mean	Standard deviation	CV (%)	Skew	Kurtosis
Depth	846	1.9	10.2	8.3	4.253132	0.845065	19.869	0.555	2.835
DEM	846	456	472	16	463.5496	2.333551	0.503	0.099	0.749

The reason for this can be considered that the groundwater depth is more affected by the region environmental conditions, such as sedimentation as a result of seasonal floods in Hamoon Lake, also authorized and unauthorized withdrawals from underground sources. Shahzad et al. (2020) in their studies report high variability in groundwater depth changes as a result of monsoon storms and regional surveys. The low variability of the digital elevation model reflects the nature and physiographic status of the lowland and floodplain areas of the region. Although the normal distribution of data is not a necessary condition for geostatistical processing, but if the geostatistical estimates are normal, they are more accurate (Mohammadi, 2006).

The values of skewness coefficient presented in the table confirm this, both the parameters of groundwater depth and digital elevation model have a normal distribution and its skewness coefficient is between 1- and +1 (Bameri et al., 2015).

It can be seen in Figure 2 that positive and significant correlation was established between groundwater depth and the parameter of the digital elevation model at the level of one percent (p <0.001). Auxiliary variable was used. Also, what can be obtained from this image is that the amount of groundwater depth has a significant relationship with geographical coordinates, which confirms the spatial dependence of groundwater depth changes in the region.

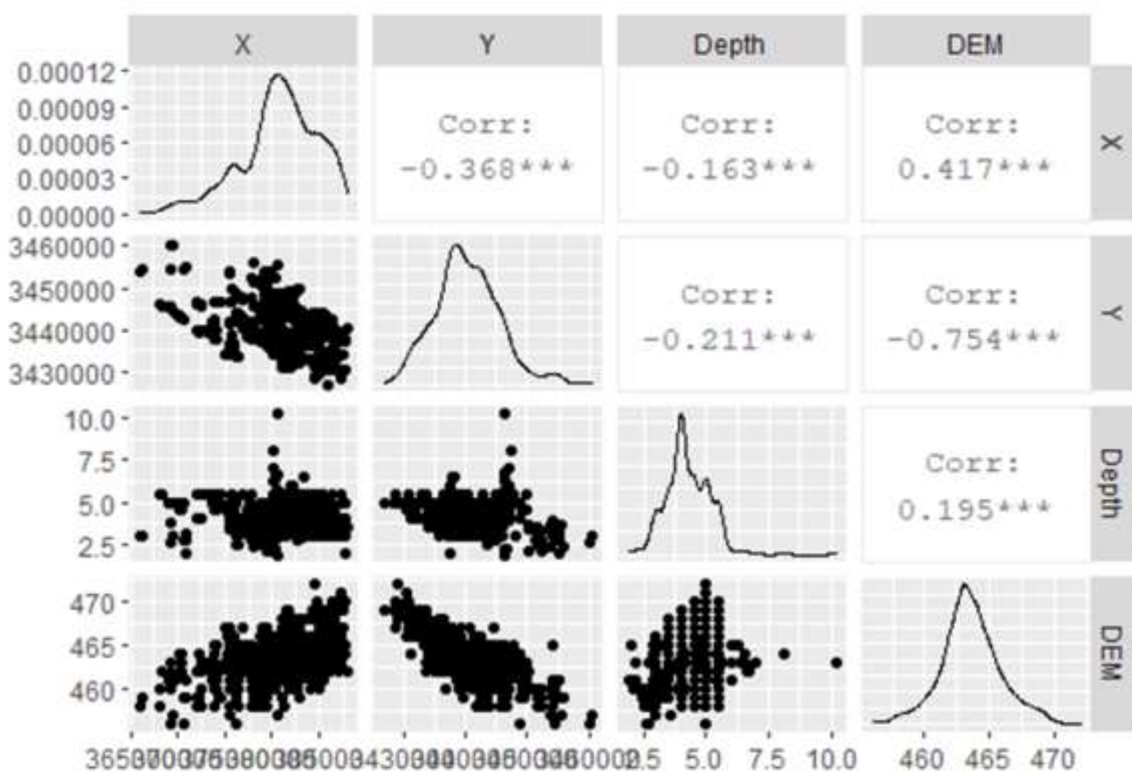

Figure 2. Investigation of correlation relationships between groundwater depth and environmental parameters (* and ** significant correlation at 5 and 1%, respectively)

After reviewing the descriptive statistics, the spatial correlation of different parameters was evaluated and the experimental variogram for groundwater depth was calculated and plotted. Experimental variogram analysis showed that the studied parameter in the region has a spatial correlation, so that the results of the correlation ratio also show that the groundwater depth parameter has a moderate correlation ratio in the study area. After obtaining the experimental variograms, the theoretical model of the variogram was fitted using GS+ software and the appropriate variogram was fitted to the groundwater depth data from the linear, linear to sill, spherical, exponential and Gaussian models. The parameters of the groundwater depth variogram and the models fitted to them are summarized in Table 3 along with the validity control of the variogram.

Table 3. Groundwater depth variogram parameters

Variable	Model	Nugget	Sill	Range (m)	Proportion	Spatial Class	R2	RSS
Groundwater Level	Spherical	0.448	0.957	21830	0.532	Moderate	0.9	0.0192

As shown in Table 3, the spherical model was better able to explain the spatial variations of the experimental variogram of the studied parameter in the region (Figure 3). Pudineh and Delbari (2017) in the study of spatial changes of groundwater depth in Iranshahr-Bampour plain reported the spherical model as the best model expressing changes in water depth with a weak correlation class.

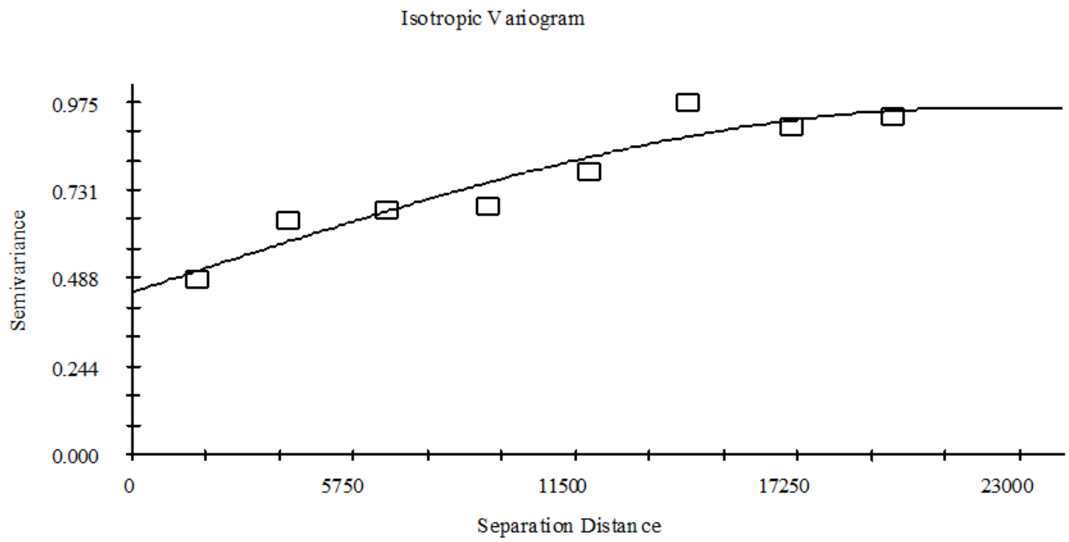

Figure 3. Semivariogram of groundwater depth in the study area.

After analyzing the variograms of groundwater depth, interpolation was performed using GIS software by kriging and cokriging geostatistical methods and a deterministic method of inverse distance weighted. These results are shown in Table 4.

Table 4. Estimated value of groundwater depth zoning error in kriging, cokriging and inverse distance weighted methods

Method	Kriging		Cokriging		IDW	
Evaluation criteria	SK	OK	SCK	OCK	IDW1	IDW2
ME	0.0051	0.00209	0.00064	-0.0005	0.00615	0.00723
RMSE	0.46904	0.45962	0.4893	0.47577	0.46187	0.4526

The results show that the definite method of inverse distance weighted with power 2 estimates a better approximation for the groundwater depth zoning than the geostatistical methods of kriging and cokriging. Regarding the cokriging method in the surface part of the study area, since this method uses an auxiliary variable with a significant correlation at the 1% level for intermediation, it should generally lead to better results than the other two methods, but due to the existence of various processes such as over withdrawal of groundwater resources, successive droughts and finally insufficient spatial correlation class of the studied parameter (moderate), this geostatistical model did not show acceptable results.

However, Pudineh and Delbry (2017) state that the accuracy of interpolation methods also depends on the density of measuring points, so that even in high-density networks, the prediction skill of the kriging method may not be more than deterministic methods such as IDW. In a study of spatial variations in groundwater depth in northwestern China, Sun et al. (2009) reported that the simple kriging model has a higher estimation power to interpolate the desired parameter than the inverse distance weighted method. The groundwater depth zoning map of the whole study area is shown in Figure 4.

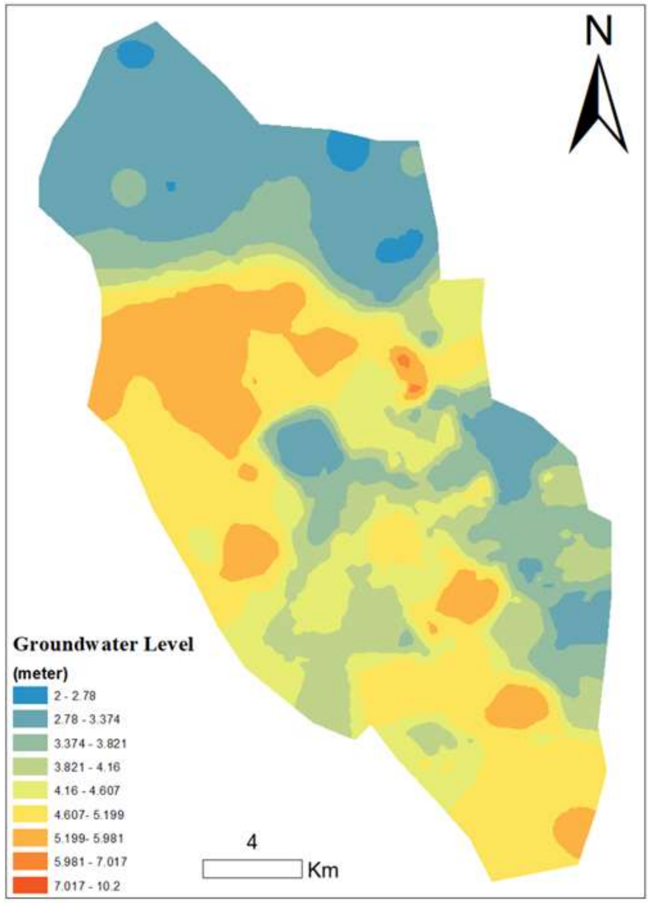

Figure 4. Groundwater depth zoning map in the whole area

As you can see in the figure 4, the depth of groundwater in the marginal areas bordering Afghanistan is less than other places and the highest depth of groundwater is in the western part and in the direction of the slope to Lake Hamoon. Inasmuch as all wells in an area are hydraulically connected to each other, the general trend of groundwater depth can be considered as decreasing. However, the drying up of Hamoon International Wetland, the rainfall reduction, the occurrence of continuous droughts in the last few years, and the illegal and unauthorized withdrawals have reduced the volume of groundwater reserves in the Sistan plain.

In addition, Yang et al. (2003) listed Iran as one of the countries with water deficit after 2000, Alcamo et al. (2000) state that Iran will be one of the countries affected by water stress in 2025, and Smakthin et al. (2004) considered Iran to have high water stress.

4. Conclusion

The purpose of this study is to provide optimal groundwater depth modeling tools in Sistan plain that help to better monitoring and proper management of the limited irrigated agriculture of Sistan plain. The results showed that although the groundwater depth in the study area has a spatial correlation, but due to successive droughts and irregular withdrawal of groundwater for agricultural purposes, the correlation class of spatial variation is moderate and consequently geostatistical methods such as Kriging and Cokriging showed lower ability than inverse distance weighted method in spatial zoning of groundwater depth.

In the last 20 years, due to the drying up of Lake Hamoon, low rainfall and rising temperatures, the natives of the region have been forced to remove groundwater, which has significantly reduced the depth of groundwater in the region. To prevent this, it is suggested that diplomacy and the Ministry of Foreign Affairs make arrangements so that they can receive the water rights of Lake Hamoon from the Afghanistan government.

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