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An Example of Kriging Method based on Environmental Temperature for Altitude Mapping Using ArcGIS Software

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Abstract

The purpose of this study is to demonstrate how Geographic Information System (GIS) software can be used for geographical interpolation, geostatistical analysis, and the creation of maps using relatively sparse data and highlighting the significance of this software in engineering and decision making. The method used in this study is applying ordinary kriging analysis on a gathered database to develop a variation map with interpolation analysis. The selected Z-values are the altitude and Environmental temperature of the selected zone which can contain a vast range. GIS can recognize and analyze the spatial relationships that exist within digitally stored spatial data. This method can bring ease for collecting data from a location that may have difficulties in visiting and gathering data by hand. By the use of semivariogram which is a graphical representation, and the covariance between every pair of points are used to calculate the spatial relationships between interpolating points. As a result, the final output of ArcGIS is a developed map showing altitude variation in the central area of Istanbul. This option can be used in making complex maps in every desired area by predicting Z-values for all the wanted zone based on the given database. Hence, the utility of GIS can bring a great improvement and ease in decision making and planning in civil engineering branches such as transportation, infrastructure, soil mechanics, and construction.

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1. INTRODUCTION

GIS are analysis and modelling tools that integrate the relation between features of the Earth's surface and their environmental effects. It is also employed in basic spatial analysis and operations (Dewata & Putra, 2021). For many disciplines that investigate spatial events, GIS provides extremely powerful analysis capabilities. Since spatial phenomena are the foundation of geostatistics, many researchers have used geostatistical analysis associated with GIS technologies (Uyan & Dursun, 2021).

Spatial interpolation is an important GIS function that is used for spatial query, spatial data visualization, and spatial decision-making processes in GIS and environmental science (Meng et al., 2013). Inverse Distance Weighting (IDW), kriging, spline interpolation, and interpolating polynomials are some popular approaches for spatial interpolation. Ordinary Kriging (OK) and IDW are the most widely used, compared, and recommended interpolation techniques (Bhattacharjee et al., 2013).

Kriging is an interpolation technique used to estimate a variable at an unknown location based on observed values at nearby locations (Shad et al., 2009). In terms of accuracy and precision, the use of kriging techniques in mining studies and reserve estimates has resulted in positive outcomes. The incorporation of GIS into these studies has elevated the mapping and visualization dimensions to new heights (Uyan & Dursun, 2021). (IDW)

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is one of the interpolation techniques that is seen as being user-friendly. In this case, the locations used either have computed values or other, unnamed places have values. Using this technique, it is possible to predict unknown values for any geographic location data. For instance, levels of pollution, height, depth, chemical parameter concentrations, and precipitation (Paramasivam & Venkatramanan, 2019). Kriging weights are deduced from a semivariogram generated by examining the spatial structure of the data. Predictions are generated for locations in the research area based on the semivariogram and the spatial arrangement of measured values that are close by in order to create a continuous surface or map of the phenomena (Shad et al., 2009). The method of kriging interpolation that is most commonly applied is ordinary kriging. By utilizing estimated location data in the area, this aids in calculating a value at a point in a region known to be a semivariogram. The mean in a moving zone with local second-order stationarity is implicitly tested by ordinary kriging (Ali & Mustafa, 2020).

In the fields of GIS and Remote Sensing (RS), predicting spatial properties is a difficult issue. To develop derived spatial features, RS satellite imagery is handled further through a number of intermediary stages (Bhattacharjee et al., 2013). It is currently possible to detect changes and design plans based on these changes thanks to recent advancements in remote sensing and GIS. Urban planners now have access to more robust and adaptable geostatistical techniques based on GIS. GIS is able to map and evaluate the population's geographic distribution in order to improve planning for future decisions and the development of the economy, education, and healthcare as well as other properties in a specific zone that are noticeable in planning (Ali & Mustafa, 2020). The GIS mainly holds these derived attributes as vector data in the form of thematic layers (Bhattacharjee et al., 2013).

Kriging techniques use statistical models that take into account the autocorrelation among a collection of measured points to produce prediction surfaces (Johnston et al., 2001). The correlation or similarity of values, usually values close to one another in a dataset. When values recorded near together in time are more comparable than values measured far apart in time, spatial information is said to display serial autocorrelation. When values measured close together in space are more comparable than values measured farther apart, geographic data is said to display spatial autocorrelation. A statistical technique called regression is used to examine the relationship between a single dependent variable and one or more independent variables that are believed to have an impact on the dependent variable. It is used to forecast the value of the dependent variable or to establish whether and how much an independent variable does, in fact, affect the dependent variable. Another statistical metric for the linear relationship between two variables is covariance. It gauges how closely two variables move in tandem with respect to their respective mean returns. (ESRI, 2023)

When these data include errors and missing values, prediction is essential (Bhattacharjee et al., 2013).

In order to weigh the spatial configuration of observed sampling points, weights are applied to measurement points based on the distance at which spatial autocorrelation is determined (Johnston et al., 2001). Environmental geochemistry data are common spatial data that may be stored in a GIS and include geographic coordinates (such as longitude and latitude) and geochemical properties (such as element concentrations) (Xu & Zhang, 2022).

A strategy for incorporating the spatial and temporal coordinates of observations into data processing is called geostatistics (Ali & Mustafa, 2020). Spatial position, distribution, and linkage are calculated via a GIS database. In its most basic form, spatial analysis is a set of techniques that yields precise outcomes with spatial correlation. Geometric and thematic data show a spatial relationship and qualities in the data components are reported (Paramasivam & Venkatramanan, 2019).

Hence, both geographic locations and qualities must also be taken into consideration while conducting data analysis in environmental geochemistry. A rising variety of spatial analysis and statistical methodologies have been combined into GIS as a result of advancements in computer hardware and software, and this has greatly aided in the monitoring and evaluation of the environment (Xu & Zhang, 2022). GIS data represents real-world phenomena including highways, land use, elevation, trees, waterways, and states. Two conceptualizations can be used to categorize the most prevalent forms of phenomena that are represented in data: discrete objects, such as a home or a road, and continuous fields such as rainfall amount or population density (Longley et al., 2015). Latitudes are horizontal lines that indicate how far away from the equator a location is. Longitudes are vertical lines that represent the east and west directions relative to Greenwich, England's meridian. Cartographers, geographers, and others can pinpoint points or locations on the globe by combining latitude and longitude. Nowadays, positions are related to other aspects and information, both geographic and non-spatial, by modules intended to manage spatial data (Paramasivam & Venkatramanan, 2019).

Numerous tasks in civil engineering are performed in an unfriendly and complicated environment, which makes it challenging for the employees to perform their duties effectively. However, the process is done more easily with the aid of GIS (Simmons, 1996). Topography, hydrology, geology, soils, utility infrastructure, and transportation are just a few of the many topics covered by GIS in civil engineering (Parker, 1996). Thematic mapping and graphic output data can be superimposed on a map image in the map display, which is the most aesthetically distinctive aspect of GIS software. The primary feature that sets GIS apart from other data systems is how geographic data are stored and accessible (Luna et al., 2008). Due to their difficulty in accessing and evaluating, formerly deemed distinct geographic information themes have been brought together by GIS. Such themes have been overlooked when carrying out activities. This creates the possibility for greater task planning, task design, and task execution decisions (Parker, 1996).

The purpose of this study is to illustrate how GIS software can be used to perform geographical interpolation, geostatistical analysis, and the development of maps depends on environmental temperature data from briefly compact data. The altitude of 20 different locations from sea surface and the temperature in Istanbul have been chosen for this study in order to make a map that shows the difference in altitude and temperature in Istanbul's center region and to highlight the usefulness of this software in civil engineering.

2. METHODOLOGY

This study has been performed in the central part of Istanbul, Turkey, with the use of GPS waypoints points have been collected in this area. With the help of ArcGIS (version 10.8.2), Kriging analysis has been performed to develop a map for altitude difference.

2.1. Study Area

The study area is Istanbul, Turkey. The following maps (Figure 1) show Turkey on world map and Istanbul's location in this country (Figure 2).

Figure 1. *Turkey (modified from Google Earth, 2023)*

***Figure 2**. Istanbul, Turkey (modified from Google Earth, 2023)*

2.2 Collection of Waypoints from the Study Area

The waypoints were collected from the study area by using Google Earth (2023) and GPS Waypoint Android Applications. Smartphone GPS units often use aided GPS (A-GPS) technology, which allows the GPS sensor to obtain ephemeris and an archive through a mobile data network (Liao, 2022).

2.3 Kriging Application on ARCGIS

In this study, the Arctoolbox in the ArcMap 10.8.2 Software was employed in this analysis. Our attribute table and data can be subjected to numerous analyses using this option. In this case, the spatial analyst's interpolation tool, Kriging was employed.

Based on the supplied data, this approach provides us with a prediction for the entire map.

Although kriging methods vary in terms of formats, they are all founded on the idea of a simple linear regression approach (Shad et al., 2009). It is possible to describe the prediction at location u in mathematical explanation as:

$$Z(u) = \sum_{\alpha=1}^{n} \lambda_\alpha(u) Z(u_\alpha) \quad (1)$$

The random variable model at location u_α is indicated by $Z(u_\alpha)$ is. The n data locations are presented by u_α, the ordinary kriging weights are shown as λ_α (u), and Z(u) is the predicted value. Here the weights λ_α (u) are subject to the process (Shad et al., 2009). However, with the kriging method, the weights are based not only on the distance between the measured points and the prediction location but also on the overall spatial arrangement of the measured points. To use the spatial arrangement in the weights, the spatial autocorrelation must be quantified. Thus, in ordinary kriging, the weight, λ_α (u), depends on a fitted model to the measured points, the distance to the prediction location, and the spatial relationships among the measured values around the prediction location (ESRI, 2023)

The predictability relation between data points located a certain distance apart is described numerically (or graphically) by a geostatistical function. Because of this predictability, the degree of confidence in a value's estimation is constrained, and as a result, risk estimation is established (Shad et al., 2009).

A semivariogram is a visual representation that shows the spatial connection of data (Ali & Mustafa, 2020). The covariance between every pair of points is used to calculate the spatial relations between interpolating points. The semivariogram model is generated using known data points, and covariance is determined using that model (Bhattacharjee et al., 2013). Kriging produces the most accurate predictions by using covariance and semi-variogram (Ali & Mustafa, 2020). The nearby local features of the sample points are not regarded by the covariance or the semivariogram. They are independent of the nearby affecting spatial characteristics and functions of distance (Euclidean distance in 2-D space) (Bhattacharjee et al., 2013). The covariance and autocorrelation matrices of the 20 data points are provided in the results section.

The semivariogram's basic properties are the semivariance value at which the variogram hits saturation is named the sill. In the semivariogram, Sill denotes the amplitude of a specific element. Range is the location where the semivariogram intersects with the lag distance. The range autocorrelation is zero after that. A semivariogram should potentially have zero at its origin. The nugget is the value of the semivariogram if it is not zero (Bostan, 2017).

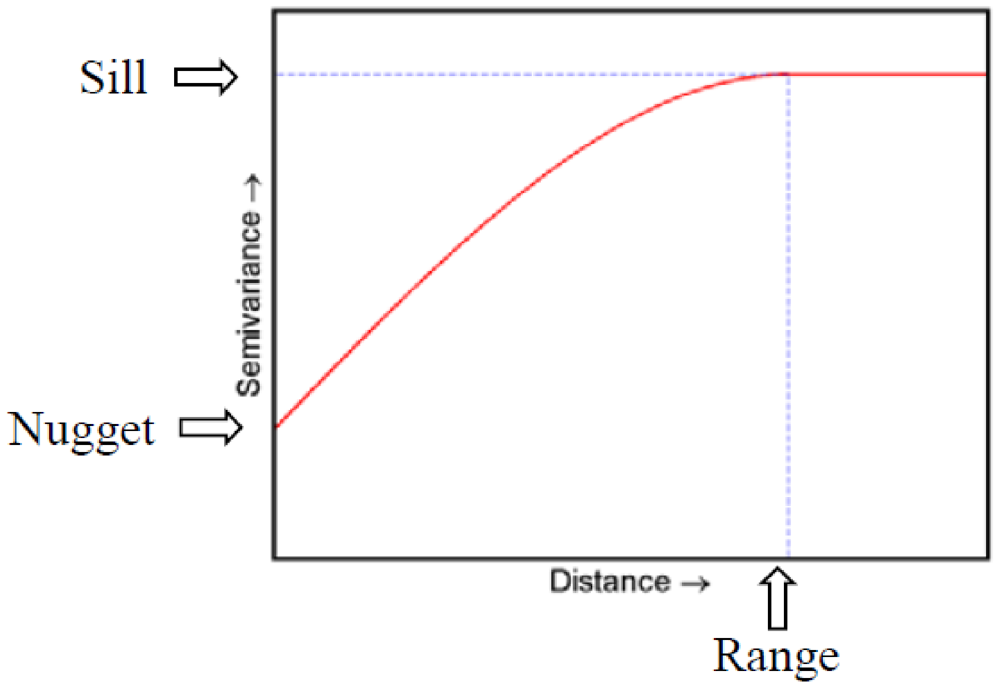

***Figure 3**. Semivariogram models (Bostan, 2017)*

This software includes a geostatistical wizard that is used to produce the geostatistical outcomes as well. By applying Ordinary Kriging interpolation, the samples dataset is utilized to estimate the spatial distribution of population size with respect to the local area.

3. RESULTS AND DISCUSSION

This section provides information about the gathered database about altitude differences in Istanbul. Moreover, it gives the final results for this analysis using the GIS software to estimate a map for the whole area with ordinary kriging.

The database for this study is shown in the attribute table (Table 1), which includes 20 waypoints in Istanbul, Turkey's central region. This data was acquired using RS Google Earth (2023) and recorded on 13^{th} of December 2022. Latitude and longitude are the two distinctive essential characteristics of each point measured in decimal degrees (DD). Therefore, it is impossible for two places to share the same latitude and longitude at the same moment. The study's variable Z value serves as the table's altitude attribute. The accuracy of this dataset is defined by GPS.

***Table 1**. The provided attribute table in this study*

Point	Latitude (DD)	Longitude (DD)	Altitude (m)	Temperature (°C)
1	40.99201	28.79558	63.0366	8
2	41.00944	28.65986	141.5022	7
3	41.02828	28.69562	68.6096	6
4	40.98781	28.72255	86.24174	7
5	40.98661	28.78823	53.21566	7
6	40.9943	28.79487	62.66478	7
7	41.01913	28.70347	101.151	6
8	40.98538	28.78006	45.18151	7
9	40.98656	28.77104	6.255881	7
10	40.98838	28.77263	4.910122	7
11	40.95709	28.8225	2.490139	8
12	40.96272	28.82487	14.94113	8
13	41.06398	28.80444	67.73499	6
14	41.03689	28.98507	77.44993	7
15	41.02005	28.68759	130.399	7
16	41.00905	28.98022	36.99921	7
17	41.01158	28.97479	39.01994	7
18	41.01605	28.97675	1.999988	7
19	41.10793	29.0058	79.33485	6
20	41.00341	28.68726	53.39499	8

By means of data analysis tool in Microsoft Excel, the covariance and autocorrelation of the data can be displayed as Table 2 and Table 3.

***Table 2**. The provided covariance matrix*

	Latitude	Longitude	Altitude	Temperature
Latitude	0.001102056			
Longitude	0.001269322	0.012133545		
Altitude	0.550961771	-1.728845581	1525.566595	
Temperature	-0.015204706	-0.003956919	-9.148377445	0.4

A positive covariance indicates that both variables frequently exhibit high or low values together. While two variables have a negative covariance, they are often low while one is high.

***Table 3.** The provided autocorrelation matrix*

	Latitude	Longitude	Altitude	Temperature
Latitude	1			
Longitude	0.347117057	1		
Altitude	0.424916853	-0.401834079	1	
Temperature	-0.724179301	-0.056798028	-0.370338185	1

The coordinate system utilized here is GCS WGS 1984. The following map (Figure 4) is produced by choosing Kriging in the spatial analyst tool in Arctoolbox's interpolation option using both altitude and temperature.

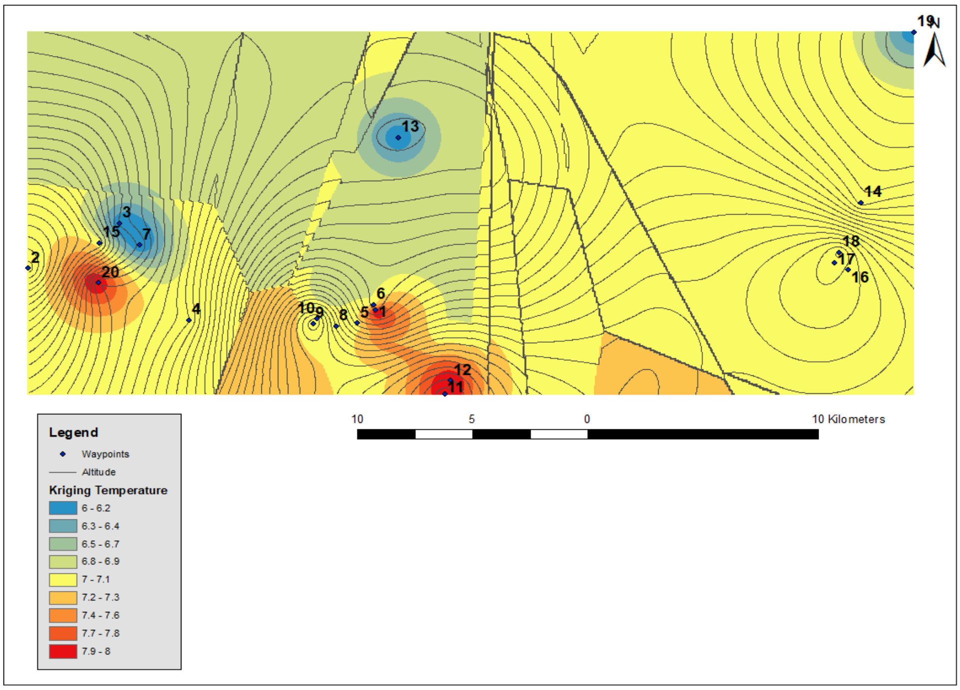

Figure 4. *The environmental temperature map of kriging interpolation*

The resulting semivariogram (Figure 5) is then displayed using the geostatistical wizard function in ArcMap. Before applying kriging to the graph, a semivariogram associated with the attribute table is necessary. The necessary factors for creating a semivariogram include Lag number, Lag distance, Angle, and Frequency, among others**.**

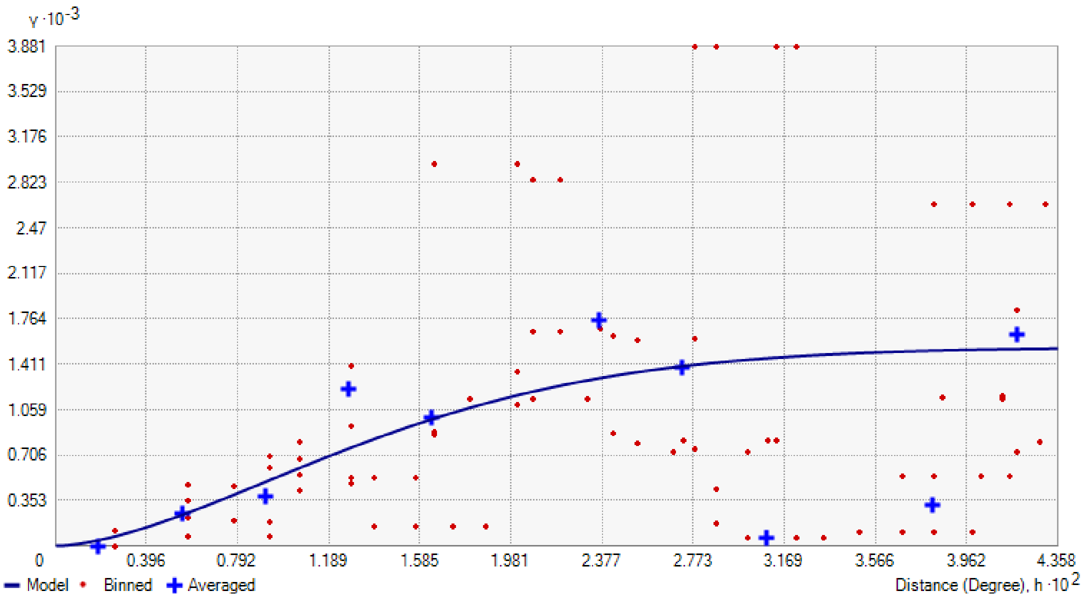

Figure 5: *Altitude variation in Istanbul semivariogram*

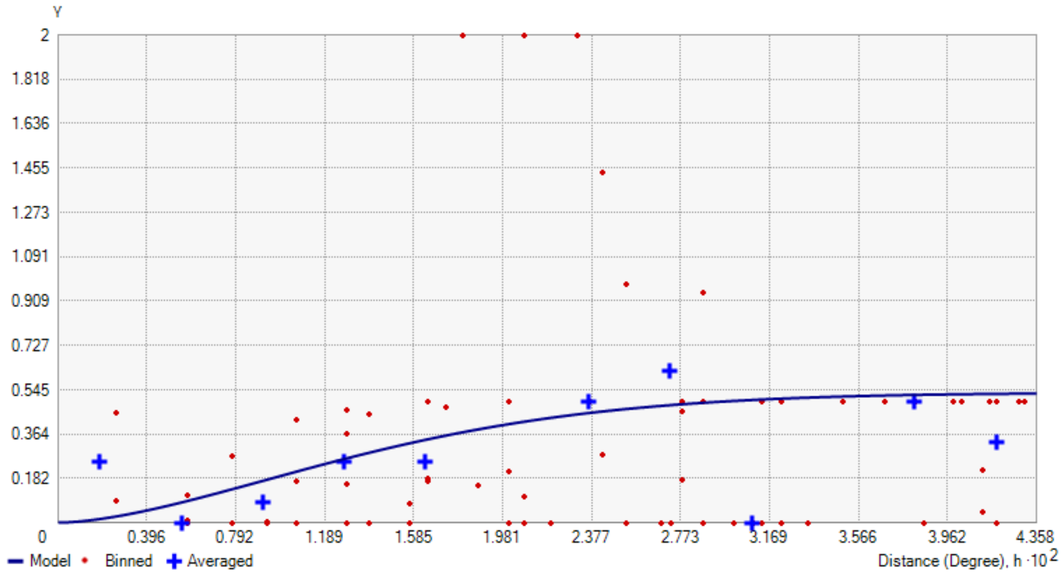

Figure 6: *Temperature variation in Istanbul semivariogram*

Semivariogram can be completed, and then ordinary kriging can be used. Therefore, the maps would be colored differently depending on the sample values. The maps after kriging are displayed below:

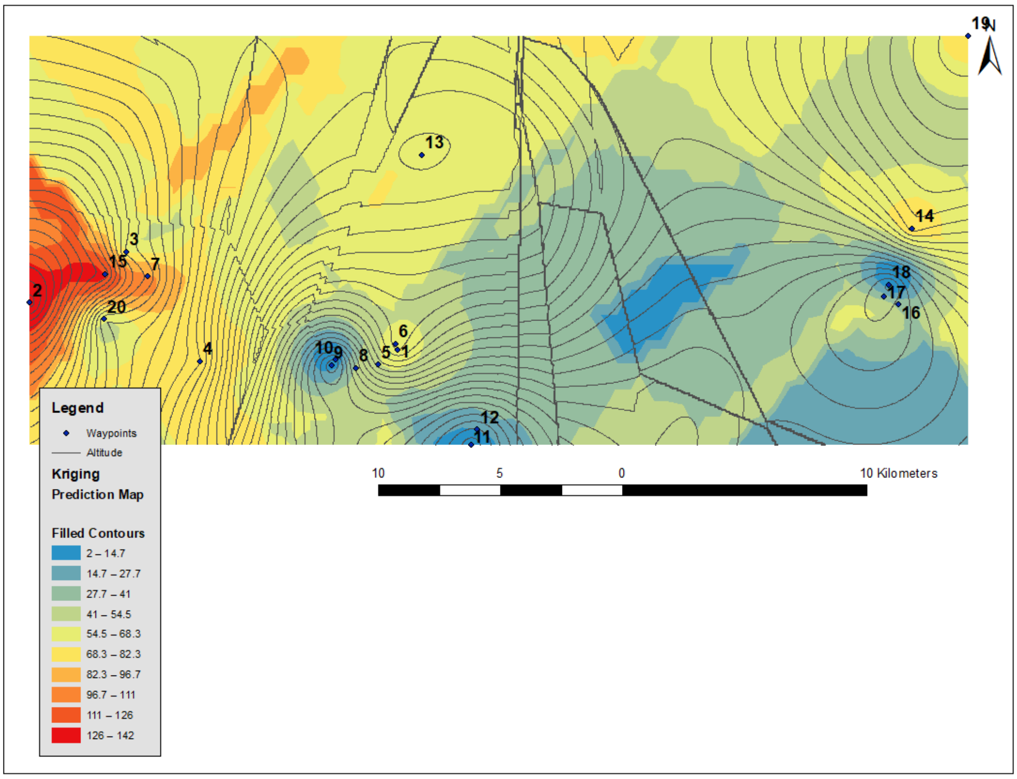

Figure 6. *Altitude variation in Istanbul (Ordinary Kriging)*

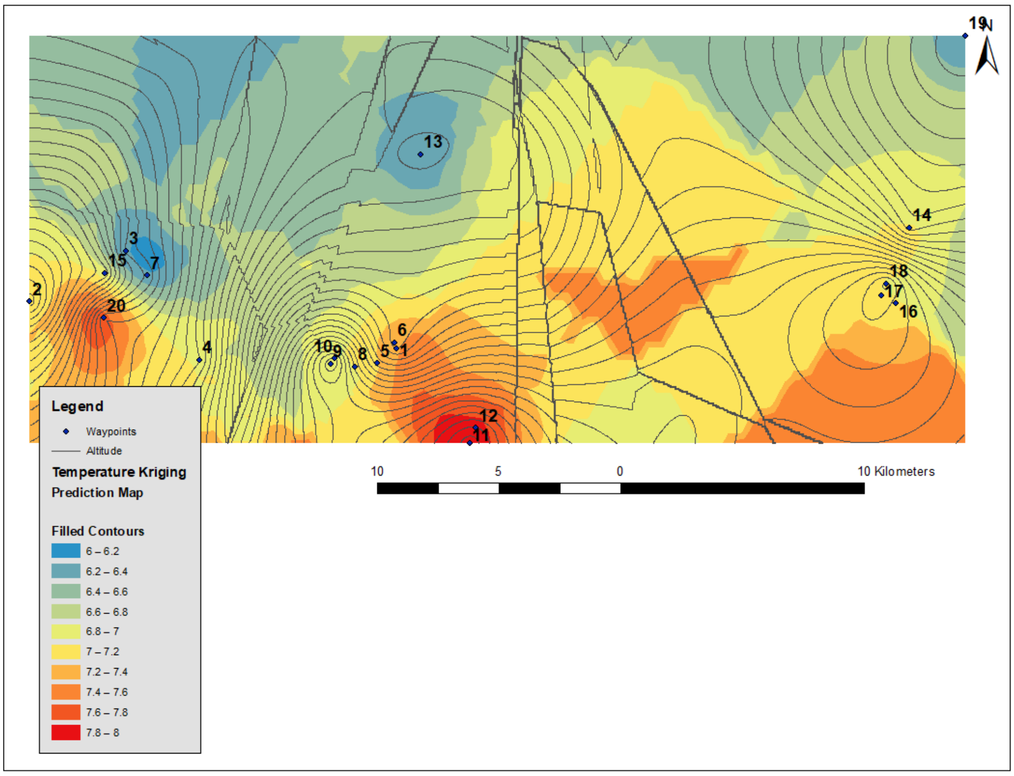

Figure 7. *Temperature variation in Istanbul (Ordinary Kriging)*

In Figure 6, the red area denotes high-altitude lands, meanwhile, the blue area indicates a low-altitude region that is simply close to the water and approximately near sea level.

With these results, as Dewata and Putra (2021) revealed, this method is useful to investigate the earth's surface to develop maps and analysis for decision makings in engineering and environmental topics. This software is one of the greatest solutions to reach this goal. As it is shown, by means of ordinary kriging GIS can make a prediction for all over the selected land based on the given database. The necessary and sufficient condition for this approach is possible by having the semivariogram of the project.

The visualized surface demonstrates X, Y, and Z positions along with topographic 3D projections. The spatial approach using different methods can provide a smooth map of the variogram and spatial query even though these techniques are relatively undeveloped (Paramasivam & Venkatramanan, 2019).

A highly accurate interpolation technique is kriging. The best estimator, which is linear and free of systematic variations, is the kriging approach. Nowadays, investigations involving geographical analysis typically use the kriging interpolation approach (Uyan & Dursun, 2021). Regression kriging is a very effective method for spatial interpolation, and findings from related investigations confirm this claim. (Meng et al., 2013).

4. CONCLUSION

As a matter of conclusion, this study has shown that GIS could be a quite helpful tool for many scientific purposes in engineering, decision making, planning, and many other engineering and management branches. Moreover, in the discuccion section, this study has covered ordinary kriging which is a highly accurate interpolation technique by means of gathered data and predicting the Z-value for a set range of locations and performing it with the use of provided semivariogram by the geostatistical wizard and having a map showing the latitude range as the result of this analysis.

GIS methodology provides considerable skills in the study of engineering and developing maps in locations that humans cannot easily have access to. This software is a powerful technique for transforming spatial changes into an understandable form that can be used for other connected objectives.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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