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Variation in Accuracy of Temperature Maps Produced Using Geographic Information Systems

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Abstract: Isopleth maps are one of the most important cartographic methods used by the geographer to represent temperatures, whether by using equal temperature lines only, or by shading the areas confined between those lines with shadows or color in red. The Spatial Analysis Tools in the Geographic Information Systems (GIS) program provided the possibility of producing high-accuracy maps by representing the data of several climate stations covering the area of the studied region, relying on spatial interpolation methods.

But the problem appears: there is a discrepancy in the accuracy of the maps produced by adopting these methods, due to the discrepancy in the number of climate stations that cover the area of the studied area. The greater the number of climate stations, the more accurate the map is, and vice versa, or because of the irregularity of the distance between those stations and the pattern of their distribution. Or there is a lack of temperature data for some stations, and this was observed when producing temperature maps for Diyala Governorate as a model.

Keywords: Isoplithic Maps, Spatial Analysis, Spatial Interpolation, Temperature Maps, Map Accuracy.

1. Introduction:

Temperature is one of the most crucial elements of climate that influences the distribution of water on Earth's surface. All other climatic elements are closely related to it. Understanding and studying temperatures requires distributing them across the Earth's surface using lines of equal temperature, which connect points (locations) where the average temperatures are the same. These maps are called isotherm maps.

Geographic Information Systems (GIS) aim to present and convey spatial information that is difficult to communicate through numbers or objective texts. Therefore, two interconnected concepts of accuracy and effectiveness in data representation cartographically have emerged. The first concept focuses on the accuracy of representation and spatial signature of temperature data, while the second concept focuses on the cartographic representation's ability to convey diverse spatial information for which the map was designed. Hence, this study focuses on evaluating the variability in the accuracy and effectiveness of these maps, in addition to assessing the efficiency of GIS in designing maps using various methods.

The Question of the Artical is revolve around discrepancy in the accuracy of the temperature maps produced using spatial interpolation methods provided by the spatial analysis tools in the geographic information systems program.

The hypothesis of study concerning about the accuracy of temperature maps produced by adopting spatial interpolation methods varies due to the variation in the number of climate stations that cover the area of the study area or the irregularity of the distance between those stations and the pattern of their distribution.

The Artcal’s objectives are:

1. Statement of the best methods for drawing temperature maps.
2. Comparison between different Interpolation Methods provided by spatial analysis tools in Geographic Information Systems (GIS).
3. Explanation of the variation in the accuracy of temperature maps produced by different spatial interpolation methods.

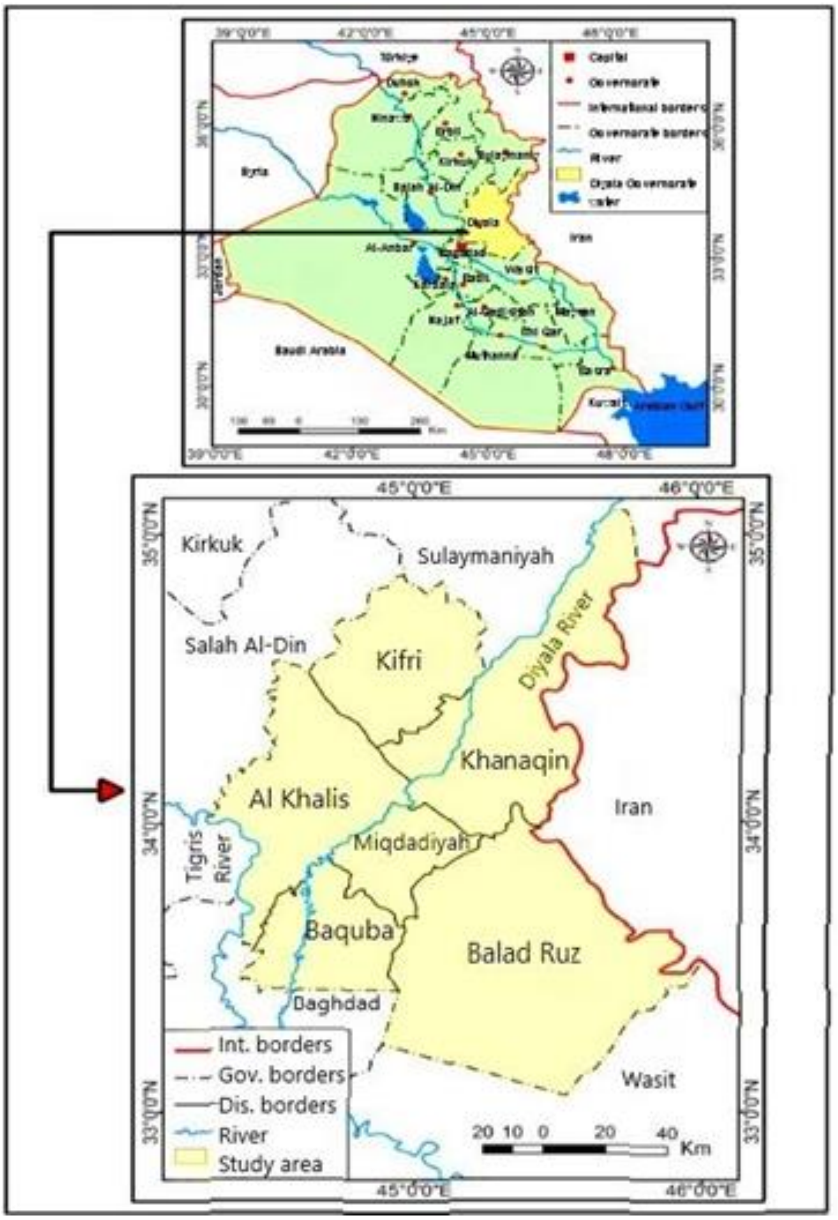
The study area is represented by Diyala Province, which has an area of 17,685 square kilometers. It is located in the central region of Iraq, east of the Tigris River. The district center is 58 kilometers north of Baghdad. Geographically, it lies between the latitudes of 33°3'6.11"N and 35°5'16.39"N, and the longitudes of 44°16'27.98"E and 46°1'19.82"E. It is bordered to the north by Sulaymaniyah and parts of Salahuddin, to the south by Wasit, to the east by the international border between Iraq and Iran, and to the west by Baghdad Governorate (Map 1). The temporal boundaries for the research are represented by the period from 2012 to 2022. The study relied on two primary climatic stations, Al-Khalis and Khanqin, and the reference station, Tuz Khurmatu (Table 1, Map 2), to represent the Diyala Province study area. Climate data were collected, tabulated, and averages calculated, then inputted into the geographic database.

Table (1) Climate monitoring stations in the study area in terms of location and altitude

Station	The latitude is north	East longitude	Height above sea level/m
Sincere	° 50¯ 33	° 32¯ 44	44
Khanaqin	° 35¯ 34	° 38¯ 45	202
Tuz Khurmatu	° 53¯ 34	° 39¯ 44	220

Source: *Republic of Iraq, Ministry of Transport and Communications, General Authority for Meteorology and Seismic Monitoring, Climate Department, coordinates of climate station locations, (unpublished data), Baghdad, 2023*.

Map No. (1) Location of the study area in Iraq and Diyala Governorate



Source: *From the work of researchers based on the program (ARC GIS 10.8.4)*

2. Temperature Maps:

Temperature is referred to as one type of energy that transfers to the atmosphere from the sun, either directly or indirectly (Furhan, 2009). Temperature maps, on the other hand, depict the geographical distribution of temperatures (maximum, minimum, average) in a specific area or part of the area during a defined period. They are a type of climatic map that focuses on the cartographic representation of climate elements' data and averages (daily, monthly, seasonal, yearly) on the map using specific symbols for a particular time, which could span a month, a season, a year, or a group of years (Sattari, 1972).

Isopleth maps (Isotherms) are one of the most important cartographic methods used by researchers in preparing temperature maps. Isotherms are imaginary lines that connect specific and predetermined points representing selected climatic stations. They are based on monthly, seasonal, or yearly temperature data. Additionally, Relative shading or choropleth maps and density maps can be used to shade or color the areas enclosed between the isothermal lines with shades or gradients of colors. The use of red colors can be employed to illustrate the geographical distribution of temperatures. Moreover, various graphical representations such as bar charts, line graphs, or a combination of both can be utilized to represent temperature data

(Altaie, 2024). Bar charts are one of the simplest types of graphical representation for monthly, seasonal, and yearly temperature averages.

Temperatures can be divided according to the period of their data into:

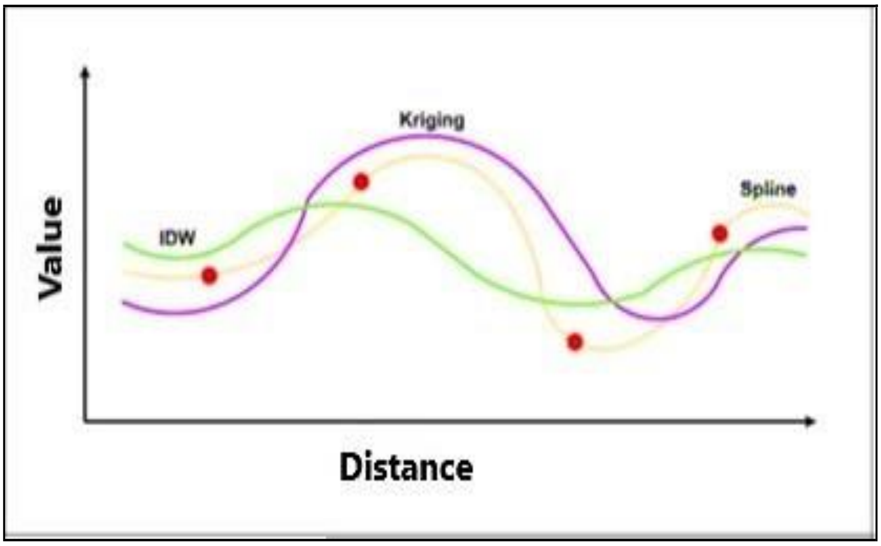
1. Annual temperature average maps: These maps illustrate the geographical distribution of annual averages or means of temperature (maximum, minimum, or average) in a specific area or part of it during a specified period. They can be drawn using isothermal lines or spatial shading, or a combination of both.
2. Seasonal temperature average maps: These maps depict the geographical distribution of seasonal averages or means of temperature (maximum, minimum, or average) in a specific area or part of it.
3. Monthly temperature average maps: These maps illustrate the geographical distribution of monthly averages or means of temperature (maximum, minimum, or average) in a specific area or part of it .

In this research, annual rates will be adopted to produce temperature maps for Diyala Governorate.

3. Producing temperature maps using spatial interpolation methods:

Spatial Analysis Tools in Geographic Information Systems (GIS) have provided the capability to produce temperature maps and represent them with high accuracy. This is achieved by representing climate station data using spatial interpolation methods (Interpolation Methods), which estimate or derive values for other climatic points based on the values recorded within the study area boundaries using statistical and computational techniques. Subsequently, these points are automatically connected with isothermal lines, or a set of gradients or shades is used to represent the density within the area enclosed by the isothermal lines. The more actual climate stations there are in the study area, the more accurate the map becomes (Sharaf, 2011). There are numerous spatial interpolation methods available in GIS software, as illustrated in Figure (1), each based on different statistical and mathematical equations to produce various temperature maps. These methods rely on the Z. Value Field, representing temperature values, whether monthly, seasonal, or yearly averages. It's up to the researcher to choose the method that best suits their study data. The most important interpolation methods include (Al-Janabi, 2022):

Figure (1) Spatial interpolation surfaces



Source: *Firas Kamel Al-Janabi, Spatial Data Interpolation Techniques and Their Applications in Map Production, 1st edition, Al-Sahaf Publishing and Distribution Press and House, Turkey, 2022, p. 18.*

1. **Kriging method:**

One of the most important interpolation methods that enhances the spatial relationship between samples for predicting values at un-sampled locations is Kriging. Kriging is an advanced statistical-geographical procedure that generates an estimated surface from a set of random points and known values. This type of interpolation is based on mathematical functions obtained from the Semivariogram. When efficiently implemented through the Kriging method, it ensures achieving spatial autocorrelation of the phenomenon represented by the sample values in creating the spatial interpolation surface. The Kriging method assumes that the direction or distance between sample points reflects a spatial correlation that can be used to explain the variation in the surface. Regarding the mathematical model of the Kriging method, it is like the Inverse Distance Weighting (IDW) method. It calculates the weights of the surrounding known values for prediction and derives unknown points. The mathematical model of the Kriging method is depicted in the following figure.

Since:

$$Z\,(So) = \sum_{I}^{N} = 1\ \gamma i\ Z\,(Si)$$

Z(si): It refers to the measured value at location i: yi.

W: Unknown weight for the measured values at location i: Si So: Prediction location

N: Number of measured values

2. **Inverse Distance Weighted (IDW) method:** One of the spatial interpolation methods used to estimate unknown values at specific locations is based on using known values along with corresponding weighted values. It relies on the distance between control points (meteorological stations), where the influence decreases as the distance increases. Conversely, the influence increases as the distance decreases. Hence, this method is called "Inverse Distance Weighted" (IDW). Isopleths of climatological data are drawn between recent points without passing through the primary control points. Using the inverse distance weighted method (IDWconstant), which was introduced in 1968 by Shepard, the weighted average of points and the distance between them are utilized. This method is commonly employed in meteorological monitoring stations, is easy to implement, and the mathematical model for the IDW method is represented as follows:

Since:

Z(Xo): Represents the studied barometric value at the unsampled location. Z(Xi): Represents the studied barometric value in the sampled area.

Wi: Represents the weight associated with each location in the sampled area.

The concept of weight entails assigning specific weights to points when calculating the center average. These weights are not solely based on the distance between points but also rely on the

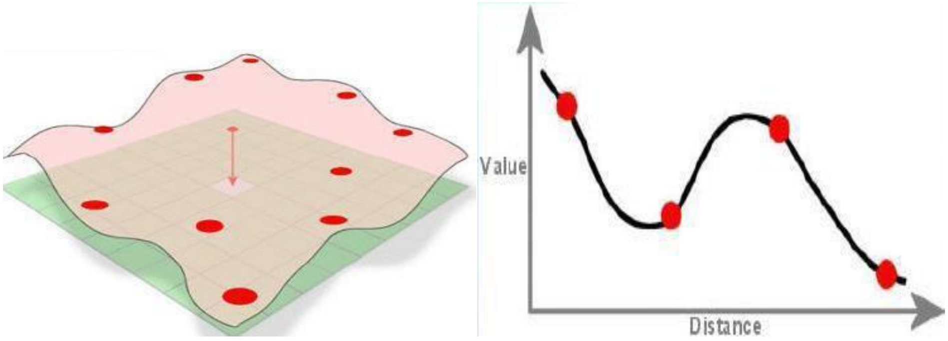
$$Z(Xo) = \sum_{i-1}^{n} Wi\,.\,Z\,(Xi)$$

spatial distributions of the points, known as autocorrelation. The weights are calculated as follows:

Wi represents the weight associated with each location in the sampled area, where ∑

(i=0 ton) Wi = 1. This means that the sum of the weights for all points equals one.

Figure (2) How to calculate point weight.



3. Spline method :

One of the spatial interpolation methods used in climatological studies is Kriging. It is employed to interpolate monthly and yearly data efficiently. However, its effectiveness diminishes when representing hourly or daily data. In cases of missing data points, it relies on mathematical equations where it passes through all points. The primary objective of this method is to minimize surface fluctuations in general.

The mathematical model of the Spline method is expressed as follows :

$S\ (x, y) = T\ (x, y) + \Sigma\ \mathrm{Yj} R(rj)$

Since:

J = 1, 2, ..., N: j ranges from 1 to N.

N: The number of points.

YJ: The equations obtained by solving the system of linear equations.

rj: The distance from point (X, Y) to point j.

In this study, the Kriging method was chosen to produce two models of isothermal lines and relative shading maps for Diyala Governorate using the Geographic Information System software ARC GIS 10.8.4. This was done for the purpose of comparing their accuracy according to the research hypothesis based on the number and distribution pattern of climatic stations in the study area. Annual averages of normal temperatures were relied upon. These maps are among the most important in geographical studies because they illustrate the overall average temperature, derived by dividing the sum of the minimum and maximum temperatures by 2. The models are:

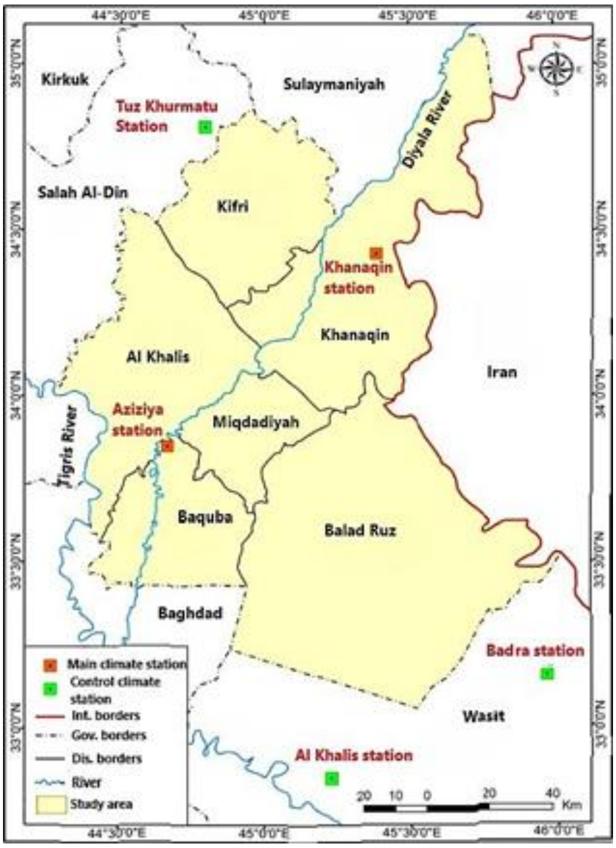
1. **The first model:** Maps of the annual averages of normal temperatures are based on actual climatic monitoring station data for the province, namely Al- Khalis and Khanqin, with the control station being Tuz Khurmatu, for the period from 2012 to 2022. Please refer to Table (2) and Maps (2) and (3)

Table (2) Annual averages of normal, maximum, and minimum temperatures for the climate stations adopted in the research for the period.)2022-2012(

Stations	Annual rates		
	Ordinary	Great	Minor
Khalis	23.21	31.64	15.37
Khanaqin	24.29	32.91	17.10
Tuz Khurmatu	22.54	30.09	16.61

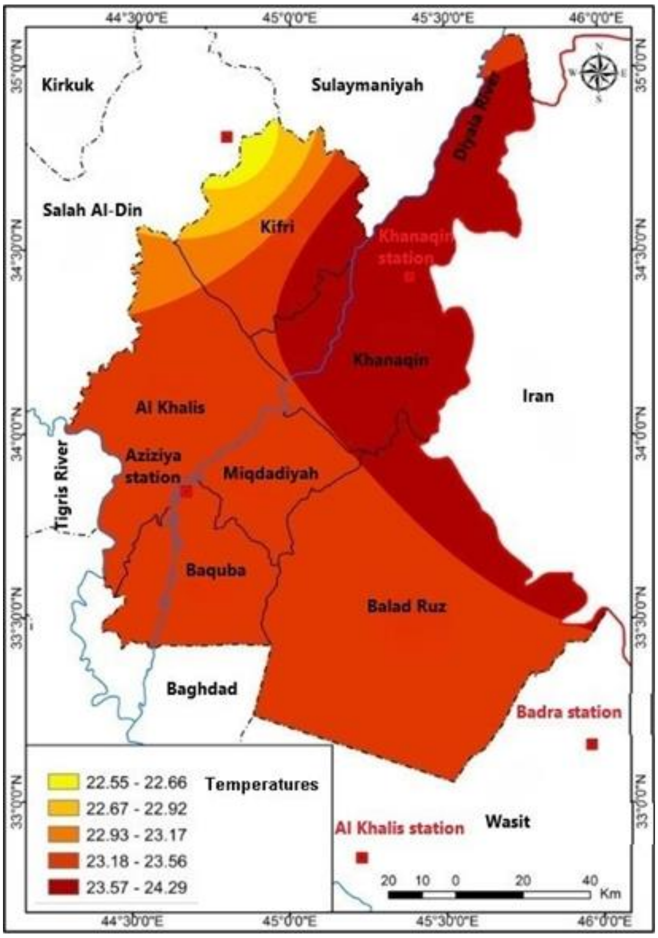
Source: *Republic of Iraq, Ministry of Transport, General Authority for Meteorology and Seismic Monitoring, Climate Section, unpublished data, 2023.*

Map (2) Location of actual and control climate monitoring stations for Diyala Governorate



Source: *Researchers: Table (1) based on the ARC GIS 10.8 program.*

Map (3) Annual averages of normal temperatures based on actual and control stations.



Source: *Researchers, Table (1) based on the program (ARC GIS 10.8.4)*

1. **The second model:** The map of annual averages of normal temperatures relies on data from (15) virtual climatic stations selected from the Power database, affiliated with the US space agency NASA. These stations are evenly distributed across the study area using ARC GIS 10.8.4 software. The data spans from 2012 to 2022. Please refer to Table (3) and Maps (4) and (5).

Table (3) Annual average temperatures (normal, maximum, minimum) for selected space climate stations

Station	Normal temperature	Great heat	Minimum temperature
1	24.5	37.47	12.67
2	24.5	37.47	12.67
3	24.1	36.36	13.02
4	23.79	36.96	11.82
5	24.24	36.72	12.94
6	24.24	36.72	12.94
7	22.09	34.39	11.12
8	23.58	36.25	11.96
9	23.42	35.94	12.14
10	23.42	35.94	12.14
11	21.57	34.61	10.43
12	20.96	33.52	9.8
13	20.96	33.52	9.8
14	20.34	33.24	8.73
15	17.24	30.87	5.74

Source: *From the work of the researcher, based on monthly data taken from the NASA website.*

4. Valuating the accuracy of the maps produced:

Spatial interpolation maps represent the outcome of geographical data, offering a degree of cartographic generalization. They serve to compare real-world phenomena with expected values. Generalization introduces statistical errors when there's a mismatch between reality and model representations of the phenomenon. Despite the existence of spatial statistical tools like Cross-Validation for spatial interpolation processes, map accuracy depends on the number of points (in our case, the number of climatic stations). The more climatic stations there are, the better the model represents reality, reducing generalization. Additionally, the distribution pattern of these climatic stations and the distance between them affect the true representation of the studied phenomenon and consequently its accuracy and coverage area.

1. In this study, we will rely on these criteria: the number of climatic stations, their distribution pattern, and the coverage area, to compare the accuracy of the temperature maps produced for Diyala province using spatial interpolation methods. We will adopt the optimal approach to investigate the accuracy of these maps based on these three criteria using the Average Nearest Neighbor method, also known as nearest neighbor analysis. This quantitative method is used to study point patterns on the Earth's surface (King.c1968). It is one of the few measures that rely on a continuous global standard for point distribution. This method analyzes the number of points (i.e., climatic stations), the distances between points, and the area of the studied region:
2. Calculating the number of points (climatic stations).
3. Calculating the area of the region (Diyala province).
4. Measuring the actual distance between climatic stations (i.e., the distance between the geographical location of one climatic station and the nearest station to it), then calculating the average distance between all stations by dividing the sum of distances between stations by the number of stations.

5. Calculating the density of station distribution (amount of stations / area of the province).
6. Calculating the Average Nearest Neighbor using the following mathematical formula: (Al-Atbi, 2013).

$$\sqrt{n/s}\dot{D}\ C = 2 *$$

Since:

C = Neighborhood index (nearest neighbor criterion)

Ḋ = Average true distance between points in the distribution n = Number of points (climate stations)

s = Area of the studied area

From the value of the neighborhood index (R), which represents the nearest neighbor criterion in the previous equation (C), the distribution pattern of the climate stations can be determined. The nearest neighbor criterion ranges from zero to more than 2. A clear and specific meaning is implied by the value indicating the distribution pattern. If the nearest neighbor criterion equals zero, it indicates high clustering. If the value equals 2, the pattern is considered perfectly regular. If the value exceeds 2, it implies high dispersion and scattering. Refer to Table.)4(

Table (4) Guide to the nearest neighbor criterion

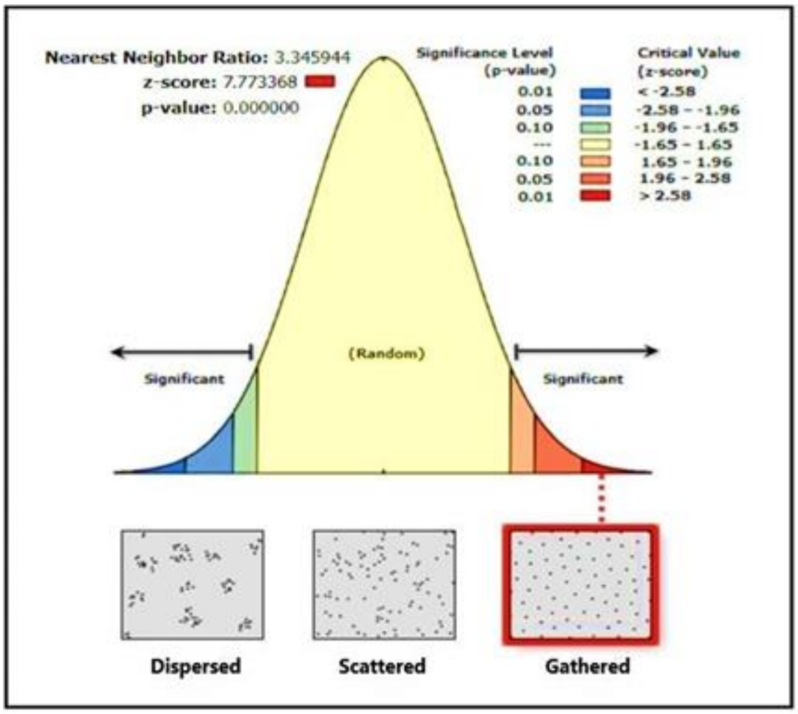
Distribution pattern	The value of the nearest neighbor criterion (R)
Convergent irregular	Zero
Convergent towards randomness	0 – 0.5
Random	0.5 - 1
Far apart in distance	1 – 2
Regular tends to be square in shape	2
Regular tends to be hexagonal	Greater than 2

Source: *Hammoud. R&Mccullagh. P,"Quantitive techniques in Geography. An Introduction", 2nd ed, Clorendon Press, Oxford, 1973, P .271.*

Based on the distribution pattern, the accuracy of the maps produced can be verified using spatial interpolation methods.

By applying this method to the first model, the temperature map based on actual climate stations and the three reference stations (Khalis, Khanqin, Tuz Khurmatu), the value of the nearest neighbor criterion (R=3.345944) was obtained (see Figure 2). Comparing this result with the nearest neighbor criterion guide in Table 3 reveals that the distribution pattern of these climate stations was scattered, dispersed, and irregular. As the coefficient value exceeds 2, the dispersion and scattering increase. Consequently, this map is less accurate and less representative of the actual temperature distribution in Diyala province.

Figure (3) Results of the nearest neighbor factor analysis for the first model



Source: *Researchers using ARC GIS.*)10.8.4

As for the second model, the temperature map based on the satellite climate stations (15) provided by NASA and distributed by the software, the value of the nearest neighbor criterion for the selected climate stations was (R=2.070978) (see Figure 3). Comparing this result with the nearest neighbor criterion guide in Table 3 reveals that the neighborhood relationship for the climate stations in this map has taken on a regular and ideal distribution pattern. This means that this map is more accurate and representative of the actual temperature distribution in Diyala province.

5. Conclusions:

- There are several cartographic methods for representing temperature, but isopleth maps, especially when combined with choropleth maps to shade or color the areas enclosed by isopleths or with graduated colors, are the most important and effective of these methods.
- Spatial analysis tools in Geographic Information Systems (GIS) software provide the capability to produce temperature maps and represent them with high accuracy.
- There are many interpolation methods in GIS software, each based on different statistical and mathematical equations to produce various maps of temperature.
- The cartographic model becomes more representative of the real world and more accurate, reducing generalization, as the number of climate stations increases.
- The second model of temperature maps, specifically the maps of annual temperature averages based on satellite climate stations, is more accurate and representative of the temperature distribution in Diyala province. This is because it has more stations, and their distribution is more uniform and ideal, as shown by the results of the nearest neighbor criterion.

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