Production of Digital Climatic Maps Using Geostatistical Techniques

Hussain Zaydan Ali

Ministry of Science and Technology-Baghdad-Iraq

hussainzayali53@yahoo.com

Saad H. Farraj

Iraqi Meteorological Organization and Seismology-Iraq

Abstract:

There is an increasing demand for girded datasets of climate variables from fields such as hydrology, ecology, agriculture, climate change research and climate model verification. The girded climate data sets developed are very suitable for digital data storage and access. The temperature is the most important climatic elements. It effects on the various human activities. There is a mutual relationship between temperature and climate. It is the base motivation engine for the rest of the climate elements. Consequently this paper attempted to make spatial interpolation, of annual and monthly maximum temperature in Iraq for the period from 1970 to 2010 using spatial geostatistics tools in ArcGIS Version 9.3. This paper presents a methodology to produce accurate climatic maps. Validation of produced maps was examined by different criteria.

Keywords: Geographic information system, Geostatistical analyst, Kriging, Temperature.

إنتاج خرائط المناخ الرقمية باستخدام التقانات الجيواحصائية

حسين زيدان علي

وزارة العلوم والتكنولوجيا – بغداد – العراق

سعد حلبوص فرج

الهيئة العامة للأنواء الجوية والرصد الزلزالي – العراق

الخلاصة:

يوجد طلب متزايد على مجاميع البيانات الشبكية للمتغيرات المناخية من حقول المعرفة المتعددة مثل الهيدرولوجي ،علم البيئة ،الزراعة ، بحوث التغيرات المناخية ،والتحقق من موديلات المناخ. إن مجاميع البيانات المناخية الشبكية المطورة تكون مناسبة للغاية لأغراض خزن البيانات الرقمية والوصول إليها ، و تعد درجة الحرارة أكثر عناصر المناخ أهمية بسبب تأثيرها على النشاطات البشرية المختلفة. توجد علاقات متبادلة بين درجة الحرارة والمناخ لكونها المحرك الأساس لبقية عناصر المناخ و نتيجة لذلك فان البحث الحالي يحاول أن يعمل استنباط مكاني لمعدلات درجة الحرارة العظمى الشهرية والسنوية بالعراق للفترة من 1970 ولغاية 2010 باستخدام الأدوات الجيواحصائية المكانية في برنامج ArcGIS النسخة 9.3 . يقدم هذا البحث طرائق لإنتاج خرائط مناخ دقيقة، وقد تم تدقيق الخرائط المنتجة باختبار معايير مختلفة.

كلمات مفتاحيه : نظام المعلومات الجغرافي،المحلل الجيواحصائي، kriging، درجة الحرارة.

INTRODUCTION:

Estimates of the spatial distribution of climatic variablesare required more than ever for sustainable management of natural resources. Determining spatial climateconditions, however, is not easy, because long-term average weather observations come from sparse, discreteand irregularly distributed meteorological stations. These discrete data has been extended spatially to reflectthe continuously and gradually changed climate pattern. Climate monitoring requires an operational analysis of the variability of climatic quantities in space and time. For this purpose, operational maps generated for regular time intervals (days, months, seasons, years) It is very useful to see at a glance the spatial variability of climate elements and change with time. Such maps are often used by national meteorological and hydrological services as a basis for climate reviews and interpretation of outstanding features of climate variability. Maps have been available for various spatial areas from the catchment scale to the whole globe. Usually, maps are a result of gridding or spatial interpolation of point data into the area. Nowadays, a large variety of mathematical and geostatistical methods for spatial interpolation is available. The choice of the gridding method depends on the selected area and the selected climate element as well [1 - 3]. Spatial climate mapping is a basic application of thedata sets. Climate distribution can be characterized and displayed cell by cell using GIS, then converted andsaved in a computer-based photograph format for further view. A large number of papers dealing with spatial interpolation of climate data have already been published and an overview of spatial interpolation methods and their application in climatology by GIS software, and many related papers [3 - 6]. More attention has been given to the application of interpolation techniques to climatic analysis in recentyears.Several interpolation approaches are available in geographical information systems (GISs) to meet the generalrequirements of interpolation. Several interpolation approaches have been used for spatial climatic analysis [7 – 9]. This paper refers specifically to spatial interpolation of monthly maximum temperature for the period 1970 to 2010. The main goal of this paper is to propose an optimal method of spatial interpolation of monthly maximum temperature data, and to examine the validity of the produced maps by calculating different criteria.

MATERIALS and METHODS

The maximum temperature was computed using data from Iraqi meteorological organization and seismology, climate department for different period of different stations extended from 1970 to 2010 divided to 3 stages each one extend to 30 years excepts third one cover 20 years. Missing value for any monthly mean was substituted by the mean of maximum temperature for the same periods. The original data is in whole degree centigrade and is computed to tenth of a degree centigrade. The mean monthly value was computed by taking the 30years mean of the monthly means. The monthly means were computed from the daily values of maximum temperature. The mean annual value was computed by taking 30 years mean of the yearly means. The yearly means were computed by averaging their 12 monthly mean values. Three periods were covered; from 1970 to 2000, from 1980 to 2010, and the third period from 1990 to 2010. Due to non-availability of abundant measurement points, reliable estimation of temperature distribution poses a great challenge.

The spatial interpolation prediction techniques (like spline, inverse distance weighting and kriging) provide better estimation of temperature than conventional methods [10 – 11]. There is'nt single preferred method for data interpolation which can meet with the selection criteria of required level of accuracy, the time and/or computer resources etc. The common approach to select the optimal spatial interpolation method has become the focus. To determine the validity of interpolated temperature maps by using statistical criteria and subjective comments.Various spatial and statistical tools were used to display and analyze trendsin temperature data. In this paper ArcGIS has been used to produce the spatially distributed temperature data by using Kriging method.

3 - Kriging Theory:

The presence of a spatial structure where observations close to each other are more alike than those that are farapart (spatial autocorrelation) is a prerequisite to the application of geostatistics. The experimentalvariogram measures the average degree of dissimilarity between unsampled values and a nearby data value, and thus can depict autocorrelation at various distances [9 , 12].

The value of the experimental variogramfor a separation distance of *h* (referred to as the lag) is half the average squared difference between the value at *z* (*xi*)and the value at *z* (*xi* + *h*)[6]:

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2 \quad (1)$$

Where *N* (*h*) is the number of data pairs within a given class of distance and direction. If the values at *z* (*xi*) and *z* (*xi* + *h*)are auto correlated the result will be small, relative to an uncorrelated pair of points. From the analysis of theexperimental variogram, a suitable model (e.g. spherical, exponential) is then fitted, usually by weighted least squares,and the parameters (e.g. range, nugget and sill) are then used in the kriging procedure.

4 - Fitting a variogram model**:**

The variogram must be expressed as a mathematical function before being used for kriging. This is typically achieved by fitting a suitable function to the experimental variogram. Each function is defined in terms of a small number of parameters that are selected to best-fit the function to the experimental variogram. In this study we use two functions, namely spherical and circular. Below the spherical function adopted, which is defined by[6]:

$$\gamma(h) = \begin{cases} c_0 & \text{when } h = \varepsilon \text{ (a very small lag)} \\ c_0 + c\left(\frac{3h}{2a} - \frac{1}{2}\left(\frac{h}{a}\right)^3\right) & \text{when } 0 < h \le a \\ c_0 + c & \text{when } h > a \end{cases} \quad (2)$$

where c0 is the nugget variance, c+c0 is sill, h is the lag and a is the range. All variograms computed in this study are all fitted with spherical model.

The spherical model is the most commonly used model for experimental data [3 , 6]. This function is expressed in terms of three parameters, namely; a range of spatial correlation, c0 the nugget effect and c1 the sill value. When a variogram is plotted using discrete experimental data points, it is called an experimental or sample variogram. A theoretical model can be fitted through the experimental data points to quantify spatial patterns. The shape and description of a “classic” variogram [8, 13, 14] is shown in Figure (1).

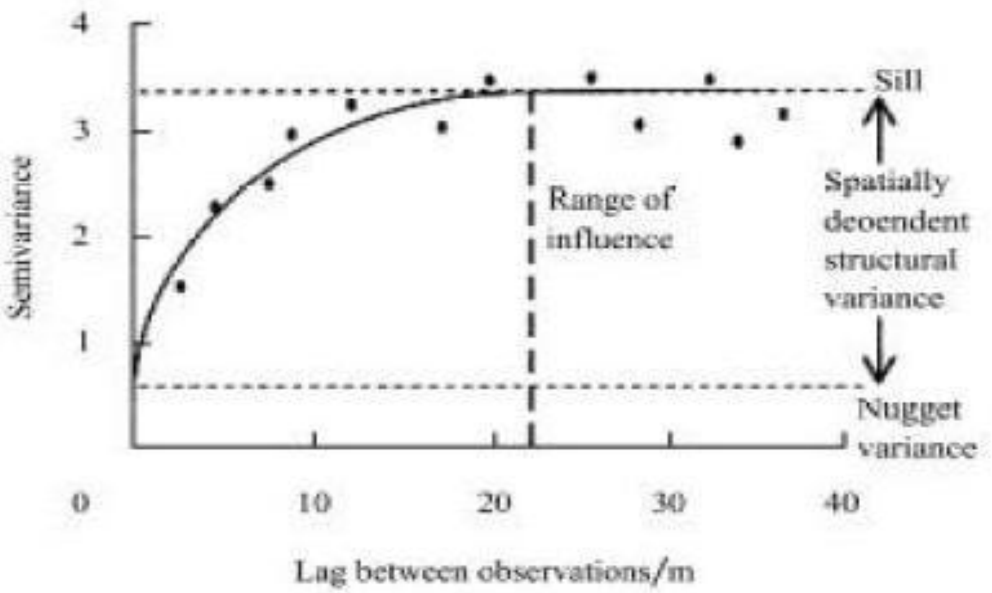

Figure (1): The variogram[6].

There are three key terms in each model, the sill, therange, and nugget variance. The sill corresponds to theoverall variance in the dataset and the range is themaximum distance of spatial autocorrelation. Thenugget variance is the positive intercept of the variogramand can be caused by measurement errors or spatialsources of variation at distances smaller than thesampling interval or both.

5-RESULTS and DISCUSSION:

Figures (2) to (7) shows the maps of maximum temperature obtained from weather stations, produced by applying Kriging interpolation method. The functions used for modeling the variogram are the spherical and circular. The results are shown in the figures below. Two months have been chosen, namely January and July, for the three periods from 1970 to 2010.

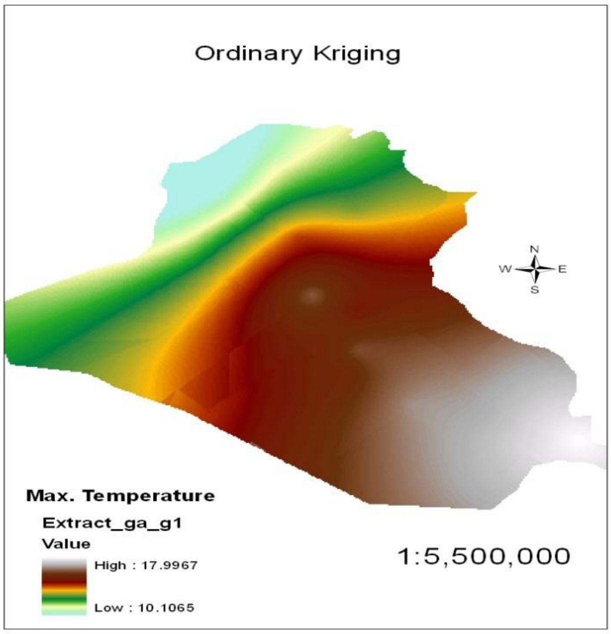

Figure (2): Maximum Temperature, First Period, January, Using Ordinary Kriging, Spherical Model.

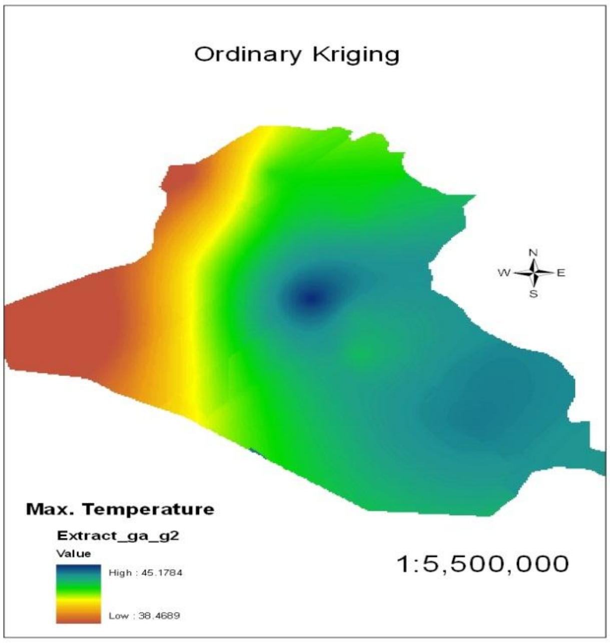

Figure (3): Maximum Temperature, First Period, July, Using Using Ordinary Kriging, Spherical Model.

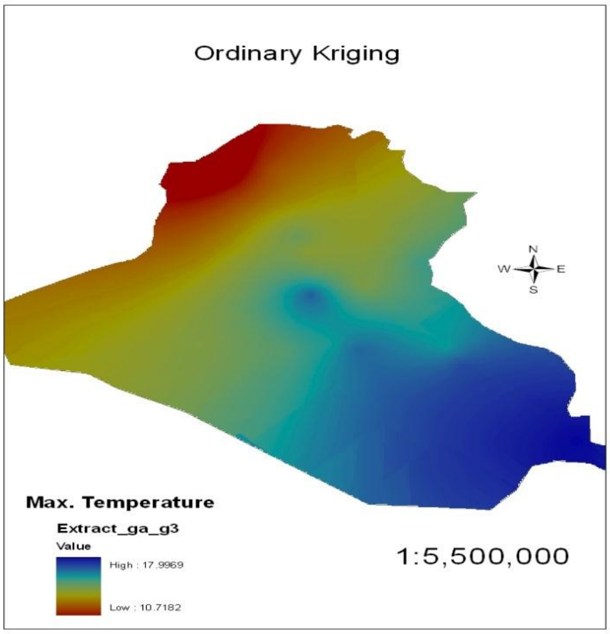

Figure (4): Maximum Temperature, Second Period, January, Using Ordinary Kriging, Spherical Model.

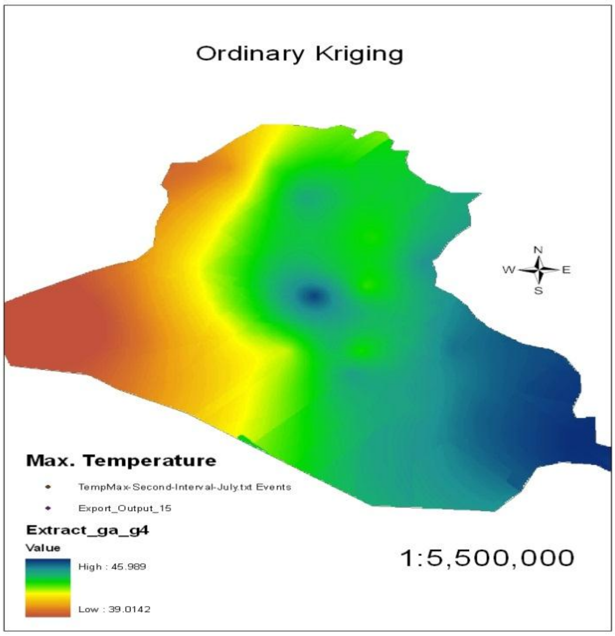

Figure (5): Maximum Temperature, Second Period, July, Using Ordinary Kriging, Spherical Model.

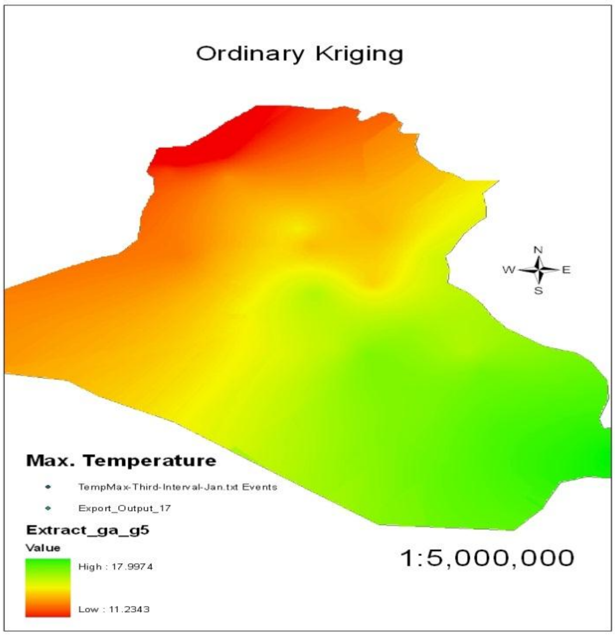

Figure (6): Maximum Temperature, Third Period, January, Using Ordinary Kriging, Spherical Model.

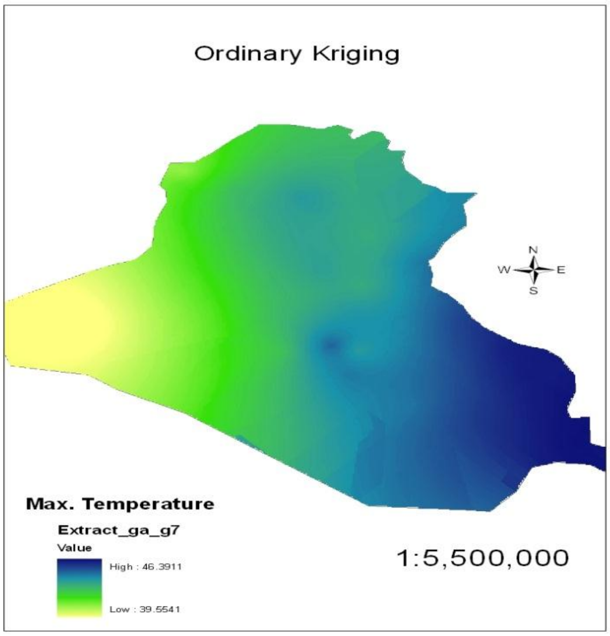

Figure (7): Maximum Temperature, Third Period, July, Using Ordinary Kriging, Spherical Model.

The main goal ofinterpolation is to discern the spatial patterns of maximum temperature by estimating values at unsampledlocations based on measurements at sample points.Geostatistics provides an advanced methodology to quantifythe spatial features of the studied variables and enables spatialinterpolation, kriging. In addition, geographicalinformation systems (GIS) and geostatistics have opened upnew ways to study and analyze spatial distributions ofregionalized variables,distributed continuously on space. Moreover, they have become useful tools for thestudy of hazard assessment and spatial uncertainty.Without a GIS, analysis and management of large spatial databases may not be possible.Since a strong spatial dependence between maximum temperature data is observed, the geostatisticalalgorithms, particularly theordinary kriging, provide accurate estimates.

CONCLUSION:

Creation of digital grid maps makes it possible to obtain climatic information at any point, whether there is a weather station or not. Multiple factors condition the difficulty of map creation, such as the location of the site samples, spatial density, spatial variability etc. Interpolating values of climate variables from measurement stations to large areas istherefore fundamental and requires minimizing the extent of interpolation errors by using a suitableinterpolation method. Given a set of meteorological data, it's possible to use a variety of stochasticand deterministic interpolation methods to estimate meteorological variables at unsampledlocations.

REFERENCES:

1. **B**urrough, P., Mc-Donnell, R. (Ed.). (1998) Principles of Geographical Information Systems. Oxford University Press.
2. Cressie, N., (1985) Fitting VariogramModels by Weighted Least Squares, Mathematical Geology, 17(5), 563-586.
3. Gyalistras D. (2003) Development and Validation of a High-resolution Monthly Gridded Temperature and Precipitation Data Set for Switzerland (1951–2000). Climate Research 25: 55–83.
4. **N**inyerola M, Pons X, Roure MJ. (2000) A Methodological Approach of Climatologically Modeling of Air Temperature and Precipitation Through GIS Techniques. International Journal of Climatology 20:1823–1841.
5. **G**oovaerts P. (1999)Geostatistics in Soil Science. Geoderma 89:1–45.
6. **J**ohnston, K., Ver Hoef, J., M., Krivoruchko, K., and Lukas, N. (2003)Using ArcGisGeostatistical Analyst, ESRI, 300.
7. **Z**hu HZ, Luo TX, Daly C. (2003) Validation of Simulated Grid Data Sets of China's Temperature and Precipitation With High Spatial Resolution. Geographical Research 22: 349–359.
8. **I**saaks, E.,Srivastava, R. (Ed.). (1989) An Introduction to Applied Geostatistics. OxfordUniversity Press.
9. **K**ravchenko, A., Bullock, D. (1999) A Comparative Study of Interpolation Methods for Mapping Soil Properties. Agronomy Journal, 91, 393-400.
10. **W**ahba G, Wendelberger J. (1980) Some New Mathematical Methods for VariationalObjective Analysis Using Splines and Cross-validation. Monthly Weather Review 108: 1122–1145.
11. **W**ebster, R., and M.A. Oliver, (1992) Sample Adequately to Estimate Variograms of Soil Properties, Journal of Soil Science, 43(2), 177-192.
12. **L**ark, R.M., (2002) Optimized Spatial Sampling of Soil for Estimation of the Variogram by Maximum Likelihood, Geoderma, 105(1-2), 49-80.
13. **Z**immerman, D., Pavlik, C., Ruggles, A., Armstrong, M. (1999) An Experimental Comparison of Ordinary and UK and Inverse Distance Weighting. Mathematical Geology, 31: 370-395.
14. **W**arrick, A.W., and D.E. Myers, (1987) Optimization of Sampling Locations for VariogramCalculations, Water Resources Research, 23(3): 496-500.