ASSESSMENT OF SOME METEOROLOGY DATA OF AVERAGE MONTHLY AIR TEMPERATURE OVER MONGOLIA USING DIGITAL ELEVATION MODEL (DEM) AND GIS TECHNIQUES

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ABSTRACT:

The climate of Mongolia is a harsh continental climate with four distinctive seasons, high annual and diurnal temperature fluctuations, and low rainfall. Because of the country's high altitude, it is generally colder than that of other countries in the same latitude. This study focuses on evaluating the suitability of two interpolation methods in terms of their accuracy at the air temperature data in Mongolia. Four data sets of air temperature from 1982 to 2019 in 60 meteorological stations located in Mongolia and elaborated from a 90 m resolution digital elevation model (DEM), latitude and longitude using two interpolation methods. ArcGIS is used to produce the spatially distributed air temperature data by using IDW and ordinary kriging. Three statistical methods are multiple regression, RMSE and bias, which showed that the IDW the best for this data from other methods by the results that have been obtained. Statistics on the latitude, longitude and surface elevation of each of the 37 years in Mongolia at 60 meteorological stations have been statistically valid with dependent coefficients at 95-99.9%. As the average air temperature, recorded at the meteorological stations, had a statistical correlation of -0.606 with latitude, 0.295 with longitude, and -0.432 with altitude, a multiple regression equation was developed and a highly accurate map for long terms air temperature covering 1982- 2019 using interpolation IDW and Kriging method. Also, the highest RMSE value for maps used IDW was 1.38 while the lowest and average values were 0.03 and 0.44, respectively, and the highest bias was 1.21, lowest 0.95, and average 1.01. As opposed to, highest RMSE value for maps that used Kriging, was 6.16, lowest 0.27 and average 1.08 while highest bias was 1.29 and lowest was 0.85, with 1.01 as average. This demonstrates that IDW offers much better accuracy as opposed to Kriging and shows less bias errors. When the air temperature map that used the IDW method is compared against the meteorological station data the significance was 0.98 and when compared against ERA5 model results, significance was 0.95 showing strong statistical significance. Also, a comparison of air temperature map, processed by Kriging method and the meteorological station data shows 0.97 statistical significance, and comparison with ERA5 model shows (validation) 0.94 significance, which is very high. The mean value of the calculated temperature regression model in Mongolia and the root mean square error 0.02-0.09 for each station indicates that the estimation method is good and can be used in the future.

1. INTRODUCTION

Annual process of Mongolia's air temperature belongs to cold middle latitudinal zones and characterized by extreme continental climate (Badarch, 1971). According to multi-year data, average air temperature of Mongolia ranges between -6ºC and +4ºC, with dominating below zero temperatures in the northern alpine area and above zero in southern steppe and Gobi regions. Coldest month is often observed in January in all regions of Mongolia with average temperature being -34 - -25ºC in northern part, and -25- -15ºC in steppe and Gobi and the warmest observed in July with average temperature of +15- +20ºC in northern part and +20- +25ºC in steppe and Gobi, depending on landscape concave and convex structure (Jambaajamts, 1985). Due to global warming, Mongolia's average air temperature rose by 2.25 degrees in the past 79 years (Mongolia Environmental Status Report, 2017-2018). And it is estimated that temperature will likely rise by 2.60C in the next 100 years (Dagvadorj and Natsagdorj, 2009). The spatial data of climate has been prepared from the observation station (Phillips et al, 1992; Price et al, 2000). There are a number of deterministic and geostatistical interpolation methods to estimate the values for no-observed space between sampling locations. For example, the Inverse Distance Weighting (IDW) (Willmott et al, 1985), Kriging (Dirk et al, 1998; Lynch, 2001; Zhao et al, 2005), and PRISM (Parameter-elevation Regressions on Independent Slopes Model) (Daly et al, 1994, 2002 and 2004; Doggett et al, 2004; Hong et al, 2007) methods have been often used to interpolate temperature and precipitation. IDW measures the value closest to the prediction location which will have the greatest influence on the predicted values than those farther away (Johnston et al, 2001). Kriging is a geostatistical technique similar to IDW in that it uses a linear combination of weights at known points is used to estimate values at other unknown points (Willmott et al, 1985; Shuman, 2007). In this case, climate data must be calculated using spatial interpolation at wider scope. Any tools using spatial interpolation is dependent on wide variety of factors, including density of research field, their distribution and surface characteristics (Burrough and McDonnell, 1998). As part of this research, Mongolian air temperature spatial distribution was

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mapped in generally using meteorological station data (Climate and hydrology Atlas of Mongolia, 1985, National Atlas of Mongolia, 1990, 2009).

Researchers set the following 4 objectives for mapping spatial distribution of summer air temperature for 37 years, covering 1982- 2019, using IDW and Kriging methods for point data from meteorological observation stations:

- Calculate statistical correlation between the air temperature, longitude, latitude and altitude and developing formula for multiple regression equation
- Using multiple regression equation, map the air temperature spatial distribution of Mongolia by two methods of interpolation
- Identify root mean square error and system error of calculated air temperature
- Compare results of research that used IDW and Kriging, against the meteorological station data and model data for validation

2. STUDY AREA

Mongolia is a landlocked country in Central Asia and East Asia, located between China and Russia. The terrain is one of the mountains and rolling plateaus, with a high degree of relief. The elevation ranges between 524 m to 4323 m above sea level (Figure 1). Its continentally increases from east to west. The area studied in this work covers the entirety of Mongolia with a total area of approximately 1 564 116 square kilometers. Mongolia is the eighteenth largest and most sparsely populated country in the world. Mongolia extends between the latitudes 41°35′ N–52°09′ N and the longitudes 87°44′ E–119°56′ E, with an average land surface elevation of 1580 m above sea level (Nanzad et al, 2019). The country’s average annual temperature varies between from −8 °C to 8 °C with strong temperature gradients.

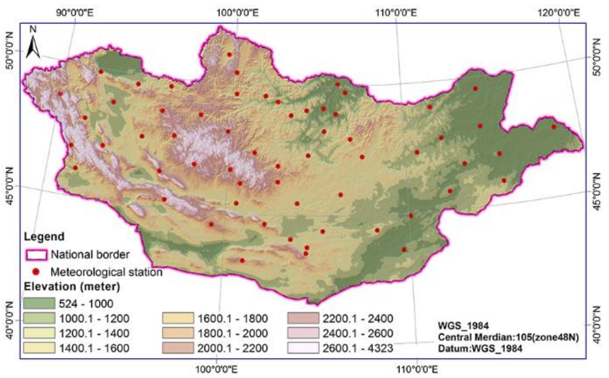

Figure 1. Mongolian topography and location of meteorological stations (n = 60) for which reference air temperature information from weather stations was available. Map of digital elevation model (DEM) was derived from the Shuttle Radar Topography Mission (SRTM-DEM) with a resolution of 90 m.

3. METHOD AND MATERIALS

3.1 Materials

We used sixty meteorological air temperature data between 1982 and 2019 (June, July and August) were obtained from the Mongolian Information Research Institute of Meteorology, Hydrology, and the Environment (IRIMHE). A digital elevation model (DEM) of the study area, for the year 2019, was downloaded from USGS as https://cgiarcsi.community/. ERA5 is the fifth generation of the ECMWF atmospheric reanalysis that has been operational at ECMWF since 2016; it covers the period from 1979 till the present, and has several significant innovative features beyond that of the discontinued ERA-Interim reanalysis model. We used 37 years of air temperature at the full ERA5 spatial resolution of 0.75◦ × 0.75◦ (about 79 km) resolution. This step is necessary due to limitations in the ECMWF’s netCDF (Network Common Data Form) implementation. ERA5 of the study area, for the year between 1982 and 2019, was downloaded from ECMWF as https://apps.ecmwf.int/.

3.2 Method

Multiple regression analysis and mapping of the spatial distribution of air temperature based on the determination of the meteorological station air temperature, elevation, longitude and latitude correlation matrix (Pearson correlation coefficient) are the most important to improve the research results. Which are discrete point locations in space. Values at any other point must be derived from neighborhood stations or form relationships with other variables. The method of spreading discrete measurements over a continuous surface represented by a regularly spaced grid is called spatial interpolation. Various statistical methods have been developed to predict the spatial distribution of climate variables. Commonly used interpolation methods for meteorological applications include Invers distance weighting and Kriging. Various statistical methods have been developed to predict the spatial distribution of climate variables (Jin and Heap, 2011). Inverse distance weighted (IDW) is a method of interpolation that estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. IDW interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location. Those measured values closest to the prediction location will have more influence on the predicted value than those farther away. Thus, IDW assumes that each measured point has a local influence that diminishes with distance. It weights the points closer to the prediction location greater than those farther away, hence the name inverse distance weighted (Watson and Philip, 1985). IDW assumes that the surface is being driven by the local variation, which can be captured through the neighborhood (Hartkamp et al, 1999). Ordinary kriging. The prediction by ordinary kriging is a linear combination of the measured values. The spatial correlation between the data, as described by the variogram, determines the weights. As the mean is unknown, fewer assumptions are made. The method assumes intrinsic stationarity, unfortunately, meteorological variables are often not stationary. In some cases, this problem can be eliminated by using different sizes and shapes of the search neighborhood. Ordinary kriging is frequently applied in meteorology, often as part of residual kriging or indicator kriging (Solomon et al, 2015). We completed this study according to the following diagram. A flow chart of the processes to obtain the spatial distribution of summer average air temperature of Mongolia (Figure 2).

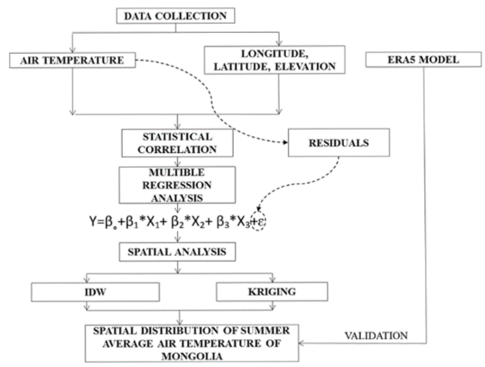

Figure 2. General scheme of research methodology.

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3.2.1 Regression analysis: Multiple regression is used when we want to predict the value of a variable based on the value of two or more other variables. A multiple regression model was used for the interpretation of the controlling complex relationships between multiple independent and dependent variables. We used parameters (temperature, digital elevation model, latitude, and longitude) obtained through regression equations were treated as dependent variables.
The following conditions must be met before performing a multiple regression analysis. These include:
• Residual or error (ε) distribution should be normal
• The probability distribution of errors should be variable
• Signs of error independence
Multiple regression determined (Mustafa et al, 2007) using the below formula (1).

$$Y = \beta_0 + \beta_1 * x_1 + \beta_2 * x_2 + \beta_3 * x_3 + \varepsilon \quad (1)$$

where x_1- Longitude
x_2- Latitude
x_3- Elevation
β_0, β_1, β_2, β_3- regression coefficient
Ɛ – residuals

3.2.2 Model Evaluation and Statistics: Two widely used statistics were calculated to assess the accuracy of the models including the RMSE and BIAS. RMSE is the difference between at the meteorological station measured and calculated values (Munkhdulam et al, 2019). It represents the accuracy of interpolation, and it is assumed that this method can be used effectively if the value is less than 1. Interpolation results that indicate no bias have a bias statistic value of 1 .That is, the average temperature estimate is equal to the average observed temperature. Bias values greater than one indicate that the estimated temperature is generally over estimated, while values less than one suggest that the interpolation method resulted in underestimation (Nawal et al, 2013).

$$RMSE = \sqrt{\frac{1}{N}\sum(Oi - Ei)^2} \quad (2)$$

where RMSE - Root mean square error
Oi - Observed temperature at i given station
Ei - Estimated temperature at i given station
i –Number of meteorological stations

$$Bias = E_{mean}/O_{mean} \quad (3)$$

where Bias – System error
E_{mean} - Mean estimated temperature
O_{mean} - Mean observed temperature

4. RESULT

4.1 Statistical variables

List of response/predictor variables and corresponding descriptive statistics (period from 1982 to 2019). The list includes the measured air temperature reference data at the meteorological station level (n = 60 for each of the June, July and August) as well as the corresponding four predictor variables extracted from elevation, longitude, land other geo-data (Table 1).

Variable	Temperature	Elevation	Longitude	Latitude
Temperature	1			
Elevation	-0.432*	1		
Longitude	0.295*	-0.585**	1	
Latitude	-0.606**	-0.245*	-0.149*	1

*p<0.01, **p<0.05

Table 1. Correlation matrix of variables.

4.2 Map resulting from the Inverse Distance Weighted (IDW) analysis

The following figure shows the spatial distribution of the average summer air temperature in Mongolia estimated by the IDW method using 5 categories. By classifying the same values, it is possible to see the temperature distribution of the year (Figure 3).

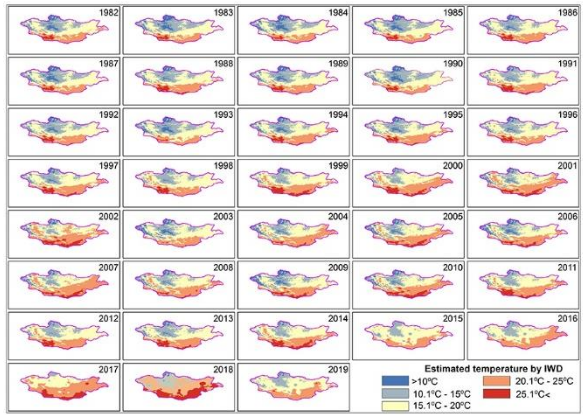

Figure 3. Spatial distribution map of summer air temperature estimated by IDW over Mongolia from 1982 to 2019.

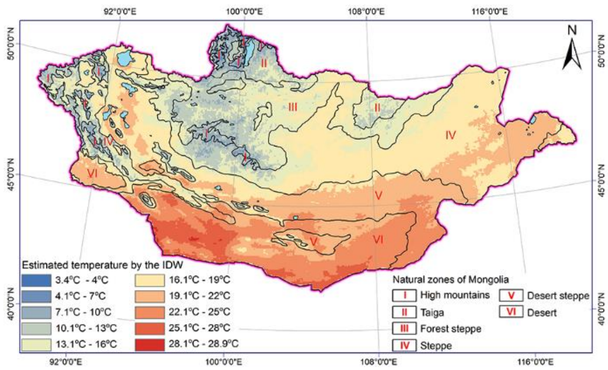

Figure 4. Spatial distribution map of summer average air temperature estimated by IDW over Mongolia.

Figure 4 demonstrates that June, July and August air temperature data from 60 meteorological stations for 37-year period between from 1982 to 2019, and resultant temperature spatial distribution value identified by IDW tool shows places with values less than 10^0C are located in high mountains 50.12%, taiga 16.35%, forest steppe 10.17% and steppe 21.78%, respectively, located at altitude of 1645- 4323 meters, in terms of natural zones. In terms of natural zones and sub-zones of areas with air temperature values between 10.1 - 19ºC, high mountain account for 2.76%, taiga 4.54%, forest steppe 27.37%, steppe 46.23%, desert steppe 18.36% and desert 0.75%, respectively, and all points are located at 1354-3720 meters of elevation. Whilst, areas with temperatures above 19.1ºC include 0.05% high mountain, forest steppe 0.02%, steppe 13.2%, desert steppe 36.6% and desert 50.31%, respectively, and are found at elevation lower than 2654 meters above the sea level.

4.3 Map resulting from the Kriging analysis.

The following figure shows the spatial distribution of the average summer air temperature time in Mongolia estimated by the Kriging method using 5 categories.

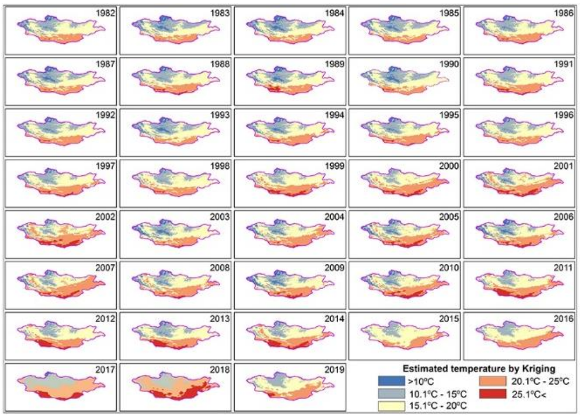

Figure 5. Spatial distribution map of summer air temperature estimated by Kriging over Mongolia from 1982 to 2019.

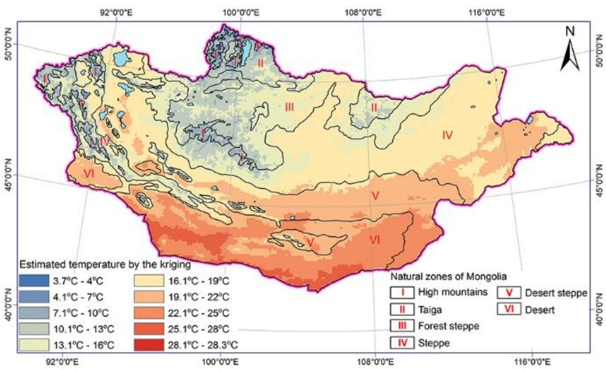

Figure 6. Spatial distribution map of summer air temperature estimated by Kriging over Mongolia.

Figure 6 demonstrates that June, July and August air temperature data from 60 meteorological stations for 37 years period between from 1982 to 2019, and resultant temperature spatial distribution value identified by IDW method shows places with values less than 10^{0}C are located in high mountains 49.98%, taiga 17.1%, forest steppe 9.6% and steppe 23.28%, respectively, located at altitude of 1716- 4323 meters, in terms of natural zones. In terms of natural zones and sub-zones of areas with air temperature values between 10.1 - 19ºC, high mountain account for 1.76%, taiga 5.85%, forest steppe 25.24%, steppe 48.47%, desert steppe 17.18% and desert 1.5%, respectively, and all points are located at 1200 – 3600 meters of elevation. Whilst, areas with temperatures above 19.1ºC include high mountain 0.04%, forest steppe 0.03%, steppe 14.6%, desert steppe 35.51% and desert 50.36%, respectively, and are found at elevation lower than 2500 meters above the sea level.

4.4 Validation

The IDW calculated RMSE value was 0.44 and the bias was 1.01, while the kriging calculated RMSE value was 1.08 and the bias was 1.01. This demonstrates that IDW offers much better accuracy as opposed to Kriging and shows less bias errors(Table2).

IDW		Kriging	
RMSE	Bias	RMSE	Bias
0.44	1.01	1.08	1.01

Table 2. Error statistics for RMSE and BIAS.

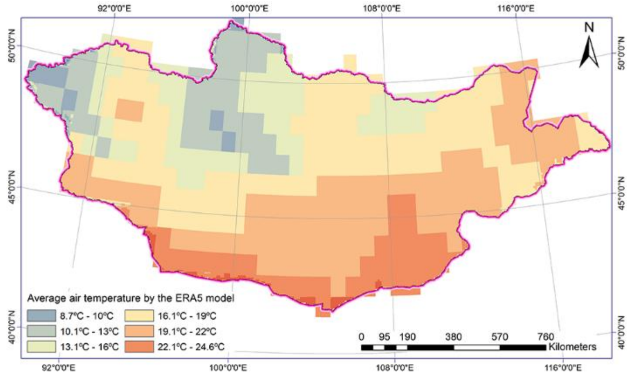

Figure 7. Average air temperature of the ERA5 model (between from 1982 to 2019).

The average air temperature of the ERA5 range between 19.1-24.6ºC in the Gobi, 16.1-19.0ºC in the Steppe and 8.7-16.0ºC in the high mountainous areas (Figure7).

Comparison of the results estimated by the ERA5 model up to validation of the air temperature mapped by the IWD and Kriging methods.

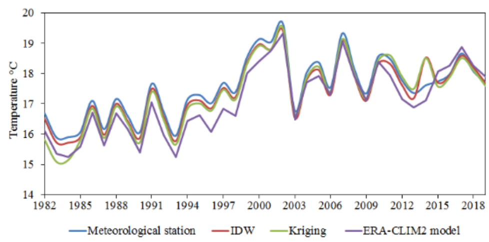

Figure 8. Station data, ERA5 model, IDW and Kriging calculated air temperature dynamics.

Figure 8 shows the dynamics of the from 1982 to 2019 meteorological station, the ERA5 model, and the 37-year station of the estimated air temperature (IDW and Kriging). As can be seen from the figure, the repeatability is better with the values estimated by IDW with real data. However, the value estimated by Kriging was 0.2-1.0 ° C lower than the actual value from 1982 to 1985. The results of the ERA5 model are lower than the meteorological temperature.

	Meteorological station	IDW	Kriging	ERA5 model
Meteorological station	1			
IDW	0.982	1		
Kriging	0.974	0.987	1	
ERA5 model	0.967	0.957	0.946	1

Table 3. Station data, ERA5 model, the correlation air temperature calculated by IDW and Kriging.

5. DISCUSSION

The spatial distribution of Mongolia's air temperature was mapped at 1: 5 000 000 scale using data from meteorological stations (Climate and hydrology Atlas of Mongolia, 1985; National Atlas of Mongolia, 1990, 2009). In terms of spatial accuracy, this map contains 50 kms of area in 1 centimeter. European Center for Medium-Range Weather Forecasts (ECMWF) processed weather forecasts and climate ia the ERA5 model and develops global mapping. In terms of accuracy, the ERA5 model's 1 pixel covers 76 km area and it has been mapped for 40 years covering the entire world, but still, its accuracy is considered low. MODIS (Moderate Resolution Imaging Spectroradiometer) satellite has developed past 22-year satellite imagery with 1 pixel 1 km ratio. Our research offers advantages of better accuracy, specifically 1 pixel: 1000 meters spatial ratio for 37 years containing point data from 60 meteorological stations. The findings of this research will further serve as the grounds for the environmental baseline study.

6. CONCLUSION

As the average air temperature, recorded at the meteorological stations, had a statistical correlation of -0.606 with latitude, 0.295 with longitude, and -0.432 with altitude, a multiple regression equation was developed and a highly accurate map for long terms air temperature covering 1982- 2019 using interpolation IDW and Kriging method. The IDW calculated RMSE value was 0.44 and the bias was 1.01, while the kriging calculated RMSE value was 1.08 and the bias was 1.01. This demonstrates that IDW offers much better accuracy as opposed to Kriging and shows less bias errors. When the air temperature map that used the IDW method is compared against the meteorological station data the significance was 0.98 and when compared against ERA5 model results, significance was 0.95 showing strong statistical significance. Also, a comparison of air temperature map, processed by Kriging method and the meteorological station data shows 0.97 statistical significance, and comparison with ERA5 model shows (validation) 0.94 significance, which is very high. Looking at the 37-year dynamics of a summer air temperature of Mongolia shows a constant increase since 1998 as opposed to a multi-year average and such increase in temperature during plant growth period lays the foundation for drought and dry climate. This results in the decline of harvest from the crop planting sector and reduction of pasture forage for the animal husbandry sector, which leads to livestock loss and social and economic negative impact. In addition, it is a comprehensive research that used some scientific data, including climate and geography data, coupled with statistical, including correlation, regression, RMSE and BIAS, and geostatistical methods, such as IWD and Kriging.

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