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APPLYING THE INVERSE DISTANCE WEIGHTING AND KRIGING METHODS OF THE SPATIAL INTERPOLATION ON THE MAPPING THE ANNUAL PRECIPITATION IN BOSNIA AND HERZEGOVINA

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Abstract: Two methods of the spatial interpolation [Inverse Distance Weighting (IDW) and the Kriging], often used in the Geographical Information System (GIS), have been applied on the mapping of the annual amount of precipitation in Bosnia and Herzegovina. For that purpose the monthly precipitation data obtained from meteorological network in the period 1960-2011. The validation of the analyzed data has been carried out by using 20-meter resolution Digital Elevation Model (DEM). The methods, which are suitable for the spatial interpolation for Bosnia and Herzegovina area, particularly for the orographic regions, were analyzed. First, the IDW linear interpolator was considered. However, in the mountain region, this method can give unrealistic results ("Bulls Eyes" effect). Namely, this effect leads to occurrence of the isohyets, which are closed around the meteorological station that is not acceptable in analysis of the pluviometric regime in the real relief. In contrast to this method the Kriging method is much more acceptable because of its (i) adaptability to the relief configuration, (ii) fast data processing and (iii) high precision in calculating the precipitation and corresponding climate indexes for the high resolution of the grid cell. An acceptable annual pluviometric model with the 50x50 m resolution has been obtained by the application of the Kriging method, which was applicable at the local spatial scale, particularly in the orographic regions. More precisely, the designed annual pluviometric model is characterized by the high precision in the areas with the pronounced relief dynamics, where the energetic classes are above 6th category.

Keywords: Spatial interpolation, Inverse Distance Weighting method, Kriging method, Bosnia and Herzegovina, Digital Elevation Model, "Bulls eyes" effect, annual pluviometric model, local spatial scale, orographic region.

1 INTRODUCTION

Various methods of spatial interpolation are used in climatological investigations of spatial distribution of basic pluviometric indicators. These methods can be divided into two groups: (i) climatographic, and (ii) Geographical Information System (GIS) models of spatial interpolation. Climatographic methods are based on use of the hypsometric model as a basis for determination of spatial distribution of pluviometric regime. Transformation of hypsometric (relief) model into pluviometric model is based on the principle of direct translation of isohyets into
adequate isohyets by calculating the changes in precipitation with elevation, i.e. calculating the vertical pluviometric gradient. In this way it is possible to obtain models which are, in 2D projection, direct transformation of hypsometric into pluviometric scale. The application of this model can be accepted just partly since it is acceptable only from the standpoint of presentation of certain and very general features of spatial distribution of the pluviometric regime. At the local level, this methodological concept gives results with doubtful accuracy, which comes from the fact that influences of numerous climate factors, particularly orography, have not been applied in the analysis.

The GIS models for the spatial interpolation are based on the advanced methodological concept, which includes application of spatial autocorrelative mathematical analysis between pluviometric data and climate factors, such as altitude, exposition, slope, degree of continentality, etc. Applied models are mostly based on several functionally interconnected operations: (i) data entry (transformation of the data into adequate form), (ii) geoprocessing (via defined process script) and geovisualisation that includes development of spatial model for treatment of the input data into thematic maps (output). Each of above mentioned components has its own predefined procedures for transformation and data processing.

Without dealing with the issue of the GIS structural concept and its user interface, for the purpose of investigations of annual pluviometric regime of the Bosnia and Herzegovina, process modules for 3D, topological and advanced spatial analyses have been used. More precisely, the aforementioned process modules were basis for analytical investigations of pluviometric features of the studied region in two-dimensional as well as the three-dimensional form.

### 2 MONITORING AND PRECIPITATION DATA

Methodology applied in the analysis of precipitation data was used according to recommended definition of recent climate period, i.e. 1961 to 1990. From these reasons, the whole climatological-statistical analysis of pluviometric regime and development of its spatial model was based on the implementation of the results of climatological monitoring, in the given period, in the Bosnia and Herzegovina meteorological network. The number of meteorological stations in the Bosnia and Herzegovina meteorological network is 106 stations (17 main stations and 89 ordinary ones). On the main meteorological stations measurements and observations of the main meteorological elements have been carried out continuously in the period indicated. Monitoring on the network of ordinary (climatological) meteorological stations included the monitoring of air temperature, relative humidity, cloudiness, amount of precipitations, wind direction and wind speed, in three main observation periods according to the mean local time. All mentioned meteorological stations are mostly operational since 1960, and therefore all of them have representative time series necessary for describing the current climate features in Bosnia and Herzegovina [Drešković, 2011]. Besides quality and structure of the monitoring, particularly important aspect in analysis of climate in Bosnia and Herzegovina is the spatial-hypsometric distribution of meteorological stations in the network. The results of this analysis are presented in Table 1.

<table>
<thead>
<tr>
<th>Altitude (m)</th>
<th>Climate belt</th>
<th>Number of MS</th>
<th>Climate belt</th>
<th>Number of MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 500</td>
<td>Continental</td>
<td>46</td>
<td>Mediterranean</td>
<td>19</td>
</tr>
<tr>
<td>500 - 1000</td>
<td>Continental</td>
<td>14</td>
<td>Mediterranean</td>
<td>16</td>
</tr>
<tr>
<td>1000 - 1500</td>
<td>Continental</td>
<td>6</td>
<td>Mediterranean</td>
<td>4</td>
</tr>
<tr>
<td>&gt; 1500</td>
<td>Continental</td>
<td>1</td>
<td>Mediterranean</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td><strong>67</strong></td>
<td></td>
<td><strong>39</strong></td>
</tr>
</tbody>
</table>
On the basis of data obtained it can be concluded that meteorological stations in the network at the whole state have extremely non representative spatial distribution, considering both their number as well as hypsometric zones. More precisely, the largest number of meteorological stations is located in the lowlands (up to 500 m) – more than 61%. These areas are distinguished by the decreased relief dynamics indicating that features of thermic-pluviometric regime do not significantly change at larger spatial areas. Mid-altitude areas (500 m -1000 m), which are also distinguished by the increased dynamics of relief comprises around three times less meteorological stations – 18.2%. The mountain region with highest relief dynamics has 10% of the total number of meteorological stations (Figure 1).

![Spatial distribution of meteorological stations in the Bosnia and Herzegovina meteorological network](image_url)

**Figure 1.** Spatial distribution of meteorological stations in the Bosnia and Herzegovina meteorological network (number indicates the number of the meteorological station). Source: The Annual Report of the Hydrometeorological Institute of Bosnia and Herzegovina.

Test of climatological data using various GIS based models of spatial interpolation has been carried out after preparation and final data processing. The results of tests indicated that only two models were acceptable, since their methods of spatial interpolation included datasets existing in the DEM for Bosnia and Herzegovina except the precipitation data. Although only one processing model has been used in the final version for spatial interpolation of climatological data, in the further text we will present methodological basis of the spatial interpolation and results obtained by both methods, i.e. the Inverse Distance Weighting (IDW) and the Kriging [Ninyerola, 2006].

3 **INVERSE DISTANCE WEIGHTING**
The IDW method for spatial interpolation, which estimates values of cells by weighting of values (point) of geometric data in the neighborhood of each processed cell. The points located closer to the cell center have more influence or weight in the process of weighting. This method assumes that influence of the variable entered on the map decreases with the increase of the distance from its sampling site. In this case, during determination of spatial distribution of precipitation data their spatial value influence decreases directly proportionally with the increase of the distance from the center of location of the meteorological station. Using this interpolation method it is possible to control importance of known points – meteorological stations in relation to the interpolated values, based on its distance from the exit point. From these reasons it is a usual practice to define the proper features in analyses of climate elements at all meteorological stations in order to obtain the same details in the spatial distribution. Therefore, a dominant influence on obtained interpolation results has the distance among neighboring meteorological stations. Let us note that the standard analyzed neighborhood is determined by the parameters of ellipse: angle, large semi axis and small one. The IDW interpolation option creates outer, central and inner ellipse at the distance the same as the result of multiplication of large semi axis with the factor of smoothing. The results of implementation of the IDW spatial interpolator are presented in Figure 2.

![Figure 2](image.png)

**Figure 2.** Pluviometric model obtained on the basis of the IDW spatial interpolation of annual amount of precipitations, measured in the Bosnia and Herzegovina meteorological network in for the period (1961-2000). Source: The Annual Report of the Hydrometeorological Institute of Bosnia and Herzegovina.

From Figure 2 is seen that in Bosnia and Herzegovina there exist three areas in the Mediterranean climate region distinguished by the increased annual amount of precipitation that coincides with three the most pronounced mountain regions. Also, the increased annual amounts of precipitation can be identified in other mountainous areas, while decrease in amount of precipitation can be noted for the northern parts of continental climate region of Bosnia and Herzegovina. However,
although the IDW could be in general considered as a relatively fast and precise deterministic interpolator, it has also several drawbacks that come from its basic modeling features.

There is a possibility of occurrence the error in the use of the IDW. As results of this error it can occur unrealistic model outputs in the vicinity of the meteorological stations ("Bulls eyes") as it is seen in Figure 3. In other word, interpolation mode, applied in the vicinity of the meteorological stations gives closed contours what is completely unacceptable in analysis of the pluviometric regime in the mountain region. Because of this limit in the use of the IDW method it cannot be applied for modeling pluviometric regime in Bosnia and Herzegovina [Whiteman, 2000].

4 THE KRIGING METHOD OF SPATIAL INTERPOLATION

The Kriging method is an advanced geostatistical one, which estimates investigated area from dispersed set of meteorological stations with different altitudes (z value). The Kriging method involves interactive investigation of spatial behavior of data analyzed before selecting the best method of assessment for derivation of output area [Oliver, 1989]. Spatial variation is quantified by semivariogram. It is selected among the semivariograms available in the corresponding archive, which is calculated from number of the data of input point sets. Value of the type of semivariogram for distance $h$ is mean square root difference in $z$ value between pairs of input sample points multiplied by $h$.

Semivariogram sample is calculated from the data sample using the following equation:

$$  \hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i) $$

where the symbol introduced have the following meaning:

- $\hat{Z}(s_0)$ - predicting location
- $\lambda_i$ - unknown weight of the measured value of pairs of points at $i$th location
- $Z(s_i)$ - measured value of pairs of points at $i$th location
- $N$ - number of measured values of pairs of points multiplied by the distance $h$

Variation of semivariogram is determined by the interpolation based on the mean variation of all points within each interval of the size of grid cell. In this case semivariogram corresponds to points of variations using the Levenberg–Marquardt method (Press et al., 1986). At least three values of variants at three distances within grid cell are necessary for averaging. Increase of the grid cell size increases number of analyzed points by interval which ensures sufficient data for assessment of semivariogram. After selection of semivariogram it is possible to...
use smaller size of the grid cell in creation of actual output grid. The Kriging method offers two procedures for spatial interpolation: the Ordinary Kriging and the Universal Kriging, which have defined features in assessment of spatial variations. In this paper we used the procedure of the Ordinary Kriging. Then the DEM for Bosnia and Herzegovina, with 20x20 m resolution, has been used for spatial validation of the data. The obtained results are depicted in Figure 4.

![Annual pluviometric model obtained by the Kriging method of the spatial interpolation of annual amount of precipitation.](image)

Results indicate that grid and line isohyets data obtained by the Kriging method are much more representative than ones that come after application the IDW method. More precisely, spatial distribution of isohyets by their shape much better fits to real relief of Bosnia and Herzegovina, particularly in the mountain region on the local scale [Antonić, 2008]. Quantitative values of isohyets also completely fit to the real values, obtained through monitoring in the of the meteorological network. The main contribution of this work is that after implementation of the Ordinary Kriging of spatial interpolation, each grid cell, with 20x20 m resolution, has its associated values for amount of precipitation.

5 RESULTS OF APPLICATION THE ORDINARY KRIGING METHOD OF SPATIAL INTERPOLATION

On the basis of the results obtained by the developed the annual precipitation model using the Ordinary Kriging interpolation procedure it is concluded: (i) amount of annual precipitation for Bosnia and Herzegovina is 1255.0 m; (ii) there exists a pronounced variation in spatial distribution ranged from 706.0 mm (alluvial plate of the Sava river – wider area around settlement Domaljevac) to 3259.0 mm.
(Mt. Orjen – wider area of the peak Velika Jastrebica -1856 m); (iii) in the most arid areas in Bosnia and Herzegovina, the annual amount of precipitation is five times less comparing to maximal level; (iv) the differences in spatial distribution of precipitation are pronounced also at the level of the climate regions in Bosnia and Herzegovina. Namely, in the continental climate regions of Bosnia and Herzegovina average amount of annual precipitation is around 1080.0 mm and varies from 706.0 mm to 2335.0 mm (in the wider area around top of the Zelengora Mountain); (v) in the Mediterranean region in Bosnia and Herzegovina the amount of precipitation is higher (1,645.0 mm) comparing to the continental climate regions, with variations from 920 mm (wider are around hydroacumulation Rama) to 3,259,0 mm; (vi) spatial change in amount of annual precipitation in these two climate belts is also different, with general conclusion that it decreases from coastal zone in the south towards the peripanonian zones in the northern parts of Bosnia and Herzegovina.

6 CONCLUSION

In this paper we obtained results that can be summarized as follows.
(1) In comparison with other GIS spatial interpolation methods, the Kriging method has evident advantages;
(2) The Kriging method offers two procedures for spatial interpolation: (i) the Ordinary Kriging and (i) the Universal Kriging. However, the first procedure has performances in spatial distribution of isohyets, which promote this method as a more useful for the practical purposes;
(3) The main contribution of this work is that after implementation the Ordinary Kriging procedure of spatial interpolation, each grid cell, with 20x20 m resolution, has associated values of amount of precipitation for this resolution.
(4) On the basis results obtained by the application of the aforementioned method we discussed the main features of the new annual pluviometric regime of Bosnia and Herzegovina.

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