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QUANTIFICATION AND SPATIAL DISTRIBUTION OF PRECIPITATION ON THE TERRITORY OF SERBIA

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Abstract: This paper describes a method for quantification and spatial distribution of precipitation on the territory of Serbia on the basis of data on mean annual rainfall and altitude of measuring points and relief data of Serbia. What has been determined first in the study is how the amount of precipitation depends on the altitude of the measuring point. The established type of the dependence of the amount of rainfall on altitude has been applied on data on elevations (relief) of Serbia, which led to the spatial distribution of rainfall. The data on average annual rainfall and altitude for 434 measuring points served as precipitation data, while the data created during the Shuttle Radar Topography Mission (SRTM) were used as data source on relief of Serbia. The research was conducted using a geographic information system (GIS). The problem of determining the spatial distribution of rainfall in the literature is usually solved by establishing a direct relationship between the height of terrain (independent variable) and precipitation (dependent variable), and then the dependence applied to the whole observed area is determined (linear dependence, kriging, etc.). In this case the relation between precipitation (P) and altitude (h) was determined indirectly. Coefficient K is defined as the ratio between precipitation and altitude at which precipitation is measured, $K = P/h$. It has been found that there is a very high correlation (> 0.95) between the coefficient K and altitude h. The relationship between the height h and the coefficient K is modelled by form $K = ah^b$. The resulting ratio is applied to the data on the relief and thus the distribution of rainfall for the area of Serbia is obtained.

Key words: precipitation, interpolation, GIS, Serbia

Introduction

The problem of determining the amount and spatial distribution of rainfall is one of the fundamental problems in climatology. The problem is solved in different ways, and one way of solving it is to use the correlation of precipitation and relief. Models that describe this relationship, as stated by Bassist, Bell & Meentemeye (1994) and Roe (2005), evolved from simpler to more complex ones. Early statistical models such as the model developed by Bass, Bell & Meentemeyer (1994) are simple and one (dominant) factor of influence on precipitation was used in them, which was usually altitude. Soon afterwards

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more complex models were developed using more topographic variables (Spreen, 1947; Hutchinson, 1973; Danard, 1976; Vidal & Varas, 1982 cited in Bass, Bell & Meentemeyer (1994). Also, Yang, Ma, & Chen (2011) suggest that multiple connections provide better results than simple ones.

In the works relating to the dependence of precipitation on relief, various models referring to various scales (macro-global, meso-regional and micro-local) and different geographic positions (latitude) have been developed and presented. Notwithstanding this diversity, even in papers published in recent times, all these models are mainly based on linear regression (Smith, 2009; Smith & Barstad, 2004) with its complex varieties (Bassist, Bell & Meentemeyer 1994; Hevesi, Istok & Flint, 1992; Martinez-Cob, 1996; Pardo-Iguzquiya, 1998; Gouvas, Sakellariou & Xystrakis F 2009), which defines the aforementioned dependencies. In complex models, analyses are generally made by using several topographic variables as predictors: altitude, slope and orientation, as well as their combinations.

Some authors emphasize the seasonal differences in the relationship between rainfall and topography. This aspect was studied by Smith (2009) who found a stronger linear dependence in the period October - May than in the period June-September for an area of the state of Alberta in Canada.

In the works of Kovačević-Majkić & Štrbac (2008) and Štrbac, Kovačević-Majkić & Miljanović (2011) the use of linear regression for the relationship between altitude and rainfall was proposed, followed by the application of low-pass spatial filter to the data thus obtained. The method was applied to the areas of individual river basins and tested on catchments of size between 400 and 1,500 km^2.

The methods of height gradient of rainfall (Zivkovic & Andjelkovic 2004), spatial determinations of amount of precipitation (Ducić & Radovanovic, 2005), regression kriging (Bajat, Pejović, Luković, Manojlović, Ducić & Mustafić, 2013) and vertical gradient (Prohaska et al. 2012) have been applied in the area of Serbia.

In this paper, the amount and spatial distribution of rainfall within Serbia were determined. A simple model was used with only one independent variable, altitude. New in this paper is the use of correlation of altitude and coefficient which represents the relationship between precipitation and altitude.

The Data and Methodology

The data on mean annual rainfall for the period 1961–2010 were used as precipitation data. The mean annual precipitation was calculated on the basis of data on monthly rainfall for the mentioned period. The total number of measuring points for which the data were collected was 434. Of these, 426 measuring points are in Serbia, and 8 out of Serbia (Figure 1). The precipitation data were taken from the Meteorological Yearbook II, the Republic Hydrometeorological Service of Serbia. The same source was also used for the data on altitude of the measuring points.

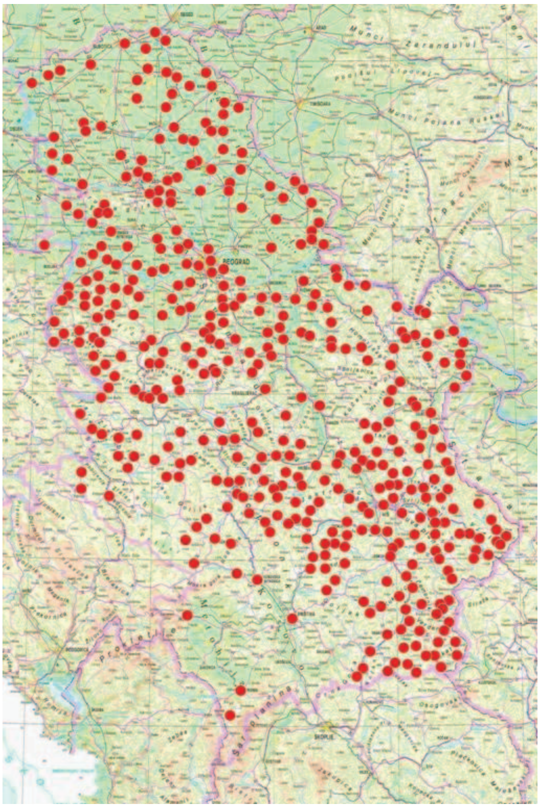

Figure 1. Arrangement of measuring points on the territory of Serbia, used in the paper.

The data created during the Shuttle Radar Topography Mission (SRTM V4)[2] were used as a source of relief data for the area of Serbia. Features of used data determined the size of the pixel raster which is 100 x 100 m.

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[2] http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1

In this study, the methodology which relies on a known correlation between altitude and precipitation was applied. The correlation between altitude (independent variable) and precipitation (dependent variable) in this study was determined indirectly by introducing the coefficient which is called the *coefficient of raining*. *The coefficient of raining* K is defined as the ratio between precipitation P and altitude h at which precipitation is extracted:

$$K = \frac{P}{h} \tag{1}$$

The first step consisted in calculating the coefficient of raining K_m for each measuring point using the equation (1). Measured amounts of rainfall P_m and data on the altitude of a measuring point h_m were used:

$$K_m = \frac{P_m}{h_m} \tag{2}$$

Analysis of the value of the coefficient of raining at measuring points has shown that there is a correlation between the value of the coefficient of raining K_m and altitude h_m. The chosen degree function best describes this correlation:

$$K = ah^b \tag{3}$$

where a and b are regression coefficients.

Using data on the values of the coefficient of raining K_m and altitude h_m, the values of the coefficients a and b in the equation (3) are calculated by the method of least squares. In this manner the model is obtained which links the coefficient of raining with altitude and allows calculation of the value of the model coefficient of raining K' for any value of altitude for the area of Serbia.

Using data on the altitude hp from the raster digital model of the terrain for the area of Serbia, the model-values of the coefficient K' are calculated for each cell of the raster, i.e. pixel:

$$K' = ah_p^b \tag{4}$$

K' is a model coefficient of raining, h_p is elevation of pixel, while a and b are previously calculated regression coefficients. By multiplying the values of the model coefficient of raining K' of an individual pixel with an elevation value h_p

of the same pixel, the model-based precipitation values P' are obtained for each pixel:

$$P' = K' h_p \tag{5}$$

Using data on rainfall P_m and altitude h_m of the measuring points by the equations (4) and (5), the model precipitation P' is calculated for each measuring point. Then the relative error of the model precipitation g is calculated for each measuring point, expressed as a percentage:

$$g = \frac{P_m - P'}{P_m} 100 \quad (\%) \tag{6}$$

A spatial interpolation of the relative errors of the model precipitation was done to obtain their values on the entire surface of Serbia. As a type of the spatial interpolation a triangulated irregular network method was used (TIN). In this way, the raster was obtained with the value of the relative errors g' for each pixel for which there was an item on its altitude hp.

The correction values *g'* from the corresponding pixels are added to the values of initially calculated precipitation P' for each pixel according to the equation (5) and thus the corrected values of precipitation P'' have been obtained for each pixel:

$$P'' = P' + P' \frac{g'}{100} \tag{7}$$

By forming the distribution of differences between the corrected model and measured rainfalls in pixels containing the measuring points, the measure of the final correction of the value of the model precipitation is also determined so as to obtain approximately unbiased assessment on the average level for the whole Serbia.

The Results

Using the data of measured amount of rainfall P_m and altitude h_m of the measuring points and applying the equation (1), the values of the coefficient of raining K_m are calculated for each measuring point.

The Figure 2 shows the dependence of the coefficient of raining on the *y* axis and altitude on the *x* axis for each measuring point. It is evident from the graph that there is a correlation between these two elements and that the degree form of regression from the equation (3) is suitable for modelling their dependencies.

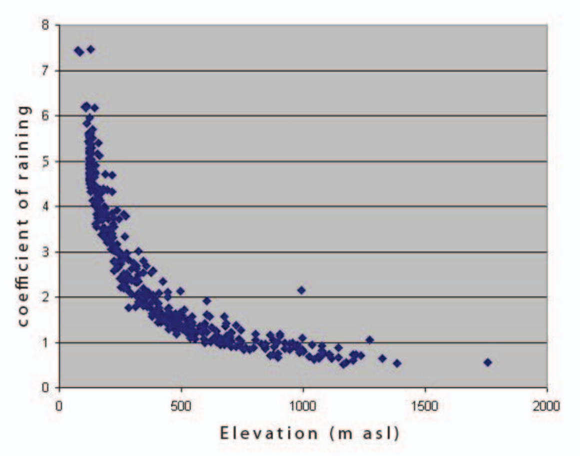

Figure 2. Ratio of the coefficient of raining and altitude for the rainfall stations in Serbia at the locations of measuring points

The calculated values of the regression coefficients of the dependence of the coefficient of raining on altitude in the form given by the equation (3) are a = 375.55 and b = -0.8894. The equation that has been used to calculate the model coefficient of raining is:

$$K' = 375.55h^{-0.8894} \tag{8}$$

K' is a model coefficient of raining, and h is an altitude for which the coefficient is calculated.

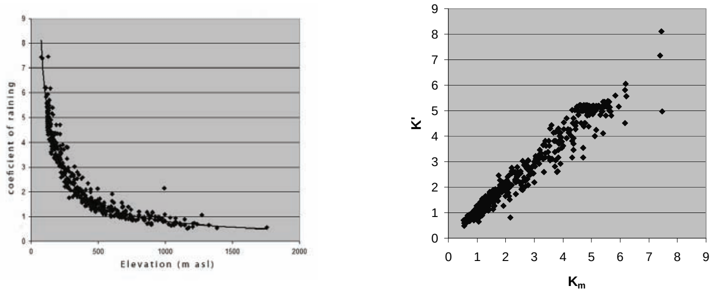

Figure 3. Regression model and empirical values of the coefficients of raining in the function of altitude (left); comparison of the empirical K_m values with the K'_m values obtained by regression model (right)

For this regression relationship the resulting value of the coefficient of determination is $R^2 = 0.9547$. The comparison of the coefficient of raining at the measuring points with the values calculated from the regression model is shown in the right graph in the Figure 3, while the regression line is represented by the full line in the left graph.

The distribution of the relative errors g defined by the equation (6) is given in the Figure 4. The percentage values of relative errors are on the x axis, and the number of measuring points in a given class is on the y axis. The arithmetic mean of relative errors is 0.94% and the standard deviation is 13.31%. The distribution of the relative errors of the model precipitation was tested by χ^2 test, which showed that there was no basis to reject the assumption on their normal distribution at the significance level of $p = 0.05$. The resulting value of χ^2 is 15.0 for 10 degrees of freedom, while the critical value of this statistic for $p = 0.05$ and the same number of degrees of freedom is 18.3.

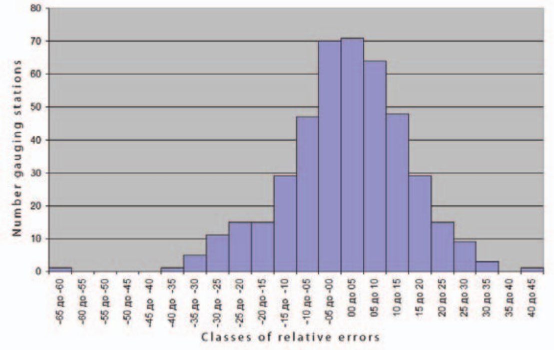

Figure 4. Distribution of relative errors of model precipitation

The spatial distribution of the relative errors of the model precipitation is shown in the Figure 5, representing a specific spatial differentiation. The two relatively homogeneous zones are singled out: zone of positive and zone of negative relative errors of the model precipitation. The zone of positive errors generally extends along the western borders of Serbia, while the zone of negative errors is the characteristic of the territory of Vojvodina and Kosovo and parts of the valleys of the Nišava, the Južna and the Velika Morava.

Using the equations (4) and (5) and the data on the latitudes for the whole territory of Serbia, the model values of precipitation are calculated for each raster element. The raster data on the heights of the terrain with the size of 100 x 100 m (sign h_p) are used as the input data. A model coefficient of raining K' is calculated for each raster cell according to the equation (4) and the initial value of the amount of precipitation P' according to the equation (5), and after entering the corrections according to the equation (7), the corrected value of rainfall P'' is obtained.

The calculated values of the amount of precipitation P'' for the pixel within which there are measuring points are compared with the measured values of precipitation P_m at these measuring points. The value of altitude in the pixel h_p and elevation of the measuring point h_m differ, and this is the cause of differences in values of the measured and model precipitation. The distribution of the relative errors between measured and model precipitation is shown in the graph in the Figure 6. It is noted that the distribution of errors is shifted towards negative values in relation to the expected zero error. By adding the values of 24 mm, which is the median of these differences, to all calculated values P'', the shift of the distribution is compensated. After the second correction, the distribution of the relative errors between the measured and calculated amounts of rainfall is given in the Figure 7.

Discussion and Conclusions

In the applied way of obtaining the spatial arrangement of the amount of precipitation two phases can be singled out. The regression dependence of the amount of precipitation on altitude is determined in the first phase by using the newly introduced parameter called the coefficient of raining for which it has been found to have a strong correlation relationship with altitude.

The analysis of the distribution of relative errors has shown a spatial differentiation of positive and negative values of the relative errors which speaks of the regional characteristics of the sign and value of the relative errors. The dependence of these errors on the local features should be the subject of future research.

The second phase was aimed at determining the spatial arrangement of rainfall in Serbia by using the developed dependence of the coefficient of raining on the altitude. The goal is achieved by using raster elevation data in the form of a raster resolution of 100 x 100 m. Applying the resulting regression relationship to each raster cell, the initial values of precipitations are calculated which are then corrected by the value of the relative error in each cell.

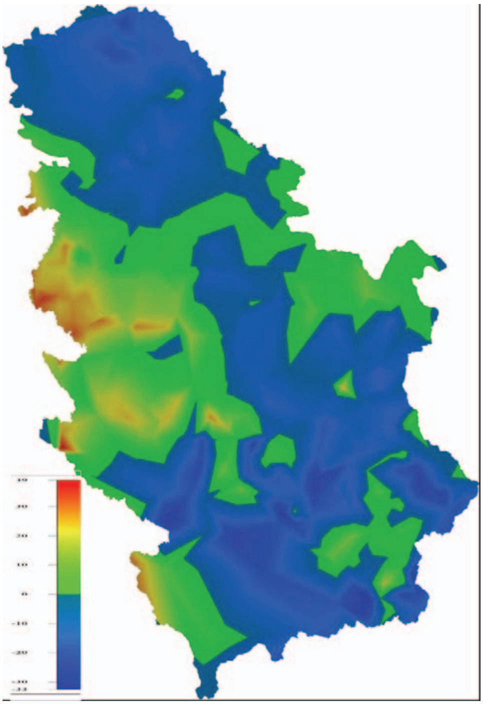

Figure 5. Spatial distributions of relative errors of model precipitation in [%]

In this procedure altitude in a cell is the mean value of the area encompassed by the cell while the height of the measuring point is connected to a point. Hence the measured values differ from the calculated values of precipitation. Given the fact that the cell size is relatively small, it can be said that the comparison of the measured and model precipitation is possible.

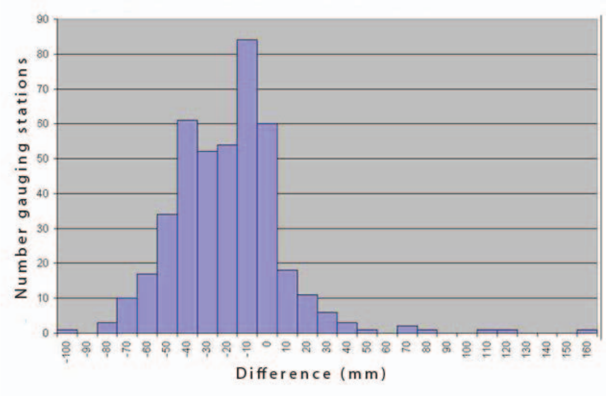

Figure 6. Distribution of differences of measured and model precipitation

After correction, the calculated values of precipitation are systematically lower than the measured ones and the difference is compensated by adding the value of the median absolute errors. In this way, the spatial distribution of precipitation for the territory of Serbia is obtained for the period 1961–2010.

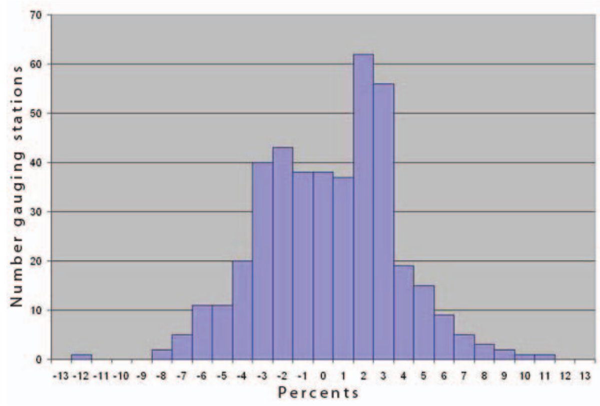

Figure 7. Distribution of relative errors of model precipitation after the addition of correction

The method applied in determining the spatial distribution of rainfall showed relatively good results. By introducing the coefficient of raining a new relationship is defined which has proved useful in the process of defining the functional connection between the precipitation and altitude.

In further research it is necessary to determine the nature of errors and thus avoid their neutralization by interpolation.

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