The analysis of spatial variability of precipitation in Poland in the multiyears 1981–2010

Antoni GRZYWNA[1] ✉, **Andrzej BOCHNIAK**[1],

Agnieszka ZIERNICKA-WOJTASZEK[2], **Joanna KRUŻEL**[2],

Krzysztof JÓŹWIAKOWSKI[1], **Andrzej WAŁĘGA**[2], **Agnieszka CUPAK**[2],

Andrzej MAZUR[1], **Radomir OBROŚLAK**[1], **Artur SERAFIN**[1]

[1] University of Life Science in Lublin, Faculty of Production Engineering, Leszczyńskiego St. 7, 20-069 Lublin, Poland
[2] University of Agriculture in Krakow, Faculty of Production Engineering, Kraków, Poland

Abstract

The purpose of the paper is to analyze the spatial variability of precipitation in Poland in the years 1981–2010. The average annual rainfall was 607 mm. Precipitation in Poland is characterized by high spatial and temporal variability. The lowest annual precipitation was recorded in the central part of the country, where they equaled 500 mm. The highest annual precipitation totals were determined in the south, equaling 970 mm. The average precipitation in the summer half-year is 382 mm (63% of the annual total). On the basis of data from 53 climate stations, maps were made of the spatial distribution of precipitation for the period of the year and winter and summer half-year. The kriging method was used to map rainfall distribution in Poland. In the case study, cross-validation was used to compare the prediction performances of three periods. Kriging, with exponential type of semivariogram, gave the best performance in the statistical sense. Their application is justices especially in areas where landform is very complex. In accordance with the assumptions, the mean prediction error (*ME*), mean standardized prediction error (*MSE*), and root mean-square standardized prediction error (*RMSSE*) values are approximately zero, and root-mean-square prediction error (*RMSE*) and average standard error (*ASE*) reach values well below 100.

Key words: *climate change, kriging, Poland, precipitation, spatial variability, water resources*

INTRODUCTION

Precipitation, along with air temperature, are among the most important climate characteristics. This element is very diverse both spatially and temporally. However, changes occurring in the global hydrological cycle due to warming are not homogeneous. Depending on the observed period, the annual precipitation amounts show a not statistically insignificant upward trend [ŻMUDZKA 2002] or downward trend [MAGER *et al*. 2009]. Despite the relatively extensive documentation in the literature, showing the long-term fluctuations of this element of the weather, across the country [CZARNECKA, NIDZGORSKA-LENCEWICZ 2012; KIRSCHENSTEIN, BARANOWSKI 2005; SZWED 2019; ZAWORA, ZIERNICKA 2003; ZIERNICKA-WOJTASZEK 2006] and in the regions [BANASZKIEWICZ *et al*. 2008; ILNICKI *et al*. 2012; OTOP 2010], these issues are still the subject of research. In addition, in recent years, due to damage caused by floods, interest in precipitation has increased again. On a seasonal basis, in the past half century, a slight increase in rainfall was noted in spring and autumn, and a decrease in summer and winter. On a monthly basis, however, only in March a statistically significant positive trend of the sum of precipitation is observed [SZWED 2019]. Despite the above facts, the pluvial regime in Poland changed, however, over 50 years (1951–2000). The main symptom of these changes is a decrease in the share of summer precipitation sums in the annual sum. The most

noticeable increase in precipitation was observed in the winter half-year [SZWED 2019]. According to DEGIRMEN-DŽIĆ *et al*. [2004] the observed greater time variability means that the main features of the continental climate are becoming less visible. Despite the lack of significant trends, rainfall variability is increasing [ZIERNICKA-WOJ-TASZEK 2006]. Precipitation is characterized by high variability and shows temporal and spatial discontinuity. In many publications, there is also a correlation between the incidence of precipitation in a given area and air circulation or a synoptic situation [TWARDOSZ *et al*. 2011]. An increase in precipitation sums in time and space has been observed, manifesting in frequent high daily rainfall [TWARDOSZ *et al*. 2011; SZYMANOWSKI *et al*. 2019]. Therefore, the incidence of drought increases in summer [BEREZOWSKI *et al*. 2016].

Global climate change and related water shortages require more efficient water management systems [IPCC 2008]. In recent years, it is increasingly recommended to collect and use rainwater, mainly due to the limited freshwater resources in the world and rising water prices from water supply systems [FARRENY *et al*. 2011]. In addition to the significant benefits of saving through the use of rainwater, there are other benefits, e.g. the use of soft rainwater improves plant vegetation [SINGH *et al*. 2013]. In the catchment area there is a balance between the amount of precipitation and the amount of water used for drainage, evaporation and retention in this area. The existence of such a balance is based on the concept of water balance. The water balance can be determined for large areas, such as a country or catchment area covered with peat bogs [GRZYWNA *et al*. 2016a], lakes [DAWIDEK, FERENCZ 2014] or forests [STASIK *et al*. 2008].

The geospatial methods, originally applied in geological research, now are also used to interpret economic, social and environmental issues, medicine [FENG *et al*. 2004; LAKHANKAR *et al*. 2010]. Methods like Inverse Distance Weighted (IDW) kriging, Radial Basis Functions (RBF), polynomial or spine interpolation allow to map the phenomena that occur in the natural environment. In recent years has soil components is crucial into consideration the information on the location of the examined parameters, which traditional statistical analyses do not provide. Many other studies in recent years have shown comparisons of various spatial methods to describe phenomena related to different types: meteorological data [HADI, TOMBUL 2018], groundwater pollution [GONG *et al*. 2014] or, landscape structure soil components [MENG *et al*. 2013]. The accurts varies depending on the reduction of the data grid and the individual parameters. One of these methods is kriging, which is a technique that allows optimal and unbiased estimates of regionalized variables at unstapled locations to be made using the structural properties of a semivariogram and an initial dataset [GRZYWNA *et al*. 2016b]. Many other studies in recent years have shown that: soil component kriging technique were used in the analysis. The estimation of spatial autocorrelation in the kriging technique is based on the experimental semivariogram [ZAWADZKI 2011]. If the semivariogram model and the kriging procedure adequately reproduced the observed

values, the summary statistics would have satisfied the criteria given below and described in other publications [GERMANN, JOSS 2001; UYAN, CAY 2013].

The aim of the paper is the application of the ordinary kriging method to develop map the spatial variability of precipitation. It will help in the assessment of the possibility of utilizing rainfall in the moderate climate in Poland in the context of the climate changes. On the basis of kriging method the country was divided into areas with homogeneous precipitation amounts.

MATERIAL AND METHODS

Poland is located in the central part of Europe, in the zone of moderate latitudes. Its location in the moderate zone results in high variability of weather conditions from month to month and from year to year. This is related to frequent and active movement of air masses.

The study uses meteorological data regarding average monthly precipitation values from 53 meteorological stations from the years 1981–2010. The data was obtained from the Polish Institute of Meteorology and Water Management (Pol. Instytut Meteorologii i Gospodarki Wodnej). The station selection was dictated by the necessity to consider the variability of the amounts of annual precipitation in the whole country. The obtained data provided the basis for the calculation of mean annual precipitation totals, as well as precipitation totals in the summer half-year (from May to October) and in the winter half-year (from November to April) in the years 1981–2010 for the Poland. The spatial distribution of mean precipitation totals for the entire year, the winter and summer half-year in the territory of Poland were estimated based on the source data.

Worldwide analyses of spatial variability of precipitation have been conducted since the beginning of the previous century in world. Various methods have been applied for these purposes: Thiessen polygons, inverse distances, triangulation, isohyets, and polynomial interpolation. With time, geostatistical methods began to be applied in different disciplines, such us: meteorology, hydrology, soil components and many more [GOOVAERTS 2000].

The experimental semivariograms were fitted with various theoretical models. The theoretical model that gave the minimum standard error was chosen for further analysis. The adequacy of the fitted models was checked on the basis of validation tests. In this method, known as a jack-knifing procedure, kriging is performed at all the data points, ignoring, in turn, each of them one by one. Differences between estimated and observed values are summarized using cross-validation statistics [KREŠIĆ, MIKSZEWSKI 2013]. For all points, cross-validation sequentially omits a point, predicts its value using the rest of the data, and then compares the measured and predicted values. The calculated statistics serve as diagnostics that indicate whether the model is reasonable for map production.

Differences between estimated and observed values are summarized using the cross-validation statistics: mean prediction error (*ME*), root-mean-square prediction error (*RMSE*), average standard error (*ASE*), mean standardized prediction error (MSE), and root mean-square standardized

prediction error (*RMSSE*). If the semivariogram model and kriging procedure adequately reproduce the observed value, the summary statistics should satisfy the criteria [NA-MYSŁOWSKA-WILCZYŃSKA 2006; UYAN, CAY 2013].

The precipitation maps were produced with the ArcMap module from GIS software package ArcGIS 10.6. Geospatial interpolation was done using ordinary kriging method available in geostatistical wizard from ArcGIS Geostatistical Analyst extension.

RESULTS

The first stage of geospatial analysis was explorative data analysis. Values of mean precipitation totals from the years 1981–2010 for the entire year were within a range from 500 up to 970 mm. The mean precipitation value equaled 606.66 mm, and the standard deviation of 88.49. Mean values from the winter half-year varied from 163 to 329 mm, and from the summer half-year from 313 to 651 mm. Due to the asymmetry of the distribution of the analyzed variables and high kurtosis values, the data were subject to logarithmic transformation for all periods.

The performances of the predictions were assessed using the cross-validation technique, in which the accuracy of the surface generated was examined. The cross-validation results that were used to determine the validity of the fitted model and the semivariogram parameters are shown in Table 1. The jackknifing procedure results showed that the selected model and its parameters adequately described the measured data. The jackknife method is often used to calculate the impact of individual measurements on the estimate of the considered parameter. It is resample method, in which subsamples are created from original one by omitting 1 or more subsequent observation and predicting values using the data at the rest of the locations [WANG, YU 2019]. This process allows the detection of outliers, which disturbed modeling.

Table 1. Cross validation results for the kriging model in the Poland (1981–2010)

Series	Time	Value in season	
	year	summer	winter
ME	−0.457	−0.2722	−0.00165
RMSE	62.83	39.6359	26.997
MSE	−0.00452	0.003408	−0.00162
RMSSE	0.957	0.9102	0.00126
ASE	62.874	39.710	27.9773

Explanations: *ME* = mean prediction error, *RMSE* = root-mean-square prediction error, *ASE* = average kriging standard error, *MSE* = mean standardized prediction error, *RMSSE* = root mean-square standardized prediction error.
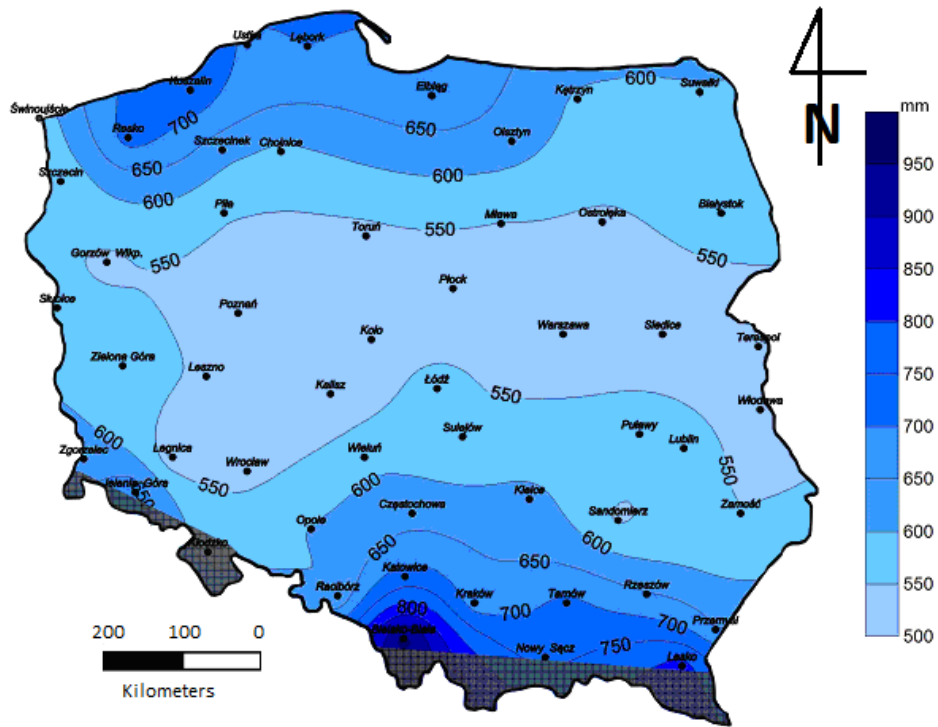Source: own study.

The values obtained in Table 1 suggest very good adjustment of the model to empirical data. *MSE* and *ME* values of 0 indicate a perfect fit. According to MORIASI *et al.* [2007], the model is very good if *ME* is less than ±10%. The greatest error of *RMSE* was obtained for precipitation from the winter half-year, and the lowest for annual precip-

itation. Considerably better information can be obtained based on relative *ME* error. The values of errors vary from 0.001 to 0.457%. The prediction error calculated using the jack knife cross-validation method also do not indicate significant outliers that disturb precipitation modelling. Values of *RMSSE* are small, and *ASE* are very close to *RMSE*. According to the criterion of estimation, results from cluster analysis correspond to the very good model.

Based on the analysis of spatial variability, equal rainfall intervals were generated every 50 mm. 10 intervals of equal precipitation were generated for the annual period. The first compartment (rainfall is 500–550 mm) covers 15 stations located in central Poland. In the years 1981–2010, the lowest rainfall was recorded at the Kalisz station (500 mm). The second compartment (550–600 mm) covers 13 stations located North, South and West of the first area. The third compartment (600–650 mm) includes 6 stations. The fourth compartment includes 5 stations with rainfall ranging from 650 to 700 mm. The fifth compartment includes 3 stations with precipitation ranging from 700 to 750 mm. The ranges 800–850 mm and 950–1000 mm include 1 station, Lesko and Bielsko-Biała, respectively. No stations are located in the 750–800 mm, 850–900 mm, 900–950 mm ranges. During the multiannual period 1981–2010, the highest precipitation was recorded at the Bielsko--Biała station (970 mm). The average calculated for the analyzed multi-year period was 607 mm.

Nine intervals were generated for mean precipitation of the summer half-year (Fig. 1). The first group included 19 stations. The stations were located in central Poland. They were characterized by a precipitation at 300–350 mm. The lowest annual precipitation total was recorded in Gorzów Wielkopolski (313 mm). The second group covered 18 stations located north and south of the previously designated belt. They are characterized by a precipitation at 350–400 mm. The third group comprised 12 stations with precipitation at 400–450 mm. The fourth group included 1 station, characterized by a high value of precipitation at 450–500 mm. The fifth group comprised 1 station with the precipitation at 500–550 mm. The last group included 1 station with precipitation at 550–600 mm. No stations are located in the 600–650 mm ranges. In Bielsko-Biała, it reached the highest value of 651 mm (Fig. 1). The average precipitation total in the summer half-year was 384 mm.

In the winter half-year, the highest precipitation values occurred locally in the stations Resko and Bielsko-Biała (319 mm). Somewhat lower precipitation at 250–300 mm was observed in the north-western part of the country, and in the south-eastern part (stations Katowice and Lesko). This group covered 7 stations. The third group comprises 28 stations with a precipitation at 200–250 mm. The lowest precipitation at 150–200 mm were recorded in the eastern and south-western part of Poland and in the stations Płock, Toruń, Koło and Kalisz. This group includes 16 stations. In Legnica, it reached the lowest value of 163 mm. The average precipitation total in the winter half-year was 224 mm (Fig. 1).
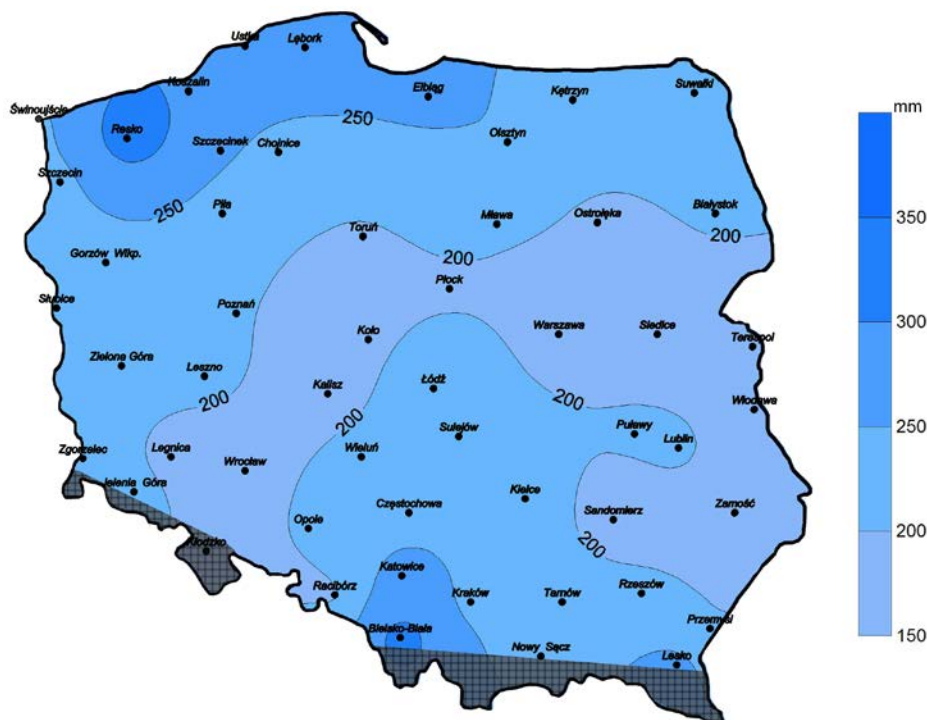
Fig. 1. Spatial distribution of precipitation in Poland for the years 1981–2010:
a) annual, b) summer half-year, c) winter half-year; source: own study

DISCUSSION

The research presented in the paper is in accordance with the estimated mean precipitation in the periods 1891–1960 and 1951–1980 [CZARNECKA, NIDZGORSKA-LENCE-WICZ 2012]. Mean annual precipitation for the whole of Poland, calculated on the basis of measurements from all meteorological stations, during the successive periods: 1891–1930, 1931–1960, 1961–1990 and 1971–2000, reached the values of: 604, 600, 609 and 601 mm, respectively [ZAWORA, ZIERNICKA 2003]. Annual precipitation of period 1981–2010 was 607 mm. Averaged annual precipitation in the study period, in comparison to the standard 30-year period 1961–1990 and 1971–2000, were subject to no substantial changes [LORENC 2005; ZIERNICKA-WOJTA-SZEK 2006]. Differences of up to 6 mm, i.e. 1%, were not statistically significant. The variability of precipitation expressed by the value of the variability coefficient, constituting a ratio of the standard deviation to the mean value, decreased. The value of the coefficient for the multiannual period 1971–2000 for annual totals was 0.168, and for the multiannual period 1981–2010 it equaled 0.146. A comparison was made of the spatial distribution of annual precipitation in Poland in 1971–2000 and 1981–2010. The following differences appear from map analysis: a slight increase in the region of Gdańsk and Szczecin, a slight decrease in the area of Terespol. In addition, the rainfall below 550 mm shifted from western Poland to the east. There was no significant change in the amount of precipitation in the rest of the country. However, the average annual rainfall was similar in both periods.

CONCLUSIONS

The estimated average precipitation from the 53 meteorological stations was estimated at 607 mm. Precipitation in the Poland is characterized by high spatial and temporal variability. The lowest precipitation were recorded in the central part in lowlands, where they equaled even 500 mm (Kalisz). The highest annual precipitation were determined in the south in the mountains, where they reached up to 970 mm (Bielsko-Biała). Annual precipitation shows uneven distribution within a year. The average precipitation in the summer half-year is 382 mm (63% of the annual total). The average precipitation in the winter half-year is 224 mm (37%).

The accurate estimation of the precipitation pattern in complex areas requires a very dense network of measuring stations. This paper uses the interpolation method kriging to analyze the spatial variability of precipitation. The techniques were illustrated by using annual and half-year precipitation observations collected at 53 climatic stations in Poland. In the case study, cross-validation was used to compare the prediction performances of the three period. Kriging gave the best performance from a statistical point of view.

Their application is justified especially in areas where landform is very complex. In accordance with the assumptions, the mean prediction error (*ME*), mean standardized prediction error (*MSE*) values are approximately zero. Kriging was applied for the estimation of precipitation also in other countries. The calculated values of estimation errors suggest very good adjustment of the model to the empirical data.

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