Spatial-temporal statistical analysis of daily rainfall for Košice station in eastern Slovakia

A. Repel¹, V Jothiprakash², Helena Hlavatá³ S Galas⁴, and M M Portela⁵

¹ Institute of Environmental Engineering, Department of Environmental Engineering, Faculty of Civil Engineering Technical University of Košice, Vysokoskolska 4, Košice 04200, Slovakia
² Department of Civil Engineering, Indian Institute of Technology, Bombay, Mumbai 400076, India
³ Slovak Hydrometeorological Institute, Branch Office Košice Ďumbierska 26, 041 17 Košice, Slovakia
⁴ Department of Environmental Analysis, Geological Mapping and Economic Geology, AGH Krakow, Adama Mickiewicza 30, 30-059 Kraków, Poland
⁵ Instituto Superior Tecnico, Universidade de Lisboa, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal

Abstract. Hydrologic processes, especially rainfall is characterized for their variability in time and space. These processes are known as stochastic processes. For engineering practice it is very important to know the behavior of time series for long period. This paper is focused on spatial-temporal analysis of daily rainfall for Košice station in eastern Slovakia. Time series of daily rainfall from period 1951 to 2018 was analyzed by basic statistical analysis and also by descriptive statistical analysis. Results of basic statistical analysis showed the basic parameters of time series, such as average daily rainfall, maximum daily rainfall or total annual daily rainfall and other basic parameters. Descriptive analysis is used to describe behavior of a time series. Results showed, that time series of daily rainfall in Košice station is stationary, homogeneous and there is no noise in time series, which is good for using this time series in further research.

1. Introduction
Distribution of rainfall and its changes during the time is one of the most important aspects of climate change and it needs detailed investigation is the time. One of the most important climatic variables is rainfall and it is because it affects important hydrological events such as floods and droughts. Rainfall and other hydrologic processes are known as stochastic processes. It means, that they evolve in space and time in a way that is partly predictable or deterministic and partly random [1]. Rainfall and other hydrological processes are characterized for their variability in space and in time. There are many ways how to analyzed the variability, for example by examining trend, stationarity, homogeneity, periodicity or noise [2]. Long term rainfall data presents time series, which is a series of data points indexed in time order. Many authors in the world analyzed historical time series of rainfall in many countries in the world. In Asia, between Nepal and Tibet in the Himalayan region was showed that the annual precipitation amount is increasing in the period between 1943 and 1993 [3]. Similar results were presented also in other studies in many Canadian series [4] or in many places in South America, where authors analyze the
number of rainy days per year and the daily rainfall amount [5]. In Europe, studies on Ireland series collected from 1940 to 1990 confirm the increasing of the total annual precipitation, in particular on the west coast [6]. Study from Ireland also shows how the intensity of rainfall is growing up and the return period of the extreme events is reducing. Results of this study is, that 30-year return period events are becoming 10-year events nowadays [7]. In Italy, it was proved that dry periods tend to be longer with increasing variability of the length of the dry spells and this is also associated with shorter duration of rain episodes with an evident effect on rainfall extremes [8]. In Slovakia, there are not many studies of rainfall time series in last years. Daily rainfall data were analyzed by Dub in 1950 and second, very complex analyze was done in 1973 by Šamaj and Valovič. Since these studies, not many authors have dealt with this issue. Statistical analysis of daily rainfall is very important for further use of data, for example for engineering practice.

2. Study area and data
Slovakia country with area of 49 035 km² is located in central Europe. There are very diverse topographic patterns throughout Slovakia. The relief declines from the Greater Carpathian range in the North, with an elevation 2655m at Gerlachovsky peak to lowlands in western and eastern part of Slovakia with lowest altitude around 100m. The city of Košice is located in the eastern part of Slovakia in the Košice region, near the border with Hungary (20km), Ukraine (80km) and Poland (90km) at the crossroads of historic trade routes. It is about 400 km from the capital Bratislava. City of Košice lies in the river Hornad basin in the altitude 202 m above the sea level and GPS coordinates of the city are **48°43'15.994"N, 21°15'28.447"E**. Territory, where Kosice city is situated belongs to the northern temperate climatic zone with a regular change of four seasons of the year and variable weather with a relatively smooth distribution of precipitation during the year. Average annually temperature in Košice is around 9°C, average annually rainfall is around 650mm [9].
For the statistical analysis of rainfall data was used manually recorded daily data from period 1951 to 2018, the observation period is 68 years. Time series of manually recorded daily rainfall data is shown in Figure 1. These data were provided by Slovak hydrometeorological institute (SHMI). Basic and descriptive statistical analysis were done for the time series. Statistical analysis includes trend, homogeneity, periodicity and noise for the time series.

![Figure 1. Time series of daily rainfall in Košice station for the period from 1951 to 2018](image)

3. Methods and methodology
The temporal variation and behavior in the rainfall data time series was analyzed using several statistical tests. Two types of statistical analysis were done and it was basic statistics and descriptive statistics. Basic statistics consist of mean (average), standard deviation, skewness, kurtosis, maximum, percentage of 0 and number of 0 what presents number of days without rainfall (dry days). Descriptive statistics consist of trend analysis, stationarity, homogeneity, periodicity and noise tests. Trend in the time series
is estimated using Mann Kendall (MK) test, Sen’s slope and Spearman’s rank correlation. Stationarity of time series was tested by ADF test, Phillips-Perron test and KPSS test. Stationarity tests serve to analysis the behavior of the mean and variance in time series. Homogeneity tests indicates the variations in the time series (like stationarity tests) but homogeneity analysis also gives the break point where changes happened in time series (if there is break point in time series). Homogeneity tests used in present study are Pettit test, SNH test, Buishand’s test, Von Neumann ratio. For determining white noise in time series, these tests are used: Box Pierce, Ljung-Box, McLeod-Li, Fisher’s kappa, Bartlett’s Kolmogorov-Smirnov. For determining the periodicity of time series, spectral analysis was used. All the tests were carried out at 5% significance level. In all the tests, \( p \) value is calculated, and if the \( p \) value is less than 0.05 (5% significance level), then the null hypothesis is rejected and the alternative hypothesis is accepted. The methodology and types of tests used in the present study are shown in Figure 2.

![Figure 2. Flow chart of methodology used in the study](image)

4. Results and discussion

4.1. Basic statistics

The basic characteristics of the time series, such as maximum or average rainfall are shown in Table 1. Average annual rainfall is 614.8 mm per one year. Maximum of annual rainfall was in 2010 and minimum was in 1956. Maximum daily rainfall was observed in august 1963 and it was 110.5 mm.

| Total of rainfall (in mm) (1.1.1951-31.12.2018) | 41 806.10 |
|-----------------------------------------------|----------|
| Average daily rainfall (in mm)                | 1.684    |
| Average annual rainfall (in mm)               | 614.8    |
| Maximum and minimum annual rainfall (in mm)   | 958.9 (in 2010), 418.9 (in 1986) |
| Maximum daily rainfall (in mm)                | 110.5 (13.8.1963) |
| Average number of dry days in year            | 220 (60.3%) |
For each day in the year, the maximum of daily rainfall was found in 68 years of observing. Time series of maximum daily rainfall for each day is shown in Figure 3.

![Figure 3. Maximum of daily rainfall for each day for the period from 1951 to 2018](image)

From the Figure 3 it is clear, that maxims of the daily rainfall occurred especially in summer period from Jun to August and these rainfalls are presented as storms from the heat. Months with the lowest maxims of daily rainfall are from January to April.

![Figure 4. Average daily rainfall in the period from 1951 to 2018](image)

Average daily rainfall remains constant over the observation period, what is shown in Figure 4. There is also no trend in average daily rainfall during last 68 years (from 1951 to 2018). Average daily rainfall was maxim in 2010 and it was 2.627mm per day.

Maximum of daily rainfall in each year is shown in Figure 5. It can be said that there is also no change in these values. Highest maximum daily rainfall was observed in 1963 and in 2010.
In the Figure 6, there is percentage of dry days for each year in the period from 1951 to 2018. Percentage of dry day means the quantity of days without rainfall in each year. Average percentage is 60% and from the Figure we can said, that there is positive trend in percentage of dry days. It means, that there are more dry days in one year than in the past.

4.2. Descriptive statistics
Descriptive statistical analysis consists of trend, stationarity, homogeneity, periodicity and noise tests and was done on time series of daily rainfall. A description of each method is given in the section Methods and the methodology. The results of descriptive statistical analysis are in Table 2.

| TREND          | STATIONARITY       | HOMOGENEITY        | PERIODICITY     | NOISE             |
|----------------|--------------------|--------------------|-----------------|-------------------|
| Mann Kendall:  |
| Kendall’s tau =|
| -0.0066        |
| p-value = 0.16 |
| alpha= 0.05    |
| NO TREND       |
| ADF test       |
| p-value= 0.00001|
| alpha= 0.05    |
| STATIONARY     |
| Pettit test:   |
| p-value= 0.278 |
| alpha= 0.05    |
| HOMOGENEOUS    |
| Phillips-Perron|
| p-value= 0.0015|
| alpha= 0.05    |
| STATIONARY     |
| SNH test       |
| p-value= 0.550 |
| alpha= 0.05    |
| HOMOGENEOUS    |
| 365.25 days    |
| Box pierce:    |
| p-value= 0.0001|
| alpha= 0.05    |
| NO NOISE       |
| McLeod-Li:     |
| p-value= 0.0001|
| alpha= 0.05    |
| NO NOISE       |
| Spearman’s     |
| rank: Coeff. = 0.35 |
| WEAK TREND     |
| KPSS test      |
| p-value= 0.972 |
| alpha= 0.05    |
| STATIONARY     |
| Buishand’s :   |
| p-value= 0.6992|
| alpha= 0.05    |
| HOMOGENEOUS    |
| Von neumann ratio: |
| Fisher’s kappa: |
The trend in the daily rainfall time series was estimated using MK test, Sen’s slope test and Spearman’s rank correlation coefficient methods. Globally we can say that there is no trend in the time series. The stationarity test was carried out by ADF test, Phillips-Perron test and KPSS test. The result of all the three methods concludes that the daily rainfall series in Košice station is significantly stationary at 5% significance level as shown Table 2. It means, that any hydrologic model can be used to model daily rainfall. It can be concluded that the daily rainfall series is not showing much variation in mean and standard deviation. The homogeneity was tested using Pettitt’s test, standard normal homogeneity (SNH) test, Buishand test and von Neumann’s test. Time series of daily rainfall in Košice station is homogeneous, what was proven by all four tests at 5% significance level. It means, that there is no the break point in the time series. From the table 2 it is clear, that there is no white noise in the time series and periodicity of the series is 365 days.

5. Conclusion

Climate change is a frequently mentioned term nowadays. This paper is focused on the evaluation of daily rainfall and statistical analysis of daily rainfall in Košice station in the period from 1951 to 2018. Statistical analysis was divided into two parts, basic statistical analysis and descriptive statistical analysis. Basic statistical analysis consists of basic parameters, such as mean, maximum, minimum, total, standard deviation, number and percentage of zeros and other. Basic statistical analysis is done in tabular and also in graphic form. Average daily rainfall in Košice station is 1.684 mm per day, average annual rainfall is 614.8 mm per year. The rainiest year was the 2010 with total annual rainfall 958.9 mm. Average daily rainfall remains constant over the last 68 years. There has been a slight increase in the number of days without rainfall in recent years, while the annual total rainfalls remain approximately the same. Descriptive statistical analysis shows the characteristics of the time series of daily rainfall. Descriptive statistical analysis consists of trend, stationarity, homogeneity, periodicity and noise tests. These parameters were tested by multiple tests. The results show that the time series of daily rainfall does not show positive or negative trend and the time series is stationary, homogeneous with periodicity 365.25 days and there is no noise in time series. These results show that the data in time series are reliable and should be used for further analysis or more complex statistical methods.

6. References

[1] V. Te Chow, *Applied hydrology* (Tata McGraw-Hill Education, 2010)
[2] Drissia T K, Jothiprakash V and Anitha A B 2019 Statistical classification of streamflow based on flow variability in west flowing rivers of Kerala, India *Theor. Appl. Climatol.* 137 1643-1658
[3] Cislaghi M, De Michele C, Ghezzi A and Rosso R 2005 Statistical assessment of trends and oscillations in rainfall dynamics: Analysis of long daily Italian series *Atmos. Res.* 77 188-202
[4] Sharma K P, Moore B and Vorosmarty C J 2000 Anthropogenic, climatic, and hydrologic trends in the Kosi Basin, Himalaya *Clim. Change* 47 141-165
[5] Hamilton J P, Whitelaw G S and Fenech A 2001 Mean annual temperature and total annual precipitation trends at Canadian biosphere reserves *Environ. Monit. Assess.* 67 239-275
[6] Lucero O A and Rozas D 2002 Characteristics of aggregation of daily rainfall in a middle-latitudes region during a climate variability in annual rainfall amount *Atmos. Res.* 61 35-48
[6] Hoppe H and Kiely G 1999 Precipitation over Ireland—Observed change since 1940 *Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere* **24** 91-96

[7] Kiely G 1999 Climate change in Ireland from precipitation and streamflow observations *Adv. Water Resour.* **23** 141-151

[8] Cislaghi M, De Michele C, Ghezzi A and Rosso R 2005 Statistical assessment of trends and oscillations in rainfall dynamics: Analysis of long daily Italian series *Atmos. Res.* **77** 188-202

[9] L. Miklós 2002 *Landscape atlas of the Slovak Republic*

**Acknowledgments**

This work has been supported by the Slovak Research and Development Agency by supporting the project SK-PT-18-0008 and project SL-PL-18-0033.