How to cite: Leščešen, I., Basarin, B., Pavić, D., Mesaroš, M. (2023) Extreme Precipitation Analysis in Novi Sad. *2023 "Air And Water – Components of the Environment" Conference Proceedings*, Cluj-Napoca, Romania, p. 140-147, DOI: 10.24193/AWC2023_14.

EXTREME PRECIPITATION ANALYSIS IN NOVI SAD

Igor LEŠČEŠEN[1] , Biljana BASARIN[1], Dragoslav PAVIĆ[1], Minučer MESAROŠ[1]

DOI: 10.24193/AWC2023_14

Abstract. A direct consequence of the global climate change is the alteration of seasonal precipitation patterns and as a consequences pluvial flood in urban areas becoming more frequent. In this study, precipitation patterns for the city of Novi Sad were analysed for the 1961-2020 period. For the extraction of extreme precipitation values, the peaks-over-threshold method was applied with the threshold level set at the 90th percentile. For the inspection of time-dependent occurrence rates and assessment of significant changes, a Kernel estimation was applied. For the assessment of the significances of the occurrence rate estimation Cox-Lewis (CL) test was used. The obtained results indicate decreasing trends in occurrence rate and frequency of minor and strong events in the second half of the 20th century. On the other hand, we argue that there is the increase of occurrence rate and frequency of extreme events at the beginning of the new millennia. Regarding the occurrence and frequency of the extreme events a clear increase in occurrence rate and frequency can be observed, especially when frequency is observed as from the year 2000 a total of 11 of these extreme years occurred in contrast to six events prior 2000. The application of the CL test yields a decreasing trend of strong events and increasing trend of extreme events. The *p* values are as small as 0.0336 and 0.0034 respectively. The test confirms what confidence bands display, i.e., more and more extreme participations per decade towards the modern times.

Keywords: precipitation, flood, urban, Novi Sad, Serbia

1. INTRODUCTION

Pluvial flooding is directly caused by intense rainstorms when the amount of precipitation exceeds the stormwater drainage system's capacity and the soil's ability to infiltrate the water (Rosenzweig et al., 2018; Kundzewicz and Pińskwar, 2022). This problem is especially enhanced in cities with

[1] Department of Geography, Tourism and Hotel Management, Faculty of Sciences, University of Novi Sad, Trg Dositeja Obradovića 3, 21000 Novi Sad, Serbia, Coresponding author: igorlescesen@yahoo.com

insufficient or non-existent sewer systems (Acosta-Coll et al., 2018). According to the 2021 report from the Intergovernmental Panel on Climate Change (IPCC), it is widely accepted that the increase in heavy rainfall seen around the world is a result of global climate change processes (IPCC, 2021). Urban areas are usually affected by this type of flooding so this has become a growing problem due to a combination of rapid urbanization and a simultaneous increase in heavy precipitation caused by climate change (Papalexiou & Montanari, 2019; Rosenzweig et al., 2018). So, increasing precipitation along with urbanization are unavoidably leading to a more frequent occurrence of urban pluvial flooding, also known as flash flood (Savić et al., 2020). Several research in recent years has suggested that due to the frequent nature of pluvial floods, total damage to property caused by those type of floods equals or may even exceed damage from river flood (Nicklin et al., 2019; Prokić et al., 2019).

This problem is getting more and more attention in Novi Sad which is the second largest city in Serbia. The constant migrations to the city, construction of the new apartment blocks, streets and boulevards are followed by decreasing areas with natural vegetation all over the city (Savić et al., 2020). The increasing urbanization causes an expansion of impermeable areas and the higher proportion of sealed soils thus resulting in an increased runoff volume and a decreased response time of a catchment (Prokić et al., 2019). There are several recurrent sites where pluvial floods occur after each extreme precipitation, i.e., traffic intersections, underpasses, streets, etc (Fig. 1). Detection of those high hazard zones is crucial for planning and application of pluvial flood mitigation measures in the future.

Fig. 1. ***Urban flooding in Novi Sad 29th of June 2018 (a. Pariske komune street; b. Overpass in Kisačka street; c. Overpass in Temerinska street), source:*** https://www.mojnovisad.com/vesti/novosadske-ulice-pod-vodom-dezurne-ekipe-na-terenu-foto-id22678.html

This research is focused on the extreme precipitation events and pluvial floods caused by them and can have an important role in obtaining knowledge and better understanding of these climate extremes and natural hazards and their impact on human societies.

2. RESEARCH AREA

Novi Sad is the second largest city in Serbia located in the Vojvodina province, on the banks of the Danube River. Novi Sad has Cfb temperate climate (Kottek et al., 2006) with the coldest month being January with − 0.3 °C and the warmest being July with 21.8 °C. The mean annual precipitation is 623 mm for the period 1949–2015 (Savić et al., 2018). The urbanized area is approximately 112 km^2 with a population around 325,000.

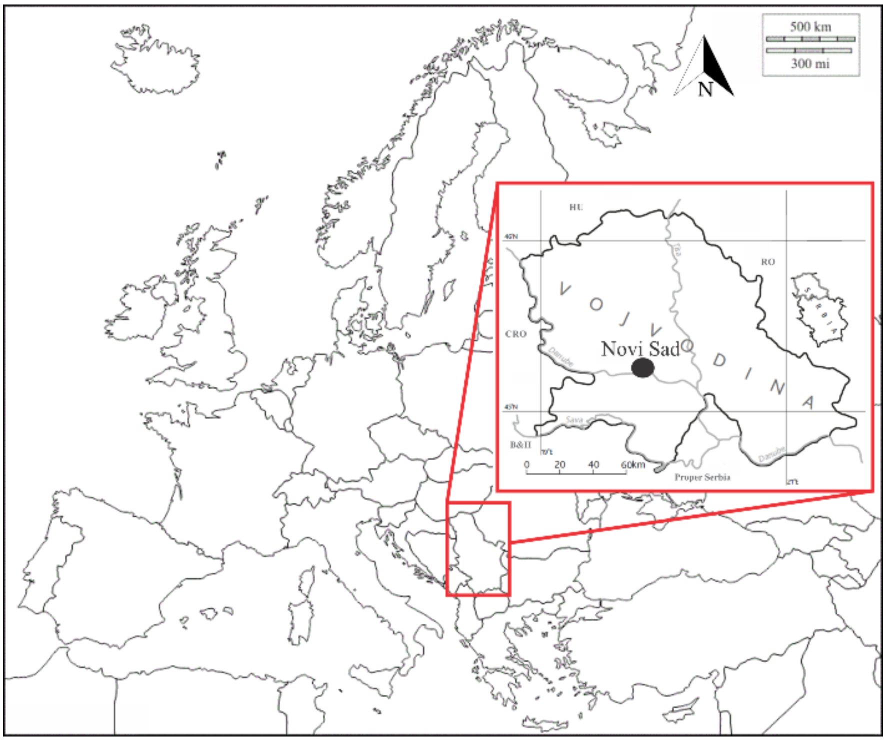

Fig. 2. ***Geographical location of Novi Sad***

3. DATA AND METHODS

For the purpose of this study, daily precipitation data was used for the 1961-2020 period. The sixty-year time span provides reliable results taking into account that the average record length recommended by the WMO is 30 years. For the extraction of extreme precipitation values, the peaks-over-threshold (POT) method was applied with the threshold level was set first at the 90^{th} percentile to exclude days with no or minimal precipitation. The 90^{th} percentile for this data series is 11.4 mm. To achieve data independence, a minimum time span of 15 days between two consecutive peaks was applied to achieve independence (Mallakpour and Villarini, 2015; Mudelsee, 2020). For the inspection of time-dependent flood occurrence rates and assessment of significant changes, a kernel estimation was applied with confidence bands. A Gaussian kernel function, *K,* was applied to weight observed flood dates, *T*(*i*), *i* = 1,…, *N* (number of floods), and estimate the occurrence rate, λ, at time t as:

$$\lambda_{(t)} = \sum_i K\left(\left(t - T_{(i)}\right)/h\right). \quad (1)$$

Cross-validation was used to selection the bandwidth (*h* = 10 years). Confidence bands (90%) around $\lambda(t)$ were determined using a bootstrap resampling technique. This procedure was repeated 2,000 times, and a 90th percentile-*t* confidence band calculated. To assess the significances of the occurrence rate estimation curves Cox-Lewis test was applied (Mudelsee et al., 2004). This test is a test which is usually applied on the extremes: whether or not there is an upward or a downward trend. It is not a test on the "general trend" based on mean values.

In this study we analysed two group of events that were based on water drainage systems absorption amount (20 mm). These events when precipitation ≥ 20 mm are also considered as very heavy precipitation days (Zhang et al., 2011; Savić et al., 2020) and second group events are events above 50mm, and can be considered as extreme precipitaiton. The second threshold was set based on most recent precipitation amount that occurred on 23 of August 2022 (50 mm).

4. RESULTS AND DISCUSSION

Daily precipitation data above the threshold of 90th percentile is presented in Fig. 3.

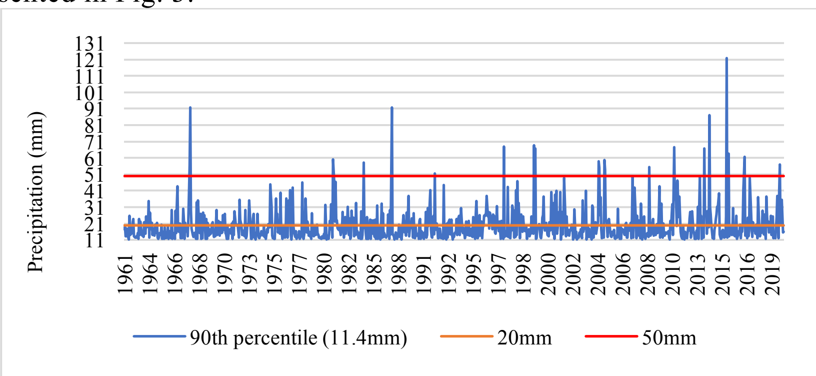

Fig. 3. ***Daily precipitation above three selected thresholds***

From the figure, it is noticeable that since the beginning of the 21st century the number of extreme events with precipitation above 50 mm has increased by 30%.

The obtained results indicate increasing trend in occurrence and frequency in the 20th century, following by decreasing trends in the first two decades of 21st century. On the other hand, we argue that there is the increase of occurrence rate and frequency of extreme events at the beginning of the new millennia (Fig. 4 and table 1).

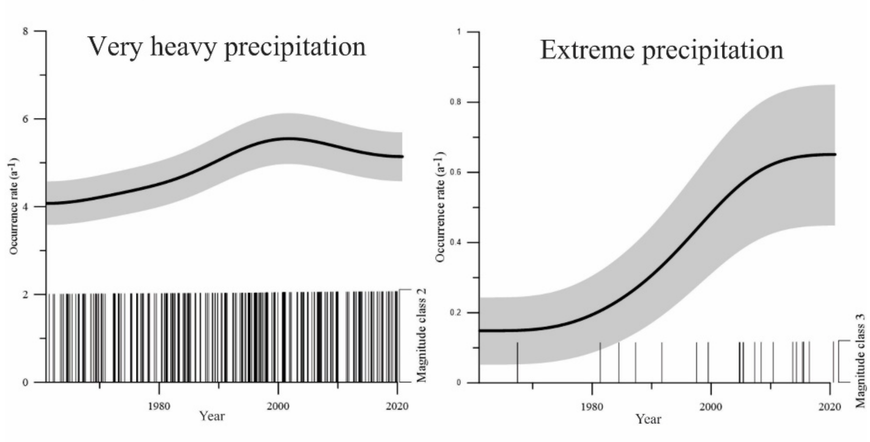

Fig. 4. ***Occurrence rates (solid lines) of precipitations at Novi Sad station for very heavy precipitation and extreme precipitation with bootstrap 90% confidence band (shaded). Kernel estimation using bandwidth of 10 years is applied to the precipitation dates. For more details on the statistical methodology, see Mudelsee (2020).***

Fig. 4 shows estimated occurrence rates of magnitude 2 and 3 precipitation events at Novi Sad station. The occurrence and frequency of strong precipitation have been steadily increasing from the beginning of observed period up to the 2000s, after the occurrence was stabilized at around five events per year (at the beginning of the period there were 4 events per year). Regarding the occurrence and frequency of the extreme events (magnitude 3) a clear increase in occurrence rate and frequency can be observed, especially when the frequency is observed as from the year 2000 a total of 11 of these extreme years occurred in contrast to six events prior 2000.

Table 1. Results of Cox and Lewis model for trend estimation for Novi Sad station

Class	**U**	**p**
Strong	-1.83	0.0336
Extreme	2.709	0.0034

The application of the Cox and Lewis test through the instrumental period of daily precipitation values from 1961-2020 yields a highly significant result, decreasing trend of strong events and increasing trend of extreme events (Table 1). The *p* values are as small as 0.0336 and 0.0034 respectively. The test confirms what confidence bands display, more and more extreme participations per decade towards the modern times.

The summers in Novi Sad became warmer, which can be seen in the increase of annual frequency of numbers of tropical days, anomalies of maximum summer temperatures above normal, numbers of heat waves and the total number of days in the heat wave (Malinović-Milićević, 2013). In the future, the further increase of extreme precipitation can be expected as to the Clausius-Clapeyron equation that indirectly quantifies a theoretical link between the warming and the pluvial flood hazard. The warming leads to an increase in the atmosphere's water holding capacity and this further increases the intense precipitation potential. It should be noted that an increase in the potential value does not have to lead to an increase of the actual value. According to the Clausius-Clapeyron equation, intense daily precipitation may increase at the rate of about 6–7% per warming at one degree Celsius, while for very extreme sub-daily precipitation, even higher scaling rates may apply (Kundzewicz and Pińskwar, 2022).

Creating the pluvial flood warning system is challenging, as it requires the combination of rainfall forecasts with a local information about the urban drainage system, topographic data, land use and soil moisture preconditions at a high spatial and temporal resolution. To combat the pluvial floods in Novi Sad it is necessary to set several local sensor networks that will automatically issue a flood warning in flood prone areas once a measurement (i.e., observed rainfall intensity or amount) exceeds a pre-defined threshold so the appropriate measures could be conducted (i.e., traffic redirection).

5. CONCLUSION

Analysis of observed records determines that pluvial floods are increasing if extreme precipitation is on the rise. The main reason for pluvial floods in Novi Sad insufficient infiltration capacity and the conveying capacity of the drainage systems that can't absorb extreme precipitation amount. To improve sustainability of rapidly growing city, as Novi Sad clearly is, several factors could be developed or improved: (1) establishing the denser monitoring network of precipitation stations that would provide more accurate spatial tendencies of the precipitation; (2) the citywide reconstruction of drainage systems is necessary so the city can face the changing amount and frequency of the precipitations; (3) developing pluvial flood alert system based on amount of precipitation over the endangered parts od the city; (4) conducting the detailed and systematic research of extreme precipitation events and the resulting occurrence of pluvial floods in the future. These factors will provide an important contribution to local communities, policy makers and stakeholders towards developing flood protection protocols and measures as well as creating adaptation and mitigation strategies.

REFERENCES

1. Acosta-Coll, M., Merelo, F., Peiro, M.M., & De la Hoz, E. (2018). Real-Time Early Warning System Design for Pluvial Flash Floods—A Review. Sensors, 18, 2255. DOI:10.3390/s18072255
2. IPCC, 2021: Climate Change 2021 (2021): *The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, In press, doi:10.1017/9781009157896.
3. Kottek, M., Grieser, J., Beck, C., Rudolf, B., Rubel, F. (2006). World map of the Koppen–Geiger climate classification updated. *Meteorol Z* 15(3): 259–263. https://doi.org/10.1127/0941-2948/2006/0130
4. Kundzewicz, Z.W., Pińskwar, I. (2022). Are Pluvial and Fluvial Floods on the Rise? *Water*, 14, 2612. https://doi.org/10.3390/w14172612
5. Malinović-Milićević, S., (2013) Summer hazards in Novi Sad, International Conference "Natural Hazards - Links between Science and Practice", Belgrade, Serbia, 8-11 October, 2013
6. Mallakpour, I., Villarini, G., 2015. The changing nature of flooding across the central United States. *Nature Climate Change* 5, 250–254. doi:10.1038/nclimate2516.
7. Mudelsee M. (2020) *Statistical Analysis of Climate Extremes*. Cambridge, UK: Cambridge Univ. Press.
8. Mudelsee, M., Börngen, M., Tetzlaff, G., and Grünewald, U. (2004). Extreme floods in central Europe over the past 500 years: Role of cyclone pathway "Zugstrasse Vb". J. *Geophys. Res*., 109, D23101, doi:10.1029/2004JD005034.
9. Nicklin, H., Leicher, A.M., Dieperink, C., & Van Leeuwen, K. (2019). Understanding the Costs of Inaction – An Assessment of Pluvial Flood Damages in Two European Cities. Water, 11(4):801. DOI: 10.3390/w11040801
10. Papalexiou, S. M., & Montanari, A. (2019). Global and regional increase of precipitation extremes under global warming. *Water Resources Research*, 55(6), 4901–4914. https://doi.org/10.1029/2018WR024067
11. Prokić, M., Savić, S., Pavić, D. (2019) Pluvial flooding in Urban Areas Across the European Continent, *Geographica Pannonica*, Volume 23, Issue 4, 216–232

12. Rosenzweig, B. R., McPhillips, L., Chang, H., Cheng, C., Welty, C., Matsler, M., et al. (2018). Pluvial flood risk and opportunities for resilience. Wiley *Interdisciplinary Reviews: Water*, 5(6), e1302.
13. Savić S, Marković V, Šećerov I, Pavić D, Arsenović D, Milošević D, Dolinaj D,Nagy I, PantelićM(2018) Heatwave risk assessment and mapping in urban areas: case study for a midsized central European city, Novi Sad (Serbia). *Nat Hazards* 91(3):891–911. https://doi.org/10.1007/s11069-017-3160-4
14. Savić, S., Kalfayan, M., Dolinaj, D. (2020) Precipitation Spatial Patterns in Cities with Different Urbanisation Types: Case Study of Novi Sad (Serbia) as a Medium-sized City. *Geographica Pannonica*, Vol 24, Issue 2, 88–99.
15. Zhang, X., Alexander, L., Hegerl, G.C., Jones, P., Tank, A.K., Peterson, T.C., Trewin, B., & Zwiers, T.W. (2011). Indices for monitoring changes in extreme based on daily temperature and precipitation data. *WIREs Climate Change*, 2, 851-870. DOI:10.1002/wwc.147
16. https://www.mojnovisad.com/vesti/novosadske-ulice-pod-vodom-dezurne-ekipe-na-terenu-foto-id22678.html