Original scientific paper

UDK 551.583:005.334(497.6)
DOI 10.7251/COMEN2502222P

HOT EXTREMES ARE INCREASING IN THE CITIES OF BOSNIA AND HERZEGOVINA

Tatjana Popov*, Slobodan Gnjato, Goran Trbić

University of Banja Luka, Faculty of Natural Sciences and Mathematics, Banja Luka, Republic of Srpska

* Corresponding author: tatjana.popov@pmf.unibl.org

Abstract: The study addresses the issue of increasing hot extremes in selected cities of Bosnia and Herzegovina – Banjaluka, Sarajevo, and Mostar. Significant trends were determined for all six analyzed temperature indices – warm days (2.8–3.4% per decade), warm nights (2.5–4.3% per decade), tropical days (5.8–7.3 days per decade), extremely hot days (0.4–3.1 days per decade), tropical nights (0.2–6.6 days per decade), and warm spell duration index (6.0–7.4 days per decade). Furthermore, significant changes were observed between the last two standard climatological periods (1961–1990 and 1991–2020), indicating an increase in the average values of the indices and a shift of their distributions towards higher values. The observed changes have a substantial impact on outdoor thermal comfort in urban areas.

Keywords: hot extremes, warm days and nights, tropical days, extremely hot days, tropical nights, warm spell duration index, trend, climate normals, Bosnia and Herzegovina.

1. INTRODUCTION

One of the most prominent features of climate change in most regions of the world is the increase in extreme weather and climate events, including hot extremes. Frequency of occurrence, duration, intensity and cumulative heat of heatwaves have intensified since the 1950s in almost all regions of the world [1], driven by anthropogenic increase in greenhouse gases [2]. Globally, the average duration of heatwaves generally doubled in 1971–2020, with growth rates of 2 days per decade [3]. The magnitude of heat extremes, such as warm days (TX90) and warm night (TN90p), have also significantly increased [4]. In Europe, heatwaves with extremely high temperatures are now also occurring more frequently than at the end of the 20th century [5–6]. Several major record-breaking heatwaves occurred over the last two decades – in 2003, 2010, 2018, and 2021 [7].

An increase in hot extremes has also been observed in cities in the region. For instance, in Podgorica (Montenegro) research carried out for the period 1951–2018 found increase in occurrence of summer days, tropical days, tropical nights, days with maximum temperatures above 35°C and 40°C [8]. During the period 1960–2019, warm extremes increased in summer season in Zagreb, Croatia (in urban and suburb area) [9]. The increase in hot extremes (warm days, summer days, and heatwaves) was also evident in different parts of Serbia in 1949–2018. Particularly high frequencies of occurrence were recorded over the last twenty years [10]. In Serbia, particularly high increase was found for warm nights in summer (7 days per decade) [11].

The aim of this study is to analyze changes in hot extremes that have occurred since 1961 in three cities of Bosnia and Herzegovina – Banjaluka, Sarajevo, and Mostar. In addition to determining the trend, the study will also examine the changes that have occurred between the last two standard climatological periods, 1961–1990 and 1991–2020.

2. DATA AND METHODS

For the analyses of changes in hot extremes in the cities of Bosnia and Herzegovina daily maximum and daily minimum temperatures were used as input data. Data from three meteorological stations, each representing one of the macromorphological regions of Bosnia and Herzegovina (Table 1), were collected from the Republic Hydrometeorological Institute of the Republic of Srpska and Federal Hydrometeorological Institute of Federation of Bosnia and Herzegovina. Six extreme air temperature indices, calculated using RClimDex [12], were used in the analyses: warm days (TX90p), warm nights (TN90p), tropical days (TR30), extremely hot days (TX37), tropical nights (TR20) and warm spell duration index (WSDI).

Changes in the annual occurrence of hot extremes in 1961–2023 were determined based on trend analysis conducted using the nonparametric Mann-Kendall test and Sen's slope to estimate trend slopes and their statistical significance. Further, changes between the last two thirty-year standard climatological periods (1961–1990 and 1991–2020) were examined using the nonparametric Kolmogorov-Smirnov test.

3. RESULTS AND DISCUSSION

The statistically significant positive trends in the frequency of all analyzed indices show that hot extremes are increasing in the cities of Bosnia and Herzegovina. One of the more prominent characteristics of climate change in Bosnia and Herzegovina is the increase in the frequency and intensity of hot extremes, such as warm days and nights, tropical days, extremely hot days, and tropical nights.

During the period 1961–2023, the frequency of warm days (TX90p) increased in the range from 2.8% per decade (or 10 days per decade) in Mostar to 3.4% per decade (or 12 days per decade) in Banja Luka (Table 2). The average annual frequency of warm days (TX90p) in Bosnia and Herzegovina during 1991–2020 exceeded that of the reference period (1961–1990) by 8–10% (Table 3). At all three locations, changes in the distribution of warm days between the two standard climatological periods were statistically significant. In Sarajevo and Mostar, the maximum index values were recorded in 2012 and 2022, and in Banjaluka in 2019. In those years with maximum values, the annual frequency of warm days exceeded 30%. Since the beginning of the 21st century, a frequency of occurrence lower

Table 1. *Geographical locations of meteorological stations from which data were used for the analysis*

Meteorological station	Altitude (m)	Latitude (°)	Longitude (°)	Macromorphological region
Banjaluka	153	44.80806	17.21278	Peri-Pannonian
Sarajevo	630	43.86778	18.42278	Dinaric Mountains and Basins
Mostar	99	43.34806	17.79389	Adriatic

Table 2. *Decadal trends in hot extremes in the cities of Bosnia and Herzegovina for the period 1961–2023*

Index	Warm days (TX90p) (%)	Warm nights (TN90p) (%)	Tropical days (TR30) (days)	Extremely hot days (TX37) (days)	Tropical nights (TR20) (days)	Warm spell duration index WSDI (days)
Banjaluka	3.4*	4.3*	7.3*	1.2*	1.1*	6.0*
Sarajevo	3.1*	2.5*	6.3*	0.4*	0.2*	7.1*
Mostar	2.8*	2.7*	5.8*	3.1*	6.6*	7.4*

* Statistically significant trend at $p < 0.01$

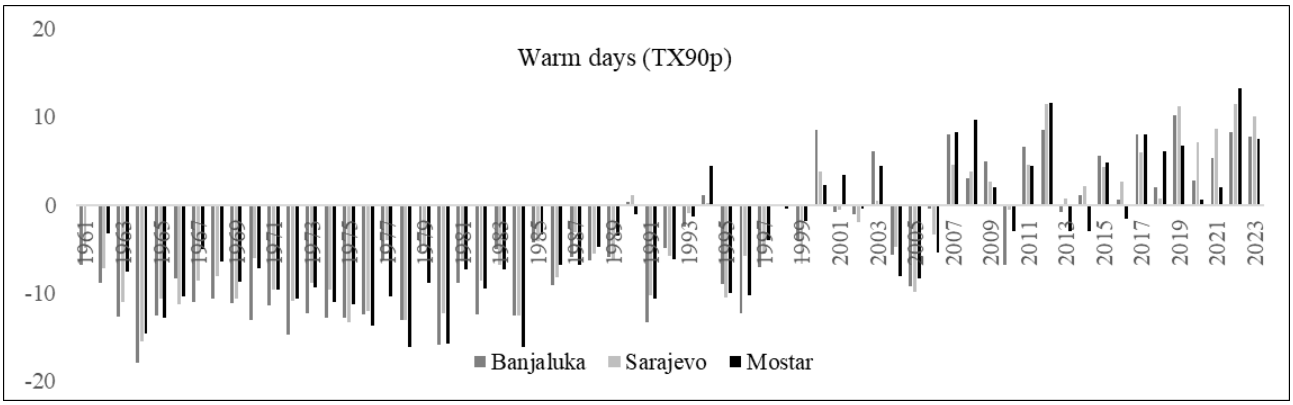

Figure 1. *Anomalies in the annual occurrence of warm days (TX90p) in the cities of Bosnia and Herzegovina relative to the average of the standard climatological period 1991–2020 (in %).*

than the average in the standard climatological period 1991–2020 was recorded only during the several years (in 2004, 2005, 2010, etc.) (Figure 1).

The intensification of the warming in the cities of Bosnia and Herzegovina also demonstrates pronounced and significant upward trends in the frequency of warm nights (TN90p). The occurrence of warm nights increased significantly in 1961–2023 from – 2.5–2.7% per decade in Sarajevo and Mostar to even 4.3 % per decade in Banjaluka (Table 2). Record values of warm nights at the analyzed stations were observed in recent years – maximum in 2018 (Figure 2). In 2018, the annual frequency of warm nights reached 38.1% in Banja Luka, 32.3% in Mostar, and 29.3% in Sarajevo. The average annual frequency of warm nights significantly increased in the period 1991–2020 compared to the reference period 1961–1990. It almost doubled in Banja Luka (13% vs. 25%) and Mostar (11% vs. 20%) (Table 3).

A significant positive trend in tropical days (TR30) was present in all three cities – in the range of 5.8–7.3 days per decade (Table 2). In the north (Banja Luka) and in Sarajevo the average number of tropical days between the last two standard climatological periods was doubled (increase for 22 and 18 days, respectively) (Table 3). In Mostar, the average number of tropical days increased by one third (increase of 20 days). Based on the results of Kolgomorov-Smirnov test, changes in distribution of the index values were significant at all three locations (shift towards higher index values were observed in the latter period). The highest annual number of tropical days has been recorded in the years since the beginning of the 21st century. In Banja Luka and Sarajevo, the largest number of tropical days—almost 50% above the 1991–2020 average—was recorded in 2012 and 2022 (Figure 3). In Mostar, the maximum values were registered in 2003 and 2012 (reaching 113 and 108 days, respectively).

Table 3. *Difference (d) in average annual values of hot extremes indices in the cities of Bosnia and Herzegovina between the last two standard climatological periods, 1961–1990 (a) and 1991–2020 (b)*

Index		Banjaluka	Sarajevo	Mostar	Index		Banjaluka	Sarajevo	Mostar
Warm days (TX90p)	a	10	11	10	Extremely hot days (TX37)	a	1	0	4
	b	20	19	19		b	4	1	13
	d	10*	8*	9*		d	3**	1	9*
Warm nights (TN90p)	a	13	12	11	Tropical nights (TR20)	a	1	0,6	25
	b	25	19	20		b	4	1,1	43
	d	12*	7*	9*		d	3*	0,5	18*
Tropical days (TR30)	a	23	13	57	Warm spell duration index (WSDI)	a	4	4	5
	b	45	31	77		b	22	22	26
	d	22*	18*	20*		d	18*	18*	21*

* Statistically significant difference at $p < 0.01$ (based on Kolgomorov-Smirnov test)

** Statistically significant difference at $p < 0.05$ (based on Kolgomorov-Smirnov test)

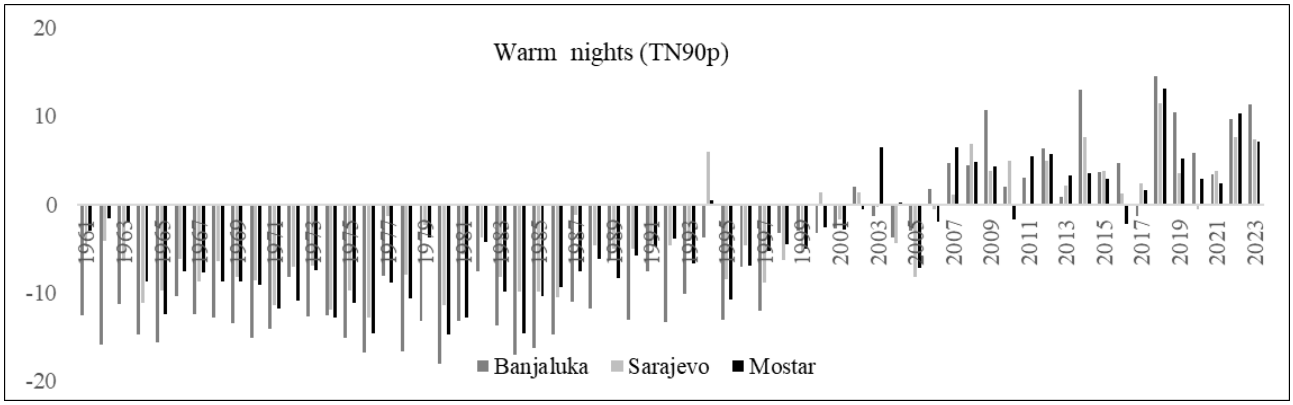

Figure 2. *Anomalies in the annual occurrence of warm nights (TN90p) in the cities of Bosnia and Herzegovina relative to the average of the standard climatological period 1991–2020 (in %).*

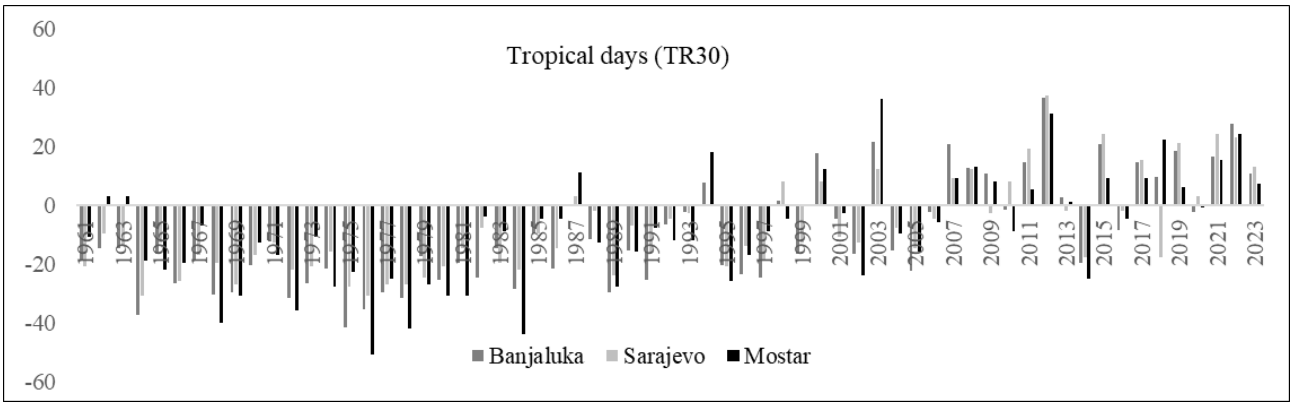

Figure 3. *Anomalies in the annual number of tropical days (TR30) in the cities of Bosnia and Herzegovina relative to the average of the standard climatological period 1991–2020 (in days).*

Extremely hot days (TX37) occur rarely across most parts of Bosnia and Herzegovina (they do not occur at all in higher mountain regions). They are commonly observed in lowland of Herzegovina region. Although their frequency of occurrence was low, the significant upward trends were determined in 1961–2023 (Table 2). In Banja Luka and Sarajevo trend magnitudes were only about 0.4–1.2 days per decade. The trend was only more prominent in Mostar, where these events were also most frequent – increase by 3.1 days per decade. The statistically significant changes in the annual number of extremely hot days (TX37) were determined between the two analyzed periods in Banjaluka and Mostar (Table 3). In Banjaluka, the mean number of these days increased by 3 days during the 1991–2020 period, as such days were rare in the reference period. In Mostar, the number of extremely hot days increased by 9 days in the later period, which represents an increase of nearly 3.5 times. Figure 4 shows that in the reference period the frequency of occurrence for all years was below 1991–2020 period average (except for Mostar in 1988, when an above-average frequency was recorded). This indicates that hot extremes have been increasing in recent decades. In Banja Luka, after 1990, around ten times more extremely hot days (TX37) were recorded compared to the period 1961–1990 (144 days vs. 15 days, respectively). In Sarajevo, only one extremely hot day was recorded in the reference period, whereas even 41 such days were recorded afterwards (up to 2023). In Mostar, the number of extremely hot days quadrupled compared to the reference period (457 vs. 111 days). The highest number of extremely hot days was recorded in 2012 (36 days, nearly four times more than the average for the entire observed period 1961–2023). In Banja Luka and Sarajevo, the highest annual numbers of TX37 were recorded in 2021 – 17 and 12 days

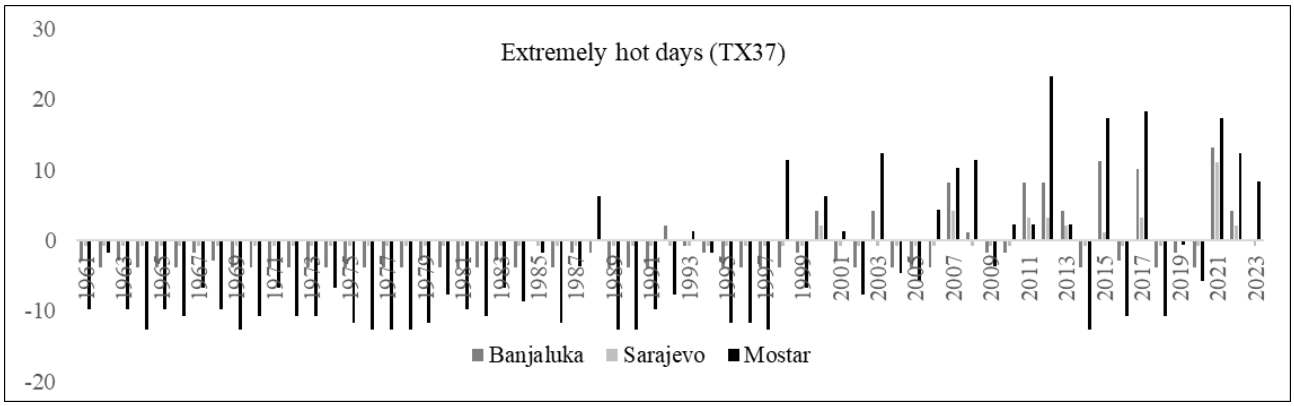

Figure 4. *Anomalies in the annual number of extremely hot days (TX37) in the cities of Bosnia and Herzegovina relative to the average of the standard climatological period 1991–2020 (in days).*

(6 and 17 times more than the average), respectively.

One of the most noticeable changes in hot extremes was the increase in the occurrence of tropical nights. That significantly affects outdoor thermal comfort in the cities. In most areas of Bosnia and Herzegovina, tropical nights are rare in occurrence (annually only a few occur, or they occur only once every few years), and they do not occur at higher altitudes. Their occurrence is typical only in the south – in lowland of Herzegovina region. For instance, in Mostar, an average of 32 tropical nights occur annually. During the period 1961–2023, a statistically significant positive trend in the annual number of tropical nights in the range of 6.6 days per decade was recorded in Mostar (Table 2). The average number of tropical nights in the reference period 1961–1990 (20 days) doubled in the period 1991–2020 (40 days) (Table 3). Before 1990, the frequency of occurrence was below the 1991–2020 period average in all years (Figure 5). In recent decades, tropical nights have also become more frequent in the lower parts of the peri-Pannonian region in the northern part of Bosnia and Herzegovina. For instance, in Banja Luka, the number of tropical nights increased significantly in 1961–2023 by 1.1 days per decade. The last year without tropical nights was 2001. The average number of tropical nights in the period 1961–1990 (1 days) increased in the period 1991–2020 (4 days). Moreover, since the beginning of the 21st century, tropical nights have been recorded even in parts of Bosnia and Herzegovina where they had not occurred before. For example, in Sokolac (located at an altitude of 913 m), where no tropical nights were recorded in the period 1961–1990, tropical nights were observed in 2000, 2003, and 2007 (one in each year) [13]. Even in areas where only a few tropical nights were recorded before 1990, their occurrence has become more frequent in the 21st century – such examples include area of Bugojno (at 562 m altitude) and Ivan Sedlo (at 967 m) [14]. However, in the highest

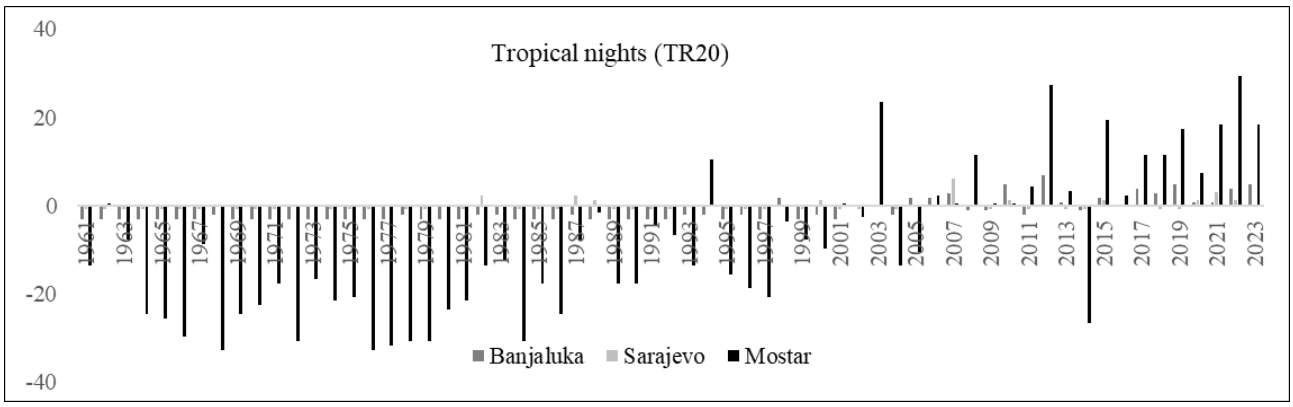

Figure 5. *Anomalies in the annual number of tropical nights (TR20) in the cities of Bosnia and Herzegovina relative to the average of the standard climatological period 1991–2020 (in days).*

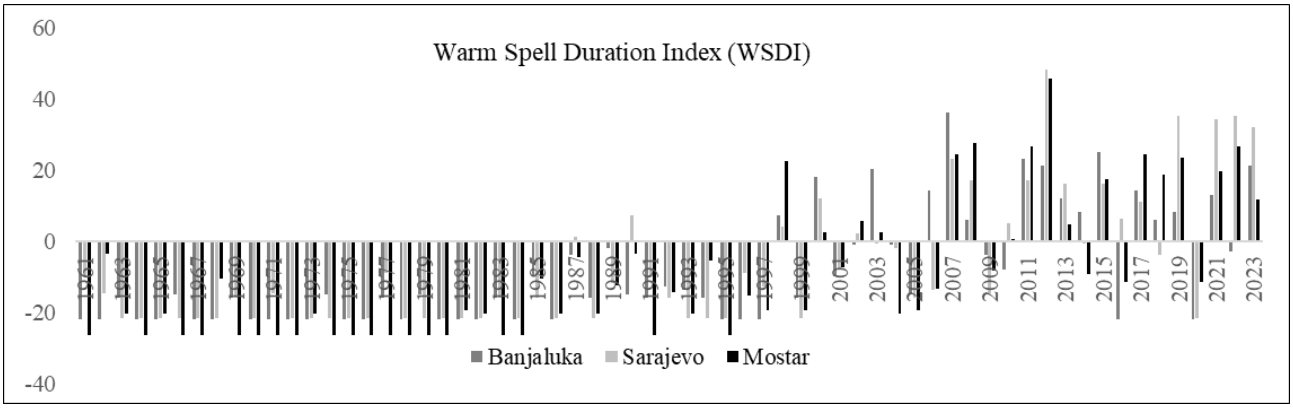

Figure 6. *Anomalies in warm spell duration index (WSDI) in the cities of Bosnia and Herzegovina relative to the average of the standard climatological period 1991–2020 (in days).*

mountainous areas, tropical nights still do not occur.

Across the entire territory of Bosnia and Herzegovina WSDI is increasing [15–18], including in large cities. During the period 1961–2023, the statistically significant positive trends were found for all three analyzed cities. Growth rates were high at all three locations (ranging from 6.0 days per decade in Banjaluka to 7.4 days per decade in Mostar (Table 2). Before 1990, the frequency of WSDI occurrence was below the 1991–2020 period average in all years. In over half of the years there were no WSDI (Figure 6). The maximum WSDI values were recorded in years with intense and prolonged heatwaves − in Banja Luka, record WSDI value was registered in 2007 and in Sarajevo and Mostar in 2012. Between the two thirty-year periods, the reference period (1961–1990) and the latter one encompassing the period during which climate change became more pronounced (1991–2020), the average WSDI increased fivefold at all locations (Table 3).

4. CONCLUSION

The obtained results show that significant upward trends of hot extremes are present in the analyzed cities of Bosnia and Herzegovina. Compared to the earlier studies that did not include the most recent years [15–19], which were among the hottest both globally and in our region, the results of this study indicate that the rates at which the frequency of hot extremes is increasing have accelerated. This all points to a worsening of thermal stress for ecosystems, socioeconomic systems (agriculture, water management, energy, tourism, etc.), and human health.

Research previously conducted in Banja Luka has already demonstrated that climate change is increasing thermal stress in urban areas of Bosnia and Herzegovina. Based on outdoor thermal comfort indices – Physiologically Equivalent Temperature, Universal Thermal Climate Index, and Mean Radiant Temperature for the long-term period 1961–2020, an intensive increase in extreme and strong heat days was found in the city of Banja Luka in the last twenty years (number of days in these thermal stress categories was five times higher compared to numbers in the 1970s s and 1980s) [20]. The opposite tendency was found for the occurrence of extreme and strong cold days (decrease during the last two decades).

All the stated indicates that the adoption and implementation of mitigation and adaptation measures to climate change will be necessary in order to achieve climate-resilient cities in Bosnia and Herzegovina.

5. ACKNOWLEDGMENTS

This research was partly funded by the Ministry of Scientific and Technological Development and Higher Education of the Republic of Srpska within the project “Mapping Local Climate Zones and Analysis of Outdoor Thermal Comfort for Defining Adaptation Measures in the Urban Area of Banja Luka” (grant number: 19.032/961-102/23).

6. REFERENCES

[1] S. E. Perkins-Kirkpatrick, S. C. Lewis, Increasing trends in regional heatwaves, Nature Communications, 11(1) (2020) Article 3357.

[2] P. De Luca, M. G. Donat, Projected changes in hot, dry, and compound hot-dry extremes over global land regions, Geophysical Research Letters, 50(13) (2023) Article e2022GL102493.

[3] C. Yin, Y. Yang, X. Chen, X. Yue, Y. Liu, Y. Xin, Changes in global heat waves and its socioeconomic exposure in a warmer future, Climate Risk Management, 38 (2022) Article 100459.

[4] Y. Zhang, Q. Li, Y. Ge, X. Du, H. Wang, Growing prevalence of heat over cold extremes with overall milder extremes and multiple successive events, Communications Earth & Environment, 3 (2022) Article 73.

[5] R. Zhang, C. Sun, J. Zhu, R. Zhang, W. Li, Increased European heat waves in recent decades in response to shrinking Arctic sea ice and Eurasian snow cover, npj Climate and Atmospheric Science, 3 (2020) Article 7.

[6] E. Russo, D. I. V. Domeisen, Increasing intensity of extreme heatwaves: The crucial role of metrics, Geophysical Research Letters, 50 (2023) Article e2023GL103540.

[7] O. Lhotka, J. Kyselý, The 2021 European heat wave in the context of past major heat waves, Earth and Space Science, 9(11) (2022) Article e2022EA002567.

[8] D. Burić, M. Doderović, Changes in Temperature and Precipitation in the Instrumental Period (1951–2018) and Projections up to 2100 in Podgorica (Montenegro), International Journal of Climatology, 41(S1) (2021) E133–E149.

[9] I. Nimac, I. Herceg-Bulić, K. Cindrić Kalin, M. Perčec Tadić, Changes in Extreme Air Temperatures in the Mid-Sized European City Situated on Southern Base of a Mountain (Zagreb, Croatia), Theoretical and Applied Climatology, 146 (2021) 429–441.

[10] I. Tošić, S. Putniković, M. Tošić, I. Lazić, Extreme Temperature Events in Serbia in Relation to Atmospheric Circulation, Atmosphere, 12 (2021) 1584.

[11] I. Tošić, M. Tošić, I. Lazić, N. Aleksandrov, S. Putniković, V. Djurdjević, Spatio-Temporal Changes in the Mean and Extreme Temperature Indices for Serbia, International Journal of Climatology, 43(5) (2023) 2391–2410.

[12] X. Zhang, F. Yang, RClimDex (1.0) User Manual, Climate Research Branch, Environment Canada, Downsview, 2004.

[13] T. Popov, S. Gnjato, G. Trbić, M. Ivanišević, D. Borojević, M. Đorđević, Changes in Air Temperature and Precipitation in Sokolac (1961–2022), Гласник/Herald, 27 (2023) 1–25.

[14] T. Popov, S. Gnjato, G. Trbić, Changes in Temperature Extremes in Bosnia and Herzegovina: A Fixed Thresholds-Based Index Analysis, Journal of the Geographical Institute "Jovan Cvijić" SASA, 68(1) (2018) 17–33.

[15] T. Popov, Impact of Recent Climate Change on the Phytogeographical Features of the Republic of Srpska, Geographical Society of the Republic of Srpska, Banja Luka, 2020, 291 pp [In Serbian].

[16] T. Popov, S. Gnjato, G. Trbić, M. Ivanišević, Recent Trends in Extreme Temperature Indices in Bosnia and Herzegovina, Carpathian Journal of Earth and Environmental Sciences, 13(1) (2018) 211–224.

[17] T. Popov, S. Gnjato, G. Trbić, Changes in Extreme Temperature Indices over the Peripannonian Region of Bosnia and Herzegovina, Geografie, 124(1) (2019) 19–40.

[18] S. Gnjato, T. Popov, M. Ivanišević, G. Trbić, Changes in Extreme Climate Indices in Sarajevo (Bosnia and Herzegovina), Bulletin of the Serbian Geographical Society, 101(2) (2021) 1–21.

[19] T. Popov, S. Gnjato, G. Trbić, Analysis of Changes in Extreme Climate Indices in Mostar, Гласник/Herald, 22 (2018) 79–102.

[20] S. Savić, G. Trbić, D. Milošević, J. Dunjić, M. Ivanišević, M. Marković, Importance of assessing outdoor thermal comfort and its use in urban adaptation strategies: a case study of Banja Luka (Bosnia and Herzegovina), Theoretical and Applied Climatology, 150 (2022) 1425–1441.

ВРУЋИ ЕКСТРЕМИ СЕ ИНТЕНЗИВИРАЈУ У ГРАДОВИМА БОСНЕ И ХЕРЦЕГОВИНЕ

Сажетак: Рад анализира проблем интензивирања топлих екстрема у одабраним градовима Босне и Херцеговине – Бањалуци, Сарајеву и Мостару. Значајни трендови утврђени су за свих шест анализираних топлих температурних индекса – топли дани (2,8–3,4% по деценији), топле ноћи (2,5–4,3% по деценији), тропски дани (5,8–7,3 дана по деценији), изузетно врући дани (0,4–3,1 дана по деценији), тропске ноћи (0,2–6,6 дана по деценији) и индекс трајања топлих таласа (6,0–7,4 дана по деценији). Надаље, утврђене су значајне промјене индекса између посљедња два стандардна климатолошка периода (периода 1961–1990. и 1991–2020. године), које подразумијевају повећање просјечних вриједности индекса и помјерање њихових дистрибуција ка вишим вриједностима у каснијем периоду. Уочене промјене знатно утичу на спољашњи термални комфор у урбаним срединама.

Кључне ријечи: топли екстреми, топли дани и ноћи, тропски дани, изузетно врући дани, тропске ноћи, WSDI, тренд, климатолошке нормале, Босна и Херцеговина.

Paper received: 3 December 2025 **Paper accepted: 16 December 2025**