ГИДРОЛОГИЯ И КЛИМАТОЛОГИЯ

HYDROLOGY AND CLIMATOLOGY

UDC 551.583:556.52 (497.6:282.243.7) https://doi.org/10.5281/zenodo.15501323

Gnjato S., Popov T., Gnjato R.

University of Banja Luka, Banja Luka, Republic of Srpska, Bosnia and Herzegovina

CLIMATE CHANGE IMPACT ON STREAMFLOWS IN BOSNIA AND HERZEGOVINA: A CASE STUDY OF THE LOWER BOSNA RIVER BASIN

Abstract. *The paper analyses the impact of climate change on streamflows in the Lower Bosna River Basin in the period 1961–2020. Data on mean monthly air temperatures and precipitation were analyzed for 5 meteorological stations across the basin, whereas streamflows were analyzed for the Doboj hydrological station. The nonparametric Mann-Kendall test and the Sen's method were used to calculate the trend magnitude and its statistical significance. A significant warming tendency was present throughout the year across the entire basin, whereas the most striking warming was observed in the summer. Mean annual temperature increased significantly, whereas trends in mean annual precipitation were also positive, but mostly insignificant. Consequently, annual streamflows displayed a significant downward trend. Negative discharge tendencies were detected in all seasons but were most prominent in winter and spring. Significant air warming, combined with the downward discharge trends throughout the year will lead to decreased water availability in the future.*

Key words: *air temperature, Precipitation, streamflows, Climate change, Trend analysis.*

Гнято С., Попов Т., Гнято Р.

Университет Баня-Луки, Баня-Лука, Республика Сербская, Босния и Герцеговина

ВЛИЯНИЕ ИЗМЕНЕНИЯ КЛИМАТА НА ВОДОТОКИ В БОСНИИ И ГЕРЦЕГОВИНЕ: НА ПРИМЕРЕ НИЖНЕЙ ЧАСТИ БАССЕЙНА РЕКИ БОСНА

Аннотация. *В статье анализируется влияние изменения климата на сток в низовьях бассейна реки Босна в период 1961–2020 гг. Данные о среднемесячных температурах воздуха и количестве осадков были проанализированы по 5 метеорологическим станциям бассейна, тогда как показатели стока были проанализированы по гидрологическому посту Добой. Непараметрический тест Манна-Кендалла и оценочный метод Сена были использованы для расчета величины тренда и его статистической значимости. Значительная тенденция к потеплению проявляется в течение всего года на всей территории бассейна, но наиболее ярко тренд потепления наблюдается летом. Среднегодовая температура воздуха на территории бассейна значительно выросла, тенденции изменения среднегодового количества осадков также были положительными, но в основном незначительными. Соответственно этому годовой сток реки Босна в низовье показал значительную тенденцию к снижению. Отрицательные тренды расхода воды в реке проявились во все сезоны, но были наиболее заметны зимой и весной. Значительное потепление климата в сочетании с тенденциями к снижению расхода воды в течение года приведет к снижению водообеспеченности в будущем.*

Ключевые слова: *температура воздуха, осадки, сток, изменение климата, анализ тенденций.*

Introduction and problem statement. The impact of climate change on streamflows has become a key focus of research communities worldwide [1,2,3]. Rivers are major sources of freshwater that provideenergy, food, and a variety of socioeconomic benefitsto the environment [4]. Given the significant effects of recent global warming on freshwater

resources, it is now more crucial than ever to investigate modifications to hydroclimatic variables. Changes in key climate-related drivers, such as rising temperatures and altered precipitation patterns, significantly impact streamflow regimes and are expected to have an even greater effect on the hydrological cycle [5]. Major alterations in streamflow regimes are unambiguously induced by human activities and climate change [6]. Significant warming of the planet has sped up the water cycle and increased the frequency of floods and drought events, which in turn has affected the volume and timing of streamflows in many regions worldwide [7,8]. Furthermore, changes in land cover, freshwater exploitation, and flood management strategies also have a significant impact on streamflows and can be just as detrimental as climate change-related factors [9]. Therefore, evaluating changes in seasonality, interannual variability, and extreme hydrological events, as well as conducting comprehensive research on variations in streamflows, are crucial for water-related strategies and regulations.

Study of the problem. Previous research conducted in Southeastern Europe has confirmed notable alterations in streamflow regimes. In Serbia, a significant declining trend in annual and seasonal streamflows was found—except for the autumn season [10]. In Slovenia, *Oblak et al.* [11] observed a significant reduction in mean annual streamflows at most river gauges. Similarly, *Orešić et al.* [12] reported substantial downward streamflow trends at several river gauges along the middle stretch of Croatia's longest national river (Sava River), while *Pavlić et al.* [13] found mostly negligible upward trends in some karstic basins. Contrary *to Pavlić et al.* [13], who reported notable rising trends during winter*, Orešić et al.* [12] identified the most significant negative seasonal changes in autumn. Both studies, however, detected a decreasing trend during the summer. Negative annual streamflow trends were also observed in several Montenegrin basins [14,15,16]. In Northern Macedonia, research has revealed significant downward seasonal trends across the entire country [17]. Recent studies on streamflow trends in Bosnia and Herzegovina indicate negative tendencies across major river basins throughout the year, with the most pronounced declines occurring during the summer [4,5].

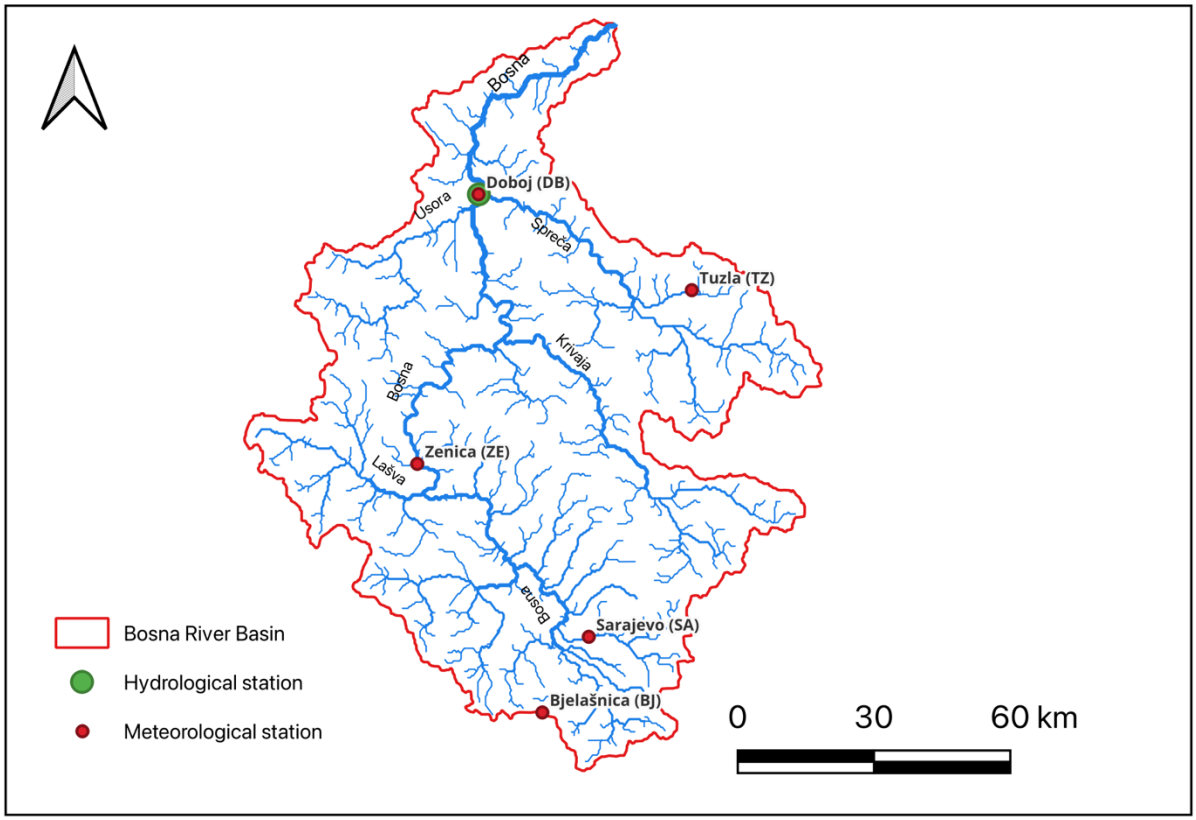


Figure 1. The map of the Bosna River Basin

The aim and objectives of the work. The primary goal of this study was to assess the impact of climate change on streamflows in the Lower Bosna River basin. Additionally, the study aimed to identify annual and seasonal trends in hydrological and climatic variables.

The Bosna River basin occupies a central position in Bosnia and Herzegovina. The basin area is 10457 km^2, the river length is 275 km, and the average elevation of the basin is 640 m. The river originates at the foot of Mount Igman at 500 m above sea level, where it appears on the surface as a strong karst spring, at the junction of the limestone section and the alluvial plain. Bosna River and its main tributaries (Lašva, Krivaja, Usora and Spreča) are characterized by the Posavina variant of the pluvial-nival water regime, characterized by the highest water levels in April and March, and the lowest in August and September. The climate conditions in the Bosna River basin shift from the mountain in the southern areas of the basin to continental and moderate continental climate types in the central and northern areas, respectively [19].

Materials and methods. Annual and seasonal hydroclimatic trends in the Bosna River basin in the period 1961–2020 were calculated using mean monthly data on air temperatures, precipitation, and streamflows. The data were gathered from five meteorological stations (Bjelašnica, Sarajevo, Zenica, Tuzla, and Doboj) located across different sections of the basin, and one rivergauge (Doboj). These stations were selected because they are the only ones with continuous long-term measurements. The input hydroclimatic data were provided by the Republic Hydrometeorological Service (Republic of Srpska) and the Federal Hydrometeorological Institute. The nonparametric Mann-Kendall trend test and Sen's nonparametric slope estimator were applied to hydroclimatic data to identify statistically significant monotonic increasing or decreasing trends. The magnitude of the trend was assessed using Sen's slope estimator. The statistical significance of the computed trend values was evaluated at the 95% and 99% confidence levels. The elementary information about hydroclimatic stations is given in Table 1.

Table 1

Details of the selected meteorological stations and the river gauge

Meteorological station	**ID**	**Elevation (m a.s.l.)**	**Coordinates**	**Record period**
Bjelašnica	BJ	2067	43°42′–18°15′	1961–2020
Sarajevo	SA	630	43°42′–18°25′	1961–2020
Zenica	ZE	344	44°12′–17°54′	1961–2020
Tuzla	TZ	305	44°32′–18°41′	1961–2020
Doboj	DB	147	44°44′–18°05′	1961–2020
Hydrological station	**ID**	**Elevation (m a.s.l.)**	**Drainagearea (km^2)**	**Record period**
Doboj	DB	137	9618	1961–2020

Results and its discussion. *Changes in climatic variables.* Seasonal and annual mean of air temperatures and precipitation at five meteorological stations over the Bosna River basin during the period 1961–2020 are shown in Table 2. The mean annual temperatures in the Bosna River basin increase from1.5 °C in the most southern and the highest positioned station (Bjelašnica) to 11.2 °C in the most northern station (Doboj) in the lowlandarea. Summer is the warmest season with average air temperatures in the rangeof 9.5–20.5 °C. Winter is the coldest season with average temperatures ranging from -5.9–1.4 °C. Annual precipitation ranged from 1195 mmat the Bjelašnica station to 808 mm at the Zenica station. As we proceed from the basin's western and southern regions into the northeast, precipitation generally declines. The precipitation regime across the vast majority of the basin is characterized by wet summers and autumns, followed by drier winters

Table 2

Mean seasonal and annual values of climatic variables over the Bosna River basin in the period 1961–2020

M.s.	Winter		Spring		Summer		Autumn		Year	
	T (°C)	R (mm)	T (°C)	R (mm)	T (°C)	R (mm)	T (°C)	R (mm)	T (°C)	R (mm)
BJ	-5.9	274	-0.3	270	9.5	295	2.8	358	1.5	1195
SA	0.7	224	9.9	229	19.0	234	10.6	253	10.0	940
ZE	1.0	171	11.0	198	19.9	223	11.0	216	10.7	808
TZ	1.0	184	10.7	231	19.5	284	10.8	209	10.5	908
DB	1.4	198	11.4	237	20.5	273	11.4	224	11.2	932

Table 3 displays the seasonal and annual trends of meteorological variables in the period 1961–2020. Over the entire basin, significant ($p<0.01$) upward trends in mean annual temperatures were found in the range 0.2–0.4 °C/decade. The largest warming rate was reported at the Zenica andDoboj stations, while a minimal warming rate was observed at Bjelašnica, the highest-located station (Table 3). The most notable warming tendency was identified in the summer when significant ($p<0.01$) increases were prevalent throughout the entire watershed. The increase in summer temperature trends wasin the range 0.4–0.5 °C/decade. The Autumn season had mostly negligible positive temperature changes (0.1–0.3°C/decade), whereas the majority of the basin also experienced notable upward temperature trends in the winter (0.1–0.4 °C/decade) and spring (0.2–0.3 °C/decade). Overall, the Lower Bosna River basin (the Doboj meteorological station) exhibited the most striking air temperature trends throughout the year.

Table 3

Decadal trends in mean seasonal and annual climatic variables over the Bosna River basin in the period 1961–2020

M.s.	Winter		Spring		Summer		Autumn		Year	
	T (°C)	R (mm)	T (°C)	R (mm)	T (°C)	R (mm)	T (°C)	R (mm)	T (°C)	R (mm)
BJ	0.1	*23.6*	0.2	**21.5**	**0.4**	-0.1	0.1	17.7	**0.2**	**61.6**
SA	**0.4**	-5.9	**0.3**	5.1	**0.5**	-2.3	*0.2*	-1.3	**0.3**	-2.7
ZE	**0.4**	1.2	**0.3**	3.0	**0.5**	9.5	**0.3**	1.0	**0.4**	10.6
TZ	*0.4*	-2.8	**0.3**	4.2	**0.4**	-2.1	0.2	4.4	**0.3**	2.4
DB	**0.4**	0.5	**0.3**	*12.3*	**0.5**	-3.3	*0.2*	4.3	**0.4**	18.8

Statistical significance: **$p<0.01$** and *$p<0.05$*

In contrast to consistent temperature patterns, annual and seasonal precipitation exhibited mostly insignificant trends of both signs. A slight increase in annual precipitation was observed across most of the Bosna River basin, whereas a minor decrease was detected only in Sarajevo (Table 3). The majority of stations showed statistically insignificant trend values, except for the Bjelašnica station, which recorded significant ($p<0.01$) increases of 61.6 mm/decade. The most notable positive seasonal trends were observed in spring (3.0–21.5 mm/decade) and autumn (1.0–17.7 mm/decade) across the Bosna River basin. Conversely, summer precipitation trends displayed negative tendencies at almost all stations (-0.1 to -3.3 mm/decade), except in Sarajevo. Winter precipitation showed inconsistent patterns of change, with both signs showing mostly negligible trends. A significant ($p<0.05$) upward trend in the Lower Bosna River basin (Doboj) was only registered in the spring season, whereas in the rest of the seasons, precipitation trends were insignificant.

Changes in streamflows. The mean annual and monthly decadal trends as well as mean streamflow values at Doboj hydrological station in the period 1961–2020 are given in Table4. The highest streamflow values were registered in the spring season (241.7 m^3/s), and the lowest in the autumn season (101.6 m^3/s). Results indicate that all seasons exhibited negative streamflow tendencies. Still, a statistically significant ($p<0.05$) negative streamflow trend was registered only in winter (-13.5 m^3/s/decade). Negative insignificant decadal streamflow trends were registered in all other seasons. Statistically significant ($p<0.01$) negative tendency was observed at the annual level (-8.4 m^3/s/decade).

Table 4

Annual and seasonal mean streamflows at the Doboj hydrological station and their decadal trends in the period 1961–2020

Season	Average (m^3/s)	Trend slope (m^3/s/decade)
Winter	194.1	*-13,5*
Spring	241.7	-7,5
Summer	104.2	-5,1
Autumn	101.6	-7,0
Year	160.2	**-8.4**

Statistical significance: **$p<0.01$** and *$p<0.05$*

Conclusion. Climate change has significantly influenced streamflow regimes in the Lower Bosna River basin. From 1961 to 2020, temperatures in the basin increased considerably, while precipitation trends were mixed in sign and mostly negligible. Consequently, streamflows in the Lower Bosna River basin have declined. This decline is primarily attributed to the significant year-round warming trend and insignificant precipitation trends throughout the year, along with the most pronounced decline in summer. Although streamflows declined throughout the year, the most distinct reductions were observed in winter and spring.

The declining streamflows in the Lower Bosna River basin will have significant negative impacts on key economic sectors, including agriculture, tourism, and energy production. Developing an adaptation plan for the basin is crucial. Rising temperatures and unpredictable precipitation patterns will increase irrigation demands, making efficient water management essential for agriculture, a key economic sector in the region. Implementing advanced hydro-melioration systems will be a critical adaptation measure. Additionally, adopting a watershed-based planning approach should be a top strategic priority.

Future research should prioritize predicting streamflow trends in the Lower Bosna River basin through the 21st century, as many studies predict decreasing streamflows in this part of Europe. Additionally, further research should focus on assessing the impacts of climate change on key sectors such as energy, water management, agriculture, and tourism, and identify potential mitigation and adaptation strategies

References:

1. Tan, X. & Gan, T. (2025). Contribution of human and climate change impacts to changes in streamflow of Canada, *Scientific Reports*, 5. https://doi.org/10.1038/srep17767

2. Lv, X., Zuo, Z., Ni, Y., Sun, J. & Wang, H. (2019), The effects of climate and catchment characteristic change on streamflow in a typical tributary of the Yellow River, *Scientific Reports*, 9. https://doi.org/10.1038/s41598-019-51115-x

3. Li, C. & Fang, H. (2021), Assessment of climate change impacts on the streamflow for the Mun River in the Mekong Basin, Southeast Asia: Using SWAT model. *Catena*, 201. https://doi.org/10.1016/j.catena.2021.105199

4. Gnjato, S., Popov, T., Ivanišević, M. & Trbić, G. (2023), Long-term streamflow trends in Bosnia and Herzegovina (BH), *Environmental Earth Sciences,* 82. https://doi.org/10.1007/s12665-023-11040-9

5. Gnjato, S., Popov, T., Adžić, D., Ivanišević, M., Trbić, G. & Bajić, D. (2021), Influence of climate change on river discharges over the Sava River watershed in Bosnia and Herzegovina. *Időjárás,* 125, 449–462. https://doi.org/10.28974/idojaras.2021.3.5

6. Khoi, D.N., Nguyen, V.T., Sam, T.T., Phung, N.K. & Bay, N.T. (2019), Responses of river discharge and sediment load to climate change in the transboundary Mekong River Basin, *Water and Environment Journal*, 34, 367–380.https://doi.org/10.1111/wej.12534

7. Pratap, S. &Markonis, Y. (2022), The response of the hydrological cycle to temperature changes in recent and distant climatic history, *Progress in Earth and Planetary Science*, 9. https://doi.org/10.1186/s40645-022-00489-0

8. Ranjan, R. & Mishra, A. (2023), Climate change impact on streamflow and suspended sediment load in the flood-prone river basin, *Journal of Water and Climate Change,* Vol. 14 (7), pp. 2260-2276. https://doi.org/10.2166/wcc.2023.037

9. Sun, C., Li, Q., Liu, Y., Cai, Q., Ren, M., Song, H., Fang, C., Liu, R. & Sun, J. (2023), Human activities have more impacts on the recent discharge reduction of the largest tributary of the Yellow River relative to last three centuries, *Science of The Total Environment,* p. 890. https://doi.org/10.1016/j.scitotenv.2023.164217

10. Kovačević-Majkić, J. & Urošev, M. (2014), Trends of mean annual and seasonal discharges of rivers in Serbia, *Journal of the Geographical Institute "Jovan Cvijić" SASA,* Vol. 64, pp. 143–160. https://doi.org/10.2298/IJGI1402143K

11. Oblak, J., Kobold, M. & Šraj, M. (2021), The influence of climate change on discharge fluctuations in Slovenian rivers, *Acta Geographica Slovenica*, Vol. 61, pp. 155–169. https://doi.org/10.3986/AGS.9942

12. Orešić, D., Čanjevac, I. & Maradin. M. (2017), Changes in discharge regimes in the middle course of the Sava River in the 1931–2010 period, *Prace Geograficzne*, Vol. 151, pp. 93–119. https://doi.org/10.4467/20833113PG.17.024.8036

13. Pavlić, K., Kovač, Z. & Jurlina, T. (2017), Trend analysis of mean and high flows in response to climate warming—evidence from karstic catchments in Croatia, *Geofizika,* Vol. 34, pp. 157−175. https://doi.org/10.15233/gfz.2017.34.11

14. Burić, D., Ducić, V. & Doderović, M. (2016), Poplave u Crnoj Gori krajem 2010. godine saosvrtom na kolebanje proticaja Morače, *Glasnik Odjeljenja Prirodnih Nauka CANU,* Vol. 21, pp. 47-64.

15. Ćulafić, G.LJ., Mitrović, L. & Golijanin, J. (2017), Uticaj klimatskih promjena na vodni režim u slivu Lima, *Zbornik radova povodom obilježavanja 20 godina rada Prirodno-matematičkog fakulteta Univerziteta u Banjoj Luci*, Banja Luka, pp. 141-147.

16. Ćulafić, G.LJ., Pešić, A.M., Vujović, F. & Golijanin, J. (2024), Spatial-temporarily Variability and Discharge Trends in the Morača River Basin, *Zbornik radova VI Kongres geografa Srbije sa medunarodnim ucešcem,* Zlatibor, Serbia, pp. 135–141. https://doi.org/10.5937/KonGef24015C

17. Radevski, I., Gorin, S., Taleska, M. & Dimitrovska, O. (2018), Natural regime of streamflow trends in Macedonia. *Geografie,* Vol. 123, pp. 1–20. https://doi.org/10.37040/geografie2018123010001

18. Canchala, T., Cerón, W.L., Francés, F., Carvajal-Escobar, Y., Andreoli, R.V., Kayano, M.T., Alfonso-Morales, W., Caicedo-Bravo, E. & de Souza, R.A.F. (2020), Streamflow variability in Colombian Pacific basins and their teleconnections with climate indices, *Water,* 12.https://doi.org/10.3390/w12020526

19. Gnjato, S. (2022), *Climate change impact on river discharges in Bosnia and Herzegovina: dissertation*, Belgrad.

Information about authors:

Slobodan Gnjato – University of Banja Luka (Banja Luka, Republic of Srpska, Bosnia and Herzegovina), Associate Professor Dr.

Tatjana Popov – University of Banja Luka (Banja Luka, Republic of Srpska, Bosnia and Herzegovina), Professor Dr.

Rajko Gnjato – University of Banja Luka (Banja Luka, Republic of Srpska, Bosnia and Herzegovina), Dr, Professor Emeritus.

Сведения об авторах:

Гнято Слободан – Университет Баня-Луки (Баня-Лука, Республика Сербская, Босния и Герцеговина), ассоциированный профессор, доктор наук.

Попов Татьяна – Университет Баня-Луки (Баня-Лука, Республика Сербская, Босния и Герцеговина), профессор, доктор наук.

Гнято Райко – Университет Баня-Луки (Баня-Лука, Республика Сербская, Босния и Герцеговина), почётный профессор, доктор наук.

For citation:

Gnjato S., Popov T., Gnjato R. (2025), Climate change impact on streamflows in Bosnia and Herzegovina: a case study of the lower Bosna River basin, *Central Asian Journal of Geographical Researches*, No. 1-2, pp. 95-101.

Для цитирования:

Гнято С., Попов Т., Гнято Р. Влияние изменения климата на водотоки в Боснии и Герцеговине: на примере нижней части бассейна реки Босна // Центральноазиатский журнал географических исследований. 2025. № 1-2. С. 95-101. (На англ. яз.).