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Changes in water balance components of river basins in the Slovak Republic and Ukraine

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This study examined the long-term changes in water balance in five river basins located in Slovakia and Ukraine. Despite small increase in precipitation between 1961–1990 and 1991–2020, the study found a clear trend of decreasing water discharge, accompanied by an increase in evaporation and a significant decrease in the runoff coefficient. Data from two Slovak rivers and three Ukrainian rivers were used, chosen based on three criteria: the presence of at least two meteorological stations within the river basin, a long-term observation period, and minimal human impact on river runoff. The results of statistical analysis indicate that the Belá river basin in the Tatra Mountains had the smallest decrease in the runoff coefficient (–1.28%). The largest decrease in the runoff coefficient (–34%) was observed in the Sula River catchment area with the smallest altitude and the most eastern location. On average, the runoff coefficient decreased by 14% in studied basins. The study highlights the importance of monitoring water balance changes, particularly in regions where water resources are limited.

KEY WORDS: water balance, discharge, precipitation, evaporation, runoff coefficient

Introduction

One of the most pressing scientific issues in modern hydrology is the impact of climate change on the water regime. Climate change has become one of the most significant global environmental challenges of our time, leading to changes in the water cycle and water balance of many regions around the world. Changes in temperature, precipitation patterns, and extreme weather events all contribute to the transformation of the hydrological cycle, which has implications for freshwater resources, ecosystems, and human societies.

The observed and expected changes in water resources vary across different regions and models. For instance, Mahmood et al. (2020) predicted changes in water resources of the Chari river basin (contributing to Lake Chad in Africa) using the harmonic regression model for the periods 2021–2050, 2051–2080, and 2081–2100 with respect to the baseline period (1971–2001). According to their results, flows are expected to decrease under the HRM and RCP2.6 scenarios but to increase under RCP4.5 and RCP8.5. In the period 1941–2002, statistically significant increasing runoff trends were found in Finland, probably because the first year of the period (1941) was the driest ever observed in many sites (Hyvärinen, 2003). In Hanel et al. (2012), the climate change impact on mean runoff in the Czech Republic was assessed. The hydrological balance was modelled using the BILAN conceptual hydrological model at 250 catchments with varying sizes and climatic conditions. Climate change scenarios were derived using a simple delta approach, where observed data for precipitation, temperature, and relative air humidity were perturbed to reflect the changes seen in 15 regional climate model (RCM) simulations between the control and scenario periods. The parameters of the hydrological model were estimated for each catchment using observed data, and these parameters were then used to calculate discharge under climate change conditions for each RCM simulation. Although there were considerable differences in the absolute values of the runoff changes, consistent patterns of change were identified. The majority of scenarios projected an increase in winter runoff in the northern part of the Czech Republic, particularly in catchments with high elevation. Furthermore, the scenarios were in agreement regarding a decrease in spring and summer runoff in most of the catchments.

Interesting results as to water balance with regard to agricultural products was published by Vanham (2013). Author focuses on quantifying the net virtual water import (net VWi, agr) amounts for agricultural products in river basins larger than 1000 km^2 within the EU28. The study reveals the highest positive net VWi, agr values along a densely populated and industrialized axis stretching from Northwest England to Milan. Specifically, the Rhine, Po, Thames, Scheldt, Elbe, and Seine river basins exhibit the highest positive values. The WFcons, agr (water footprint of consumption) for these basins is significantly higher than the WFprod, agr (water footprint of production). Conversely, the basins with the most negative net VWi, agr are located on the Iberian Peninsula (Guadiana, Ebro, and Duero), in Western France (Loire and Garonne), and in the eastern Baltic Region (Nemunas). These exporting basins have lower population densities and extensive agricultural areas.

Senf et al (2020) address the issue of tree mortality caused by drought, with a particular focus on Europe. Through the analysis of high-resolution annual satellite-based canopy mortality maps from 1987 to 2016, the study reveals a significant relationship between excess forest mortality (mortality exceeding the long-term trend) and drought across continental Europe. The authors estimate that drought caused approximately 500 000 hectares of excess forest mortality between 1987 and 2016. The research utilizes generalized additive mixed modeling to examine the statistical relationship between the fractional deviation in forest canopy mortality and the climatic water balance (CWB). The findings support the hypothesis that decreasing water availability, reflected in CWB, is associated with increased excess mortality. The study also identifies regions and years as hotspots of drought-related excess forest canopy mortality, highlighting the potential for widespread tree mortality in Europe with future increases in drought.

Previous findings suggest that lowland areas used for agricultural purposes are particularly vulnerable to decreased runoff in the region of Central Europe. Moreover, in recent years, changes in water balance have also been observed in high-altitude catchment areas, leading to forest decline due to draught.

Mammoliti et al. (2021) presented an alternative WebApp for monthly water balance calculation, based on the original Thornthwaite–Mather method. The developed solution relies on a serverless approach, exploiting a large set of cloud-based micro-services. This type of approach enables asynchronous processing (from request to result) using a queue manager that integrates and decouples distributed software components. To provide an example of its application, the basic water balance components were calculated on two small watersheds located in the Northern Apennines (Central Italy) and in Northwestern Slovenia. In similar areas in Europe, many authors demonstrated that the error associated to the use of this method is smaller than the one due to the rainfall measurements. In many of these cases, researchers focused on relatively small catchment areas located in the central part of Europe.

In the region of Slovakia, a number of scientific papers have been dedicated to the study of changes in water runoff and water balance resulting from climate change. These papers include research conducted by Garaj et al. (2019), Halmová et al. (2022), Holko et al. (2001), Parajka et al. (2023), Pekárová et al. (2005; 2009a; 2009b; 2010a; 2010b), Petrovič et al. (2010), and Sleziak et al. (2021). For instance, Garaj et al. (2019) examined the Topľa river basin situated in eastern Slovakia and discovered a significant decrease in the runoff coefficient from 0.34 to 0.29 during the period of 1961–2017.

Longer datasets were utilized to analyze changes in water balance in the Krupinica River, located in the southern part of Slovakia (Halmová et al., 2022). The runoff coefficient of the Krupinica River obtained the following values for different periods: 1931–1960: 0.32, 1961–1990: 0.27, and 1991–2020: 0.21.

The impact of climate change on evaporation, as well as long-term changes in the water regime of rivers in Ukraine, were investigated by Vyshnevskyi and Donich (2021) and Graf and Vyshnevskyi (2022).

In this study, we built upon our previous work. The primary objective of this article is to determine changes in water balance in small forested catchments, as well as large agricultural basins, located in regions with varying elevations and climate conditions in Slovakia and Ukraine. The changes in the runoff components and runoff coefficient of the analyzed river basins were identified during two periods: 1) 1961–1990, and 2) 1991–2020.

Material

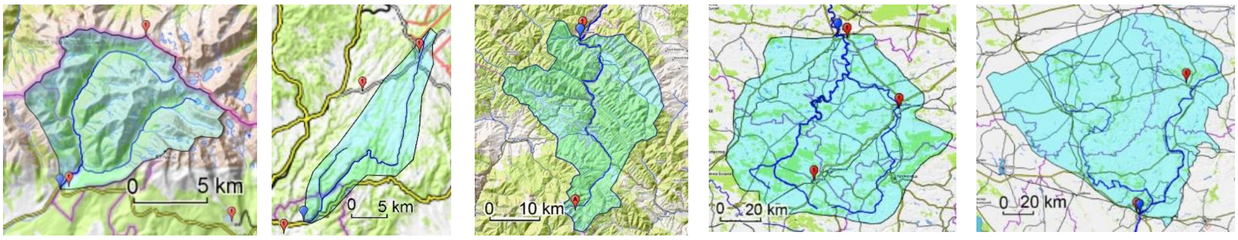
This study utilized data from five small to medium-sized river basins located across two countries: two in the Slovak Republic and three in Ukraine. Among the two Slovak rivers, the Belá River is situated in the mountains, while the Litava River is located in a highland area. One Ukrainian river, the Prut River, is situated in the Carpathian Mountains, while the other two rivers (the Styr and Sula rivers) are located on the plains. The selection of these river basins was based on three main criteria: the presence of at least two meteorological stations within the catchment area, a long-term observation period, and minimal human activity that could affect river runoff. The last criterion was particularly important in the southern part of Ukraine, where water is frequently used for irrigation (Fig. 1).

To study the meteorological and hydrological conditions of the river basins, data from various meteorological and hydrological stations were used.

The Belá river basin is situated in the Tatra Mountains. Hydrological data for this study were collected at a gauging station located in Podbanske (catchment area: 93.49 km^2, stream gauge elevation: 922.72 m above sea level). The upper part of the Belá river basin, up to the Podbanské gauge, is located within the TANAP reserve, which is a protected area unaffected by human activity. The most significant anthropogenic modifications occurred primarily in the 19^{th} century when forests were cleared for pastures. However, after the establishment of the Tatra National Park (TANAP) in 1948, grazing was prohibited, and forests were recognized for their flood protection benefits (Pekárová et al., 2009b). The vegetation within the Belá basin, up to the Podbanské water gauge, consists of 40% coniferous forests, 4.5% deciduous forests, 21% dwarf pine, 18% meadows and pastures, 15.8% rocks, and the rest consists of water bodies and built-up areas (in year 2015). Two meteorological stations situated on the edges of the Belá river catchment area provided data for this study (Fig. 2). The Polish observatory Kasprowy Wierch has an elevation of 1987 m above sea level, while the Podbanské station is at 972 m above sea level. Additionally, data from the Štrbské Pleso meteorological station were utilized (Table 1). The main hydrological characteristics of the selected basins are presented in Table 2.

The catchment area of the Litava River is situated in a region that combines highland and lowland characteristics. It originates in the Krupinska Planina mountain range, with its source located at an altitude of approximately 650 m above sea level. The Litava

Fig. 1. The location of the studied river basins: 1 – Belá: Podbanské, 2 – Litava: Plášťovce, 3 – Prut: Yaremche, 4 – Styr: Lutsk, 5 – Sula: Lubny.



1 2 3 4 5

Fig. 2. The studied river basins and the location of meteorological (in red) and hydrological (in blue) stations: 1 – Belá: Podbanské, 2 – Litava: Plášťovce, 3 – Prut: Yaremche, 4 – Styr: Lutsk, 5 – Sula: Lubny.

Table 1. The main climatic characteristics at meteorological stations located near the studied catchment areas

River	Station	Elevation [m a.s.l.]	Temperature		Precipitation	
			1961–1990	1991–2020	1961–1990	1991–2020
Belá	Kasprowy Wierch	1987	-0.77	0.16	1825	1760
	Podbanské	972	4.68	5.63	921	996
	Štrbské Pleso	1322	3.76	3.98	960	1107
Litava	Senohrad	586	–	–	681	736
	Bzovík	355	8.20	9.52	578	644
	Horné Semerovce	131	–	–	563	585
Prut	Pozhezhevska	1451	2.7	3.5	1424	1544
	Yaremche	531	6.9	7.9	930	1013
Styr	Brodu	228	7.5	8.7	689	699
	Dubno	202	7.4	8.6	612	649
	Lutsk	197	7.3	8.4	558	580
Sula	Romny	169	6.7	8.0	604	618
	Lubny	158	7.4	8.6	625	608

Table 2. The characteristics of the studied river basins, *Qa* – long term discharge; *R* – runoff depth; period 1961–2020

Station No.	The name of rivers and gauging stations	Area [km^2]	Mean elevation [m]	*Qa* [$m^3 s^{-1}$]	*R* [mm]
1	Belá: Podbanské	93.49	1572	3.52	1181
2	Litava: Plášťovce	214.3	450	0.94	138
3	Prut: Yaremche	597	990	12.7	669
4	Styr: Lutsk	7200	230	31.2	136
5	Sula: Lubny	14200	120	26.4	59

catchment area, extending up to the Plášťovce gauging station, covers an area of 214.3 km^2. The river system within the basin follows a mostly parallel course due to the relatively gentle terrain, with an average altitude of 450 m above sea level.

The Prut River upstream of the Yaremche hydrological station is a typical mountain river. Moreover, the source of the river is located near Hoverla Mountain, which is the highest mountain in Ukraine, with an elevation of 2061 m. The main part of the catchment area is covered by forest, mainly spruce. There are two meteorological stations located on the river's catchment area: Pozhezhevska and Yaremche.

The Styr River is located in the north-western part of Ukraine and it is a tributary of the Prypiat River, which in turn is the largest tributary of the Dnipro River. The upper and southern part of the catchment area, upstream of Lutsk city, is mainly located on the Volyno-Podilska highland, while the lower part is on the Poliska lowland. There are three meteorological stations (Brodu, Dubno, and Lutsk) the data of which were utilized in the study. The climate of the catchment area is moderate with cool winters and warm summers.

The Sula River is located in the north-eastern part of Ukraine, not far from the centre of Ukraine. The characteristic feature of this river is its location on the Dniprovska lowland with a flat relief. The entire catchment area is located in the Forest-Steppe zone, which has few forests. On the catchment area of the Sula River are located two meteorological stations data of which were used: Romny and Lubny. The Romny meteorological station is located in the northeast part of the river basin, and the Lubny meteorological station is located in the south. The climate of the catchment area is moderate with cool winters and warm, sometimes hot summers (Vyshnevskyi and Kutsiy, 2022).

Methods

The study utilized data from the period 1961–2020. In order to calculate the total areal precipitation and the mean basin temperature in the mountainous Belá River basin and the highland-lowland Litava River basin, precipitation and temperature gradients were employed. To determine the average monthly areal precipitation totals, monthly precipitation data from the Podbanské and Štrbské Pleso meteorological stations, as well as data from the Polish observatory Kasprowy Wierch, were used (Fig. 2). For the Ukrainian river basins, precipitation was calculated as the average value of data from meteorological stations situated within those basins.

The hydrological balance quantifies the circulation of water in a closed system with a concentrated runoff in the final profile of the catchment. The atmospheric precipitation over the basin serves as the only input to the basin balance. For a sufficiently long period, the difference in soil water content at the beginning and end of the time period can be neglected. In such cases, we can identify the total annual evapotranspiration with the difference between precipitation and runoff.

The water balance equation used is as follows:

$$P = R + ET + \Delta S \quad (1)$$

where:

P – annual precipitation depth [mm];
R – annual average runoff [mm];
ET – annual evapotranspiration depth [mm];
ΔS – average total losses that have a higher significance in shorter time intervals Δt. For the long-term water balance, this element can be neglected and replaced by $\Delta S = 0$.

For the long-term monthly balance, if we determine the monthly total evapotranspiration independently, we can calculate the change in water storage in the basin in the monthly step during the year according to the water balance equation.

Results and discussion

Precipitation

Among the river basins studied, the highest precipitation is observed at the Kasprowy Wierch climatic station, located in the High Tatra Mountains. The average annual precipitation at this station was 1825 mm during the period from 1961 to 1990 and 1760 mm during the period from 1991 to 2020. Fig. 3 illustrates the annual precipitation totals averaged over the Belá Basin. Precipitation data were calculated using the Podbanské, Kasprowy Wierch, and Štrbské Pleso stations, based on the precipitation gradient relative to the average elevation of the Belá river basin. The lowest long-term mean precipitation totals at a Slovakian station were recorded at the Bzovík station, with 578 mm during the period from 1961 to 1990 and 644 mm during the period from 1991 to 2020. Annual mean areal precipitation totals in the Litava river basin showed a slight increase over time. The largest long-term mean precipitation totals among the river basins located in Ukraine is observed at the Pozhezhevska meteorological station, with a mean annual precipitation total of 1548 mm during 1991–2020. The Yaremche meteorological station, located at a lower altitude, recorded significantly less precipitation, with a mean of 1013 mm. In the Prut river basin, precipitation increased by 100 mm during the second period. In the Sula river basin, changes in precipitation were very small during the period of 1961–2020, with no clear tendency to increase or decrease, as shown in Fig. 3.

Annual runoff

For a visual comparison of long-term variability and trends in water discharge, we have plotted the annual runoff R [mm] on Fig. 3 (right). Long-term averages of the runoff exhibit significant differences between the watersheds and are generally influenced by annual precipitation and the mean elevation (temperature) within the watershed. In the high mountain river basin of Belá, there have been no changes in the discharge observed thus far. In the Prut basin, we can observe how multi-year fluctuations in precipitation, spanning approximately 28 years, correspond to fluctuations in annual water runoff. Similar variability in discharge can also be observed in the Styr river basin.
Furthermore, a decrease in water discharge has been detected in recent years in the lowland watersheds. This decrease is particularly noticeable in the watershed of the Sula river. The decline in water discharge in lowland watersheds is caused by rising air temperatures (see Fig. 4 on the left).

Water balance and evaporation

With data on precipitation and water runoff, it is possible to calculate evaporation from river basins using equation (1). As shown in Fig. 4 on the right, there is an observed tendency of increased evaporation (with the exception of the Belá river basin), which is caused by a significant increase in air temperature after 1987. The results of comparing two 30-year periods are summarized in Table 3. As shown in Table 3, the runoff coefficient decreased significantly in all basins.

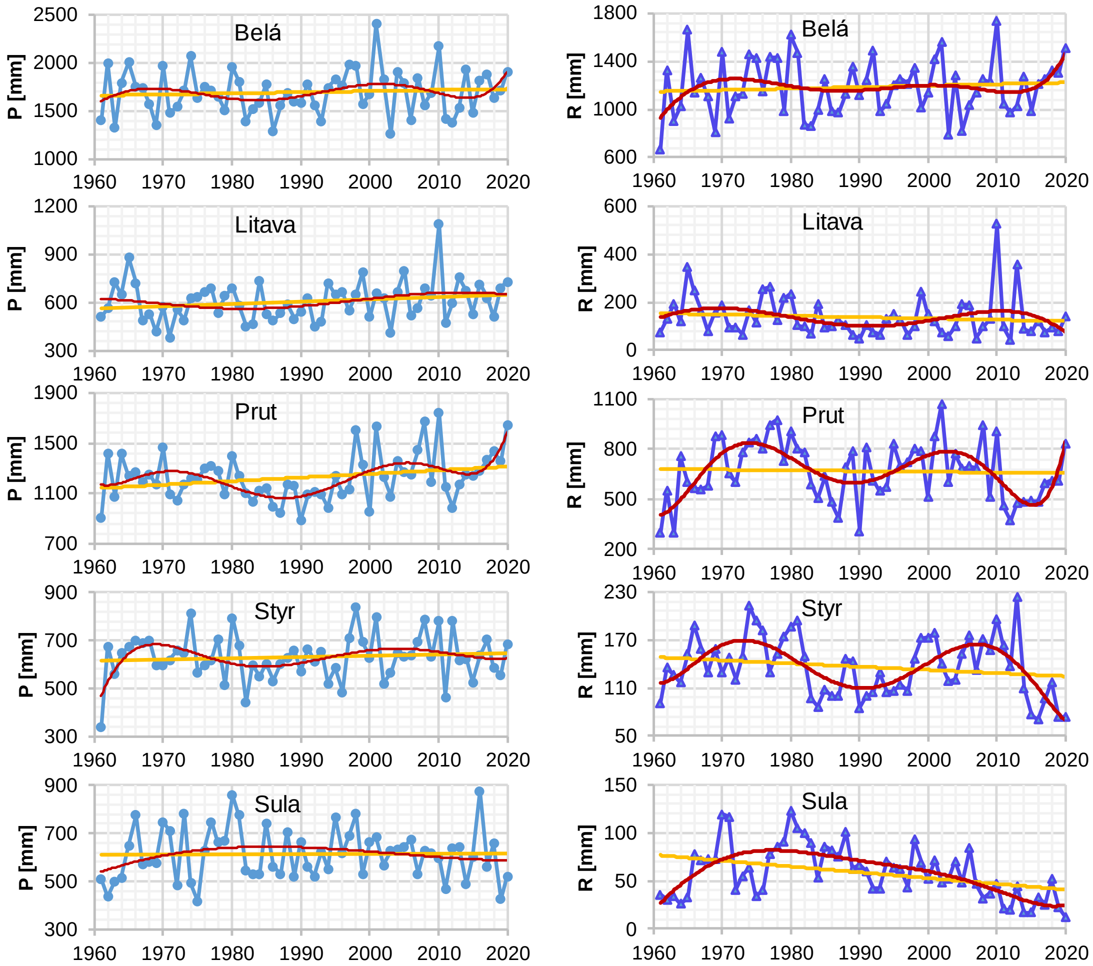


Fig. 3. Long-term changes and log-term variability of mean areal annual precipitation P (left); runoff R (right) of the studied river basins: Belá: Podbanské, Litava: Plášťovce, Prut: Yaremche, Styr: Lutsk, Sula: Lubny.

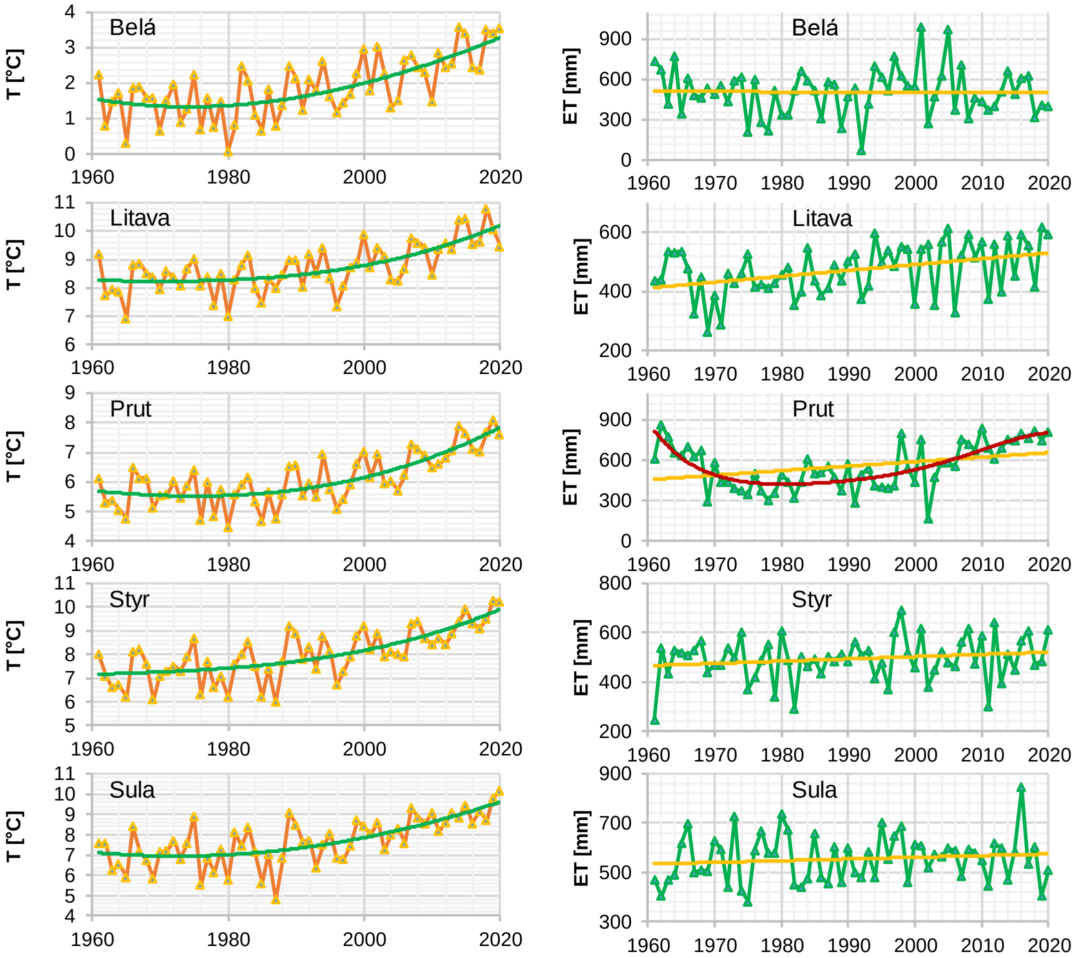


Fig. 4. Long-term changes and log-term variability of mean areal air temperatur T (left); balance evapotranspiration ET (right) of the studied river basins: Belá: Podbanské, Litava: Plášťovce, Prut: Yaremche, Styr: Lutsk, Sula: Lubny.

Table 3. The changes in the runoff components and runoff coefficient of the analysed river basins during two periods: 1) 1961–1990, and 2) 1991–2020. *P* represents precipitation, *R* represents runoff depth, *ET* represents the balance evapotranspiration, *k* represents the runoff coefficient, and *dP, dR, dET, and dk* represents the percentage change of the *P, R, ET* and *k* compared to the first period

River	*P*		*dP*	*R*		*dR*	*ET*		*dET*	*k*		*dk*
	1961–1990	1991–2020	[%]	1961–1990	1991–2020	[%]	1961–1990	1991–2020	[%]	1961–1990	1991–2020	[%]
Belá	1662	1732	**4.21**	1170	1204	**2.91**	492	528	**7.32**	0.704	0.695	**-1.28**
Litava	582	638	**9.62**	145	131	**-9.66**	438	507	**15.8**	0.248	0.205	**-17.4**
Prut	1177	1278	**8.58**	668	669	**0.15**	509	609	**19.6**	0.568	0.523	**-7.82**
Styr	620	643	**3.71**	141	131	**-7.09**	478	511	**6.90**	0.228	0.205	**-10.4**
Sula	614	613	**-0.16**	71	47	**-33.8**	544	566	**4.04**	0.115	0.076	**-33.7**

To illustrate the differences in series of precipitation, runoff, air temperature, and balance evapotranspiration of two periods (1. 1961–1990, and 2. 1991–2020), we used a box-and-whisker diagram (see Fig. 5). A boxplot is a standardized method of displaying the dataset based on the five-number summary: the minimum, maximum, sample median, and first and third quartiles. Outliers that significantly differ from the rest of the dataset are plotted

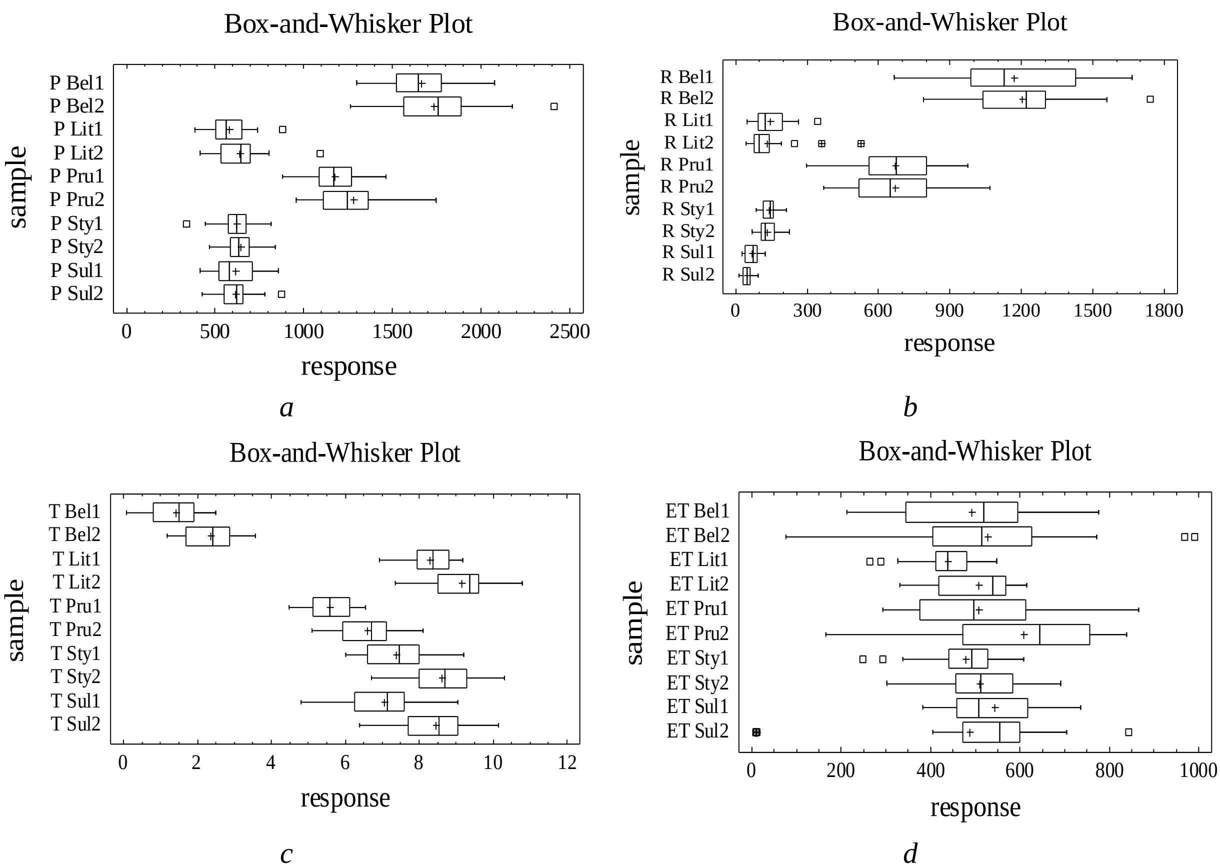


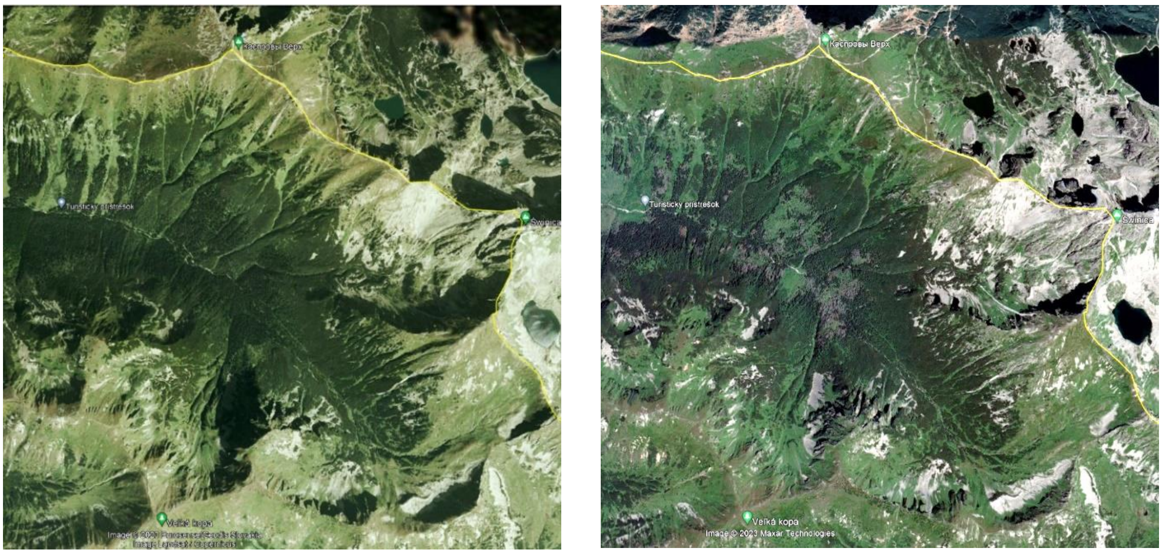
Fig. 5. Changes in basic precipitation (a), runoff (b), air temperature (c), and evapotranspiration (d) characteristics from selected five basins using box-and-whisker diagrams for the 1st period (1961–1990) and the 2nd period (1991–2020)

as individual points. According to the box-and-whisker diagrams, the most significant changes in statistical characteristics were observed in air temperature for all basins – all characteristics (the minimum, maximum, sample median, and first and third quartiles) increased. An increase in precipitation was also recorded at all basins. A decrease in runoff depths and balance evapotranspiration was observed in four watersheds. However, the runoff coefficient decreased in all basins, including the high-mountain Belá river basin (Table 2). Table 2 presents the average values of all hydrological components during the comparison of two 30-year periods. On average, the runoff coefficient has decreased by 14% in these basins.

Discussion

The data presented in Table 2 indicate that the largest decrease in the runoff coefficient (33.7%) is observed in the Sula river catchment area. This can be partially explained by significant evaporation from wetlands, reservoirs, and ponds located within the catchment area. As identified in the study by Vyshnevskyi (2022), the relationship between air temperature and evaporation from water surfaces is nonlinear. This implies that even a small increase in air temperature can result in a significant increase in evapotranspiration, particularly during the high-temperature summer months in Ukraine.

The smallest decrease in the runoff coefficient (1.28%) was observed in the mountainous Belá river basin. The absence of large changes for the Belá mountain river can be explained by the low temperature. Other possible reason could be the fact that higher air temperatures are causing spruce forests to dry out in Slovakia as well (Senf et al., 2020). In the High Tatra Mountains, there was an intensive bark beetle outbreak during the period 1993–1998. The outbreak resulted in tree mortality, affecting Norway spruce stands on both the Polish and Slovak sides of the territory. The forest mortality likely led to reduced evapotranspiration, thus resulting in a less significant decrease in the runoff coefficient in the Belá basin. Additionally, on November 19, 2004, a catastrophic windstorm occurred in the Tatra National Park and damaged an area of roughly 12 600 ha, which represented about 50% of the local spruce forests. The windthrow area in the Belá river basin was left uncleared for natural development (Pekárová et al., 2011). As a result, many trees dried up (Fig. 6a–b). In the following years, the old dry spruce forest in the Tichá and Kôprová valleys is gradually being replaced by a mixed forest (Fig. 7a–b).



a) Tichá valley, 2006 *b) Tichá valley, 2021*

Fig. 6. Tichá valley, Belá river basin (Image 2006, Eurosense/Geodis Slovakia; Image 2021, Maxar Technologies).

a) 21. 10. 2008, dead spruce forest *b) 11. 05. 2023, new mixed forest*

Fig. 7. Kôprovský stream above the confluence with Tichý stream; 977 m a.s.l., Belá river basin, Kriváň peak, 2495 m a.s.l. (photo: P. Pekárová).

Conclusions

The available data from numerous meteorological stations located in the five river basins on the territories of Slovakia and Ukraine show a clear tendency of changes in water balance. Despite the fact that the amount of precipitation was slightly higher, there is a trend towards a decrease in water discharge. Simultaneously, an increase in evaporation and a significant decrease in the runoff coefficient were observed. These changes are more pronounced in flat rivers than in those located in mountainous areas.

Although projecting water resources is important for longer-term (50–100 years) water resource planning, predicting water resources in the near future (10–20 years) is even more crucial for policymakers and planners to minimize the impacts of climate change on water resources by adopting some proper mitigative and adaptive actions.

Acknowledgement

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References

Garaj, M., Pekárová, P., Pekár, J., Miklánek, P. (2019): The Changes of Water Balance in the Eastern Slovakia. IOP Conf. Ser.: Earth Environ. Sci. 362 012014. ISSN 1755–1307. https://iopscience.iop.org/article/10.1088/1755-1315/362/1/012014

Graf, R., Vyshnevskyi, V. (2022): Forecasting Monthly River Flows in Ukraine under Different Climatic Conditions. Resources 2022, 11, 111. https://doi.org/10.3390/resources11120111

Halmová, D., Pekárová, P., Podolinská, J., Jeneiová, K. (2022): The assessment of changes in the long-term water balance in the Krupinica River basin for the period 1931–2020. Acta Hydrologica Slovaca, 23, 1, 21–31,

https://doi.org/10.31577/ahs-2022-0023.01.0003
Hanel, M., Vizina, A., Máca, P., Pavlásek, J. (2012): A multi-model assessment of climate change impact on hydrological regime in the Czech Republic. J. Hydrol. Hydromech., 60, 3, 152–161. https://doi.org/10.2478/v10098-012-0013-4
Holko, L., Parajka, J., Majerčáková, O., Faško, P. (2001): Hydrological balance of selected catchments in the Tatra Mountains region in hydrological years 1989–1998. J. Hydrol. Hydromech., 49, 3–4, 200–222
Hyvärinen, V. (2003): Trends and characteristics of hydrological time series in Finland. Nord. Hydrol. 34 (1/2), 71–90.
Mahmood, R., Jia, S., Mahmood, T., Mehmood, A. (2020): Predicted and projected water resources changes in the Chari catchment, the lake Chad basin, Africa. Journal of Hydrometeorology. 21, 1, 73–91. https://doi.org/10.1175/JHM-D-19-0105.1
Mammoliti, E., Fronzi, D., Mancini, A., Valigi, D., Tazioli, A. (2021): WaterbalANce, a WebApp for Thornthwaite–Mather Water Balance Computation: comparison of applications in two European watersheds. Hydrology, 8(1), 34. https://doi.org/10.3390/hydrology8010034
Parajka, J., Vizina, A., Komma, J., Valent, P., Štepánek, P., Haslinger, K., Schellander-Gorgas, T., Viskot, M., Fischer, M., Froschauer, W., Trnka, M., and Blöschl, G. (2023): Impact of climate change on the water balance of the Thaya basin, EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-14941, https://doi.org/10.5194/egusphere-egu23-14941
Pekárová, P., Miklánek, P., Halmová, D., Onderka, M., Pekár, J. (2011): Long-term trend and multi-annual variability of water temperature in the pristine Belá River basin (Slovakia). J. Hydrol., ISSN 0022-1694 400, p. 333–340.
Pekárová, P., Martincová, M., Miklánek, P. (2010a): Water balance of the Belá River basin in 1940/41–2004/05 period (Part I.: Basin water storage change in two 30-years periods). Acta Hydrologica Slovaca, 11, 1, 3–11.
Pekárová, P., Miklanek, P., Skoda, P., Pekár, J., Pacl, J. (2010b): Multiannual discharge variability and trend analyses of the Belá River (Slovakia) in 1895–2006. IAHS Publication 336, Wallingford, 59–64.
Pekárová, P., Halmova, D., Miklanek, P., Pekár, J., Skoda, P., Liova, S., Kucarova, K. (2009a): Homogeneity analysis of the water temperature measurements, Belá River at Podbanske. Acta Hydrologica Slovaca, 10, 1, 140–150.
Pekárová, P., Pacl, J., Liova, S., Miklanek, P., Skoda, P., Pekár, J. (2009b): Analysis of the maximum annual discharge regime in the high mountain basin of Belá River in Podbanske. Acta Hydrologica Slovaca, 10, 2, 300–311.
Pekárová, P., Pekár, J., Pacl, J. (2005): Temporal variability of annual discharges of Belá River basin for the period 1901–2000. Proc. Hydrologic days 2005, CD, SHMI, Bratislava.
Petrovič, P., Mravcová, K., Holko, L., Kostka, Z., Miklánek, P. (2010): Basin-Wide Water Balance in the Danube River Basin. In: Brilly, M. (eds) Hydrological Processes of the Danube River Basin. Springer, Dordrecht. https://doi.org/10.1007/978-90-481-3423-6_7
Senf, C., Buras, A., Zang, C. S., Rammig, A., Seidl, R. (2020): Excess forest mortality is consistently linked to drought across Europe. Nature communications, 11(1), 6200. https://doi.org/10.1038/s41467-020-19924-1
Sleziak, P., Výleta, R., Hlavčová, K., Danáčová, M., Aleksić, M., Szolgay, J., Kohnová, S. (2021): A Hydrological Modeling Approach for Assessing the Impacts of Climate Change on Runoff Regimes in Slovakia. Water, 13, 23, 3358. ISSN 2073–4441, https://doi.org/10.3390/w13233358
Vanham, D. (2013): An assessment of the virtual water balance for agricultural products in EU river basins. Water Resources and Industry, 1, 49–59. https://doi.org/10.1016/j.wri.2013.03.002
Vyshnevskyi, V. I. (2022): The impact of climate change on evaporation from the water surface in Ukraine. Journal of Geology, Geography and Geoecology. Vol. 31. N 1. P. 163–170. https://doi.org/10.15421/112216
Vyshnevskyi, V. I., Donich, O. A. (2021): Climate change in the Ukrainian Carpathians and its possible impact on river runoff. Acta Hydrologica Slovaca. Vol. 22, № 1, 3–14. https://doi.org/10.31577/ahs-2021-0022.01.0001
Vyshnevskyi, V. I., Kutsiy, A. V. (2022): Long-term changes in the water regime of rivers in Ukraine. Kyiv, 252 p. (in Ukrainian). Available online: https://er.nau.edu.ua/handle/NAU/56293

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