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The assessment of changes in the long-term water balance in the Krupinica River basin for the period 1931–2020

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The study is focused on the evaluation of changes in the hydrological balance of the Krupinica River basin to the Plášťovce station for the entire 90-year period as well as for the three 30-year subperiods 1931–1960, 1961–1990 and 1991–2020. In the first part of the study, the hydrological balance is processed in an annual step on the basis of measured series of average monthly flows from the Krupinica: Plášťovce; monthly precipitation totals on the Krupinica catchment area and average monthly temperatures in the catchment area. The hydrological balance in the monthly step was processed in the second part. Changes in water resources in the river basin over the three mentioned time subperiods were analyzed. The long-term annual precipitation total in the Krupinica River basin for the whole period was 660 mm, the annual runoff depth was 182 mm and the balance evaporation was 478 mm. A comparison of 30-year periods shows a significant decrease in the runoff of Krupinica – from 231 mm to 144 mm. This was even more pronounced in the runoff coefficient – it fell from 0.32 over 0.27 to 0.21 in the last period 1991–2020. In the third part, a simple regression relationship between runoff, precipitation and air temperature was derived to estimate the future development of the annual runoff from the basin. The relationship shows that a 100 mm decrease in precipitation in the Krupinica River basin will cause an average decrease of 52 mm in runoff. And an increase in the average annual temperature by 1°C in the Krupinica River basin results in a decrease in runoff of about 33.5 mm.

KEY WORDS: water (hydrological) balance, Krupinica River, long-term trends

Introduction

Water is essential for life. In addition to minerals, forests, fertile soils, it is another component of the country's natural wealth. Therefore, it must be managed wisely and it is necessary to monitor it, get to know it and try to understand its cycle in the country.

The time series of a hydrological components is the basic basis for assessing the regime of a hydrological process. It is possible to statistically analyse hydrological data in various steps (hourly, daily, monthly, annual, irregular). At present, the attention of hydrologists is in the first place: 1. analysis of changes in long-term runoff trends, and 2. changes in the hydrological balance in river basins. In trend analysis the parametric and non-parametric tests can be used. Generally, the zero hypothesis H0 – there is no trend has to be tested against the alternative hypothesis H1 – there is a trend. Distribution-free tests have the advantage that their power and significance are not affected by the actual distribution of the data. This is in contrast to parametric trend tests, such as the regression coefficient test, which assume that the data follow the Normal distribution, and whose power can be greatly reduced in the case of skewed data. The Mann–Kendall trend test (Mann, 1945; Kendall, 1975) based on the statistic S has therefore been widely used for testing trends in many natural time series that deviate significantly from the Normal distribution, such as temperature, rainfall, river flow, and water quality time series. Another widely used non-parametric trend test is Spearman's Rho test.

Trends of average, maximum and minimum annual discharges for the period 1877–2013 on the Danube in Bratislava were analyzed by the MK test with Blaškovičová et al. (2013). They found, that average annual flows have a balanced trend, annual low flows are on a declining trend and maxima are rising slightly. According to Pekárová et al. (2008), trends of the Danube River have a maximum of 30 days and 330 days. The difference in the maxima compared to the results of Blaškovičová was caused by the fact that in the case of Blaškovičová the water years 2010 and 2013 were already included in the analysis. Poórová et al. (2013) examined the trends of minimum annual and monthly discharges for the period 1961–2012 in Slovak river basins. According to their results, annual lows are declining in the Morava, Dolný Váh, Nitra, Hron, Ipľa, Slaná and Bodva river basins. Flows in the upper Váh, Poprad, Hornád and Bodrog river basins have an increasing trend of annual minima. Jeneiová et al.

(2015) focused on detecting changes in long-term data series of the annual peak discharges from nine stations in southern Slovakia. Trend was detected by modified MK test and Theil-Sen slope for moving time windows. It is clear from their results that the significance and magnitude of the detected trend changes with the length of the observation. Detection of changes therefore should not focus only on the statistical analysis of the time series but also in the identification of drivers behind the detected changes. Blahušiaková and Matoušková (2015; 2016) used different methods for identifying trends in data series: simple mass curve analysis, linear regression, frequency analysis of flood events, use of the Indicators of Hydrological Alteration software, and the MK test. Analyses are performed for data from two periods (1931–2010 and 1961–2010). The Mann-Kendall test shows a significant decrease in runoff in the winter period. The main causes of runoff decline are: the considerable increase in air temperature, the decrease in snow cover depth and changes in seasonal distribution of precipitation amounts. Ďurigová et al. (2019) analyzed average monthly and seasonal flows on selected Slovak streams using basic descriptive statistics, trend analysis, periodic component analysis, ARARCH model and multidimensional analysis. They found that the biggest changes in the trend and periodic component are on the Hron stream. Of the smaller river basins, in particular the Kysuca, Bystrica and Čierny Váh rivers, show statistically significant declining trends. Ďurigová and Hlavčová (2020) detected the changes in the upper Váh River basin according to decadal analysis. Their results of the air temperature analysis indicate an apparent upward trend in all the stations. Between the warmest and the coldest decades, the average difference in each river basin is 1.5°C. The precipitation regime in the earlier decades had a variable or decreasing character. Since the 1980s, there has been a slight increase. The increase in air temperature appears to affect the decreasing flow rate due to increasing evapotranspiration. The increase in precipitation in recent decades has been reflected in some stations by an increase in discharges. Šimor and Ľupták (2021) evaluated the trends for the period 1961–2000 in terms of significance and magnitude at selected water gauging stations and their possible change after the addition of 15 years (1961–2015). Trends were evaluated in a selection of 65 Slovak gauging stations with long-term observations, which was considered as unaffected. In both periods, non-significant trends prevail over significant trends in both minimum and average annual discharges, despite the occurrence of two extreme years.

To assess and better understand the evolution of water bearing is in addition to hydrological characteristic necessary assessment climatological characteristics, in particular air temperature and evaporation. Trend analysis of Zeleňáková et al. (2018) applied to precipitation and temperature monthly data for the period from 1962 to 2014 is presented for the hydrological year (from November to October) in sixteen climatic stations in Eastern Slovakia. The topography of this part of the country is very diverse and it affects the climate. The MK test coupled with Sen's slope was applied to identify the significant long-term climatic trends, as well as the magnitude of those trends. Another example of using the MK test is study of Ptak et al. (2022) where authors have determined the trends of water temperature over the study period, their magnitude, identified the break points in the data series and examined the relationships among the air temperature, river discharge and water temperature. The determination of tendencies of changes in the water temperature of the Vistula River involved the analysis of trends of changes by means of the MK test. The analysis of Holko et al. (1998; 2020) identifies the data series of Jalovecký creek that appear to exhibit trends or changes in behaviour, either in magnitude or in variability. Trends and change points detection are calculated for these time series using the MK test and the Wild Binary Segmentation method.

The MK test is based on the assumption of a linear trend in the whole observed series. However, it is also necessary to monitor long-term fluctuations – the alternation of multi-year dry and wet periods. Halmová et al. (2021) analyzed changes in N-year minimum daily discharges at selected gauging stations and long-term trends of 1- to 90-day minimum discharges at five gauging stations along the length of the Danube River and at its 5 selected significant tributaries. Average daily flows with the longest possible series of observations (since 1901 or since 1921) were used as input data. The analyzes show that there is a more or less regular alternation of water and dry periods along the entire length of the Danube. Multi-year dry seasons along the length of the Danube occur in the same periods. In contrast, on the Danube tributaries, the dry seasons are time-shifted.

After analyzing the flow trends, it is necessary to examine the effect of air temperature increase and the effect of precipitation increase / decrease on runoff. The hydrological balance is an expression of the basic relationships between the elements of the hydrological cycle. Reliable determination of the basic components of the water balance of the area (precipitation, runoff, balance evaporation) depends primarily on the accuracy of direct measurement of the first two components, from which the calculation is determined (Majerčáková et al., 1998). Considerable attention is paid to the methods of hydrological balance of forest river basins and they are described in professional hydrological and forest-hydrological literature. The hydrological balance of the six river basins of the Western and High Tatras (Roháčska, Jalovecká, Žiarska, Račkova, Tichá and Kôprová dolina) for the hydrological years 1989–1998 was prepared by Holko et al. (2001). Their results showed that even with all existing data and modern calculation methods, the existing metering network does not provide a satisfactory answer to the doubts that arise in determining the basic components of the hydrological balance in individual mountain basins. The hydrological balance of mountain river basins remains an insufficiently clarified problem. Garaj (2020) dealt with the hydrological balance of 10 Slovak river basins in his dissertation. Földes et al. (2020) detected trends and seasonal changes in the future horizons using the outputs of the Community Land Model (CLM) scenario, which is a moderately pessimistic scenario that compares well to current processes in the atmosphere, in mountainous regions of Northern Slovakia (four selected climatological station namely: Bardejov, Červený Kláštor, Javorina and Tatranská Lomnica). This region of Slovakia belongs to a slightly warm climatic area, with a mountain climate and low temperature inversions.

Krajewski et al. (2019) investigated trends in temperature, precipitation and river-flow characteristics in a small watershed, typical for Central Poland, with 53 years of observations (1963–2015) using the Mann-Kendall test. Authors founded that this short period already allows for detecting some changes in hydro-meteorological variables. These changes could be characterized by a significant increase in the mean annual air temperature on a daily basis, and a significant decrease in the mean annual discharge on a daily basis and in the minimum annual discharge on a daily basis.

Most of the mentioned studies deal with the analysis of changes in individual components of the hydrological balance since 1961 or only since 1981. The motivation for our work was to analyze changes in individual components of the hydrological balance in a uniform way for the longest possible time period not affected by human activity.

The study is focused on the evaluation of changes in long-term trends and the hydrological balance of the Krupinica river basin to the Plášťovce station for the whole 90-year period 1931–2020, as well as for the three 30-year subperiods 1931–1960, 1961–1990 and 1991–2020. One of the partial goals was to derive a simple regression relationship between runoff, precipitation and air temperature according to which it is possible to estimate the future development of the annual runoff from the Krupinica river basin at the Plášťovce gauging station.

Material and methods

River basin description and data

The Krupinica River springs in the Javorie Mountains below the peak of Veľký Lisec. It is a right-hand tributary of the river Ipeľ. The river cuts into the Pliešovská basin, Štiavnické vrchy, Krupinská planina and Ipeľská pahorkatina. The Krupinica catchment area to Plášťovce gauging station is 302.79 km^2. The long-term average flow at the Plášťovce station in the period 1931–1960 was 2.2 m^3 s^{-1}. For the period 1931–1960, the long-term average annual air temperature in the river basin was 8.38°C. On average, 695 mm of rainfall fell in the catchment area during the hydrological year (Charakteristické hydrologické údaje slovenských tokov, 1963). From this value 229 mm drained through the river network and 466 mm evaporated. The streams in the river basin form a mostly parallel river system. Due to the not very rugged terrain, the average altitude reaches 450 m above sea level.

The average monthly values of precipitation and air temperature from the stations Banská Štiavnica (latitude 48 26 58, longitude 18 55 18; 575 m above sea level) and Bzovík (latitude 48 19 9, longitude 19 5 38; 355 m above sea level), and average monthly discharges from the gauging station Krupinica: Plášťovce for the years 1931–2020 were used to evaluate the hydrological balance.

Methods

Two non-parametric tests were used to analyze long-term trends in hydrological and meteorological data: the Mann-Kendall test (MK test coupled with Sen's slope to identify the significant long-term climatic trends, as well as the magnitude of those trends) based on the statistic S, and the Spearman's ρ (rho) test. The Mann-Kendall test estimates the gradients between each datum and all the subsequent data in a sequence and tests the null hypothesis based on the standardized sum of the number of positive gradients minus the sum of the number of negative gradients. A description of these tests can be found in a variety of papers.

The hydrological balance was carried out in two time steps: 1. in the annual step, i.e. for the calendar year; 2. for 3 30-year periods in a monthly step for the hydrological year (from November to October).

The hydrological balance quantifies the water circulation in a closed river basin system with one concentrated runoff in the final profile on the watercourse. The only entry into the river basin is atmospheric precipitation in the river basin. The difference in soil water reserves at the beginning and end of the balance period can be neglected for a sufficiently long period (year). In this case, we can identify the annual total evapotranspiration with the difference between precipitation and runoff. With the monthly balance, if we determine the monthly total evapotranspiration in an independent way, we can determine from the equation of the hydrological balance the change of water supply in the river basin in the respective month.

We used a balance equation in the form:

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

where

P – average annual precipitation total [mm],
R – average annual runoff [mm],
ET – balance evaporation [mm],
ΔS – average total losses Δt.

As already mentioned, the term ΔS has a higher significance in shorter time intervals Δt. In the case of a long-term balance (30 years), this term can be neglected and replaced by $\Delta S = 0$.

Calculation of monthly potential evapotranspiration

For the calculation of the long-term monthly hydrological balance for the periods of the hydrological years 1930/31–1959/60, 1960/61–1989/90, and 1990/91–2019/20, it is necessary to know the annual course of the current evapotranspiration in the studied river basin.

Evapotranspiration or evaporation data availability is low. The average monthly and annual values of potential evapotranspiration for the Banská Štiavnica station for the period 1951–1980 can be found in tabular form in Tomlain's work (1991). In locations outside such a station, but at significantly different altitudes, the applicability of such data is limited.

We used the Thornthwaite method to calculate the average monthly values of potential evapotranspiration for the 48th parallel.

To calculate (PET) using Thornthwaite method, first the Monthly Thornthwaite Heat Index (i_m) calculation is required, using the following formula:

$$i_m = (T_m/5)^{1.514} \tag{2}$$

where

T_m – the mean monthly temperature.

The Annual Heat Index (I) is calculated, as the sum of the Monthly Heat Indices (i_m):

$$I = \sum_{m=1}^{12} i_m \, . \tag{3}$$

A Potential Evapotranspiration (PET) estimation is obtained for each month, considering a month is 30 days long and there are 12 theoretical sunshine hours per day, applying the following equation:

$$PET_{uadjusted} = 16(10t/I)^{\alpha} \tag{4}$$

where

α is:

$$\alpha = 6.75 \times 10^{-9} I^3 - 7.71 \times 10^{-7} I^2 + 1.792 \times 10^{-5} + 0.49239. \tag{5}$$

Obtained values are corrected according to the real length of the month and the theoretical sunshine hours for the latitude of interest. For latitude 50°, the values of correction coefficients are in Table 1.

Results and discussion

Development of the trend of selected characteristics of hydrological data in the Krupinica river basin

The monthly and annual precipitation total for the Krupinica River basin after Plášťovce was determined from precipitation measurements from the Banská Štiavnica and Bzovík meteorological stations for calendar years. We have data from the Bzovík station only since 1961. Therefore, for the calculation of average monthly precipitation totals in the Krupinica River basin, only data from the Banská Štiavnica station (575 m n.m.) were used, which were converted to average river basin altitude (450 m n.m.) based on the determined precipitation gradient (data were multiplied by constant 0.8465). The values of the average monthly air temperature from the Banská Štiavnica station were similarly adjusted by a gradient to the average altitude of the Krupinica River basin (data were increased by 0.6°C) (Fig. 1).

From the daily measurements of water levels at the station Krupinica: Plášťovce, the annual runoff heights R in mm from the basin were calculated. Fig. 1 shows the course of annual runoff values for the period of the calendar years 1931–2020. Subsequently, polynomial functions were used to analyze the long-term trend. During the observed period 1931–2020, the Krupinica: Plášťovce flows decreased. Despite the increase in precipitation after 1990, flows continued to decline. In this river basin, the runoff coefficient k, decreased significantly, from 0.35 to 0.2. In Fig. 1 also shows the average annual air temperatures T in the river basin and the balance evaporation ET for calendar years. The air temperature has risen sharply over the last thirty years, from 8°C to 9.5°C. The balance evaporation has a very similar course (Table 2). While the decrease in runoff until ca 1990 was due to a decrease in precipitation, after 1990 the decrease in runoff is mainly due to a sharp rise in air temperature.

The analysis of the trends of selected components in the Krupinica River basin showed different results for three shorter subperiods and for the whole 90-year period.

The trend analysis of the average annual air temperature T for three thirty-year periods showed an increasing trend at the level of significance $\alpha = 0.1$ in the years 1931–1960 and a growing trend at the level of significance $\alpha = 0.001$ in the years 1991–2020. The trend analysis of the average annual air temperature T for three thirty-year periods showed an increasing trend at the level of significance $\alpha = 0.1$ in the years 1931–1960 and a growing trend at the level of significance $\alpha = 0.001$ in the years 1991–2020. For the entire observed period, the trend at the level of significance $\alpha = 0.001$ was increasing.

In the time period 1991–2020, a growing trend of annual evapotranspiration ET was demonstrated at the level of significance $\alpha = 0.05$, and at the level of significance $\alpha = 0.1$ in the period 1931–2020.

Regarding the trend analysis of precipitation and runoff from the river basin, for the period 1991–2020 an increasing trend of precipitation P at the level of significance $\alpha = 0.05$ and a decreasing trend of runoff from the basin R for the whole period 1931–2020 at the level of significance $\alpha = 0.001$ was demonstrated.

Annual hydrological balance of the Krupinica River basin

The values of the basic components of the water balance of the Krupinica River basin calculated for the calendar years 1931–2020 and the three 30-year subperiods are given in Table 3. The long-term annual precipitation total in the Krupinica River basin for the whole period was 660 mm, and balance evaporation 478 mm.

Table 1. Monthly values of correction coefficients for monthly PET values for latitude 50°

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
0.74	0.78	1.02	1.15	1.33	1.36	1.37	1.25	1.06	1.01	0.78	0.74

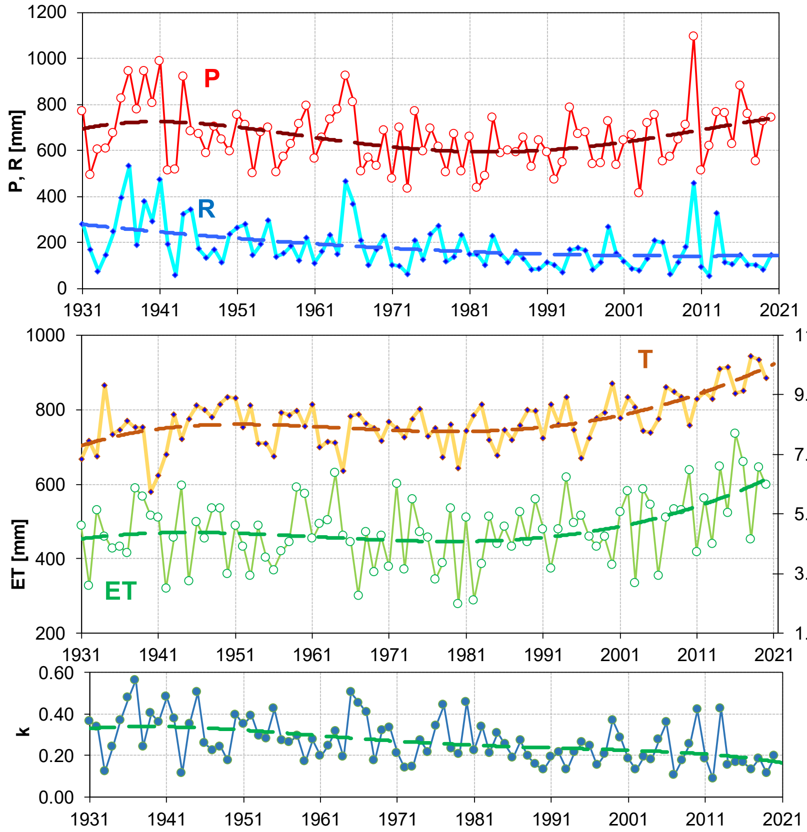


Fig. 1 *Annual precipitation totals P and annual basin runoff R, over the Krupinica River basin up to Plášťovce, (upper), course of the annual evaporation ET and mean annual basin air temperature T; Runoff coefficient k (lower); time period 1931–2020. Polynomial trends.*

Table 2. Results of MK test for trends of selected characteristics at Krupinica: Plášťovce (*P* – annual precipitation totals, *R* – annual basin runoff over the Krupinica basin up to Plášťovce, *ET* – annual evaporation, *T* – mean annual basin air temperature)

Time series	Mann-Kendall trend				Sen's slope estimate	
	First year	Last Year	Test Z	Signific.	A	B
T [°C]	1931	1960	1.855	+	0.033	7.452
T [°C]	1961	1990	0.642	n.s.	0.009	7.386
T [°C]	1991	2020	3.925	***	0.066	3.661
T [°C]	1931	2020	3.491	***	0.012	7.496
ET [mm]	1931	1960	0.000	n.s.	-0.261	460.7
ET [mm]	1961	1990	0.000	n.s.	-0.002	459.2
ET [mm]	1991	2020	2.319	*	5.162	141.8
ET [mm]	1931	2020	1.693	+	0.727	443.4
P [mm]	1931	1960	-0.624	n.s.	-2.000	959.5
P [mm]	1961	1990	-0.999	n.s.	-3.685	1119.6
P [mm]	1991	2020	1.998	*	5.960	-8.540
P [mm]	1931	2020	-0.812	n.s.	-0.572	834.2
R [mm]	1931	1960	-1.213	n.s.	-2.794	422.4
R [mm]	1961	1990	-1.570	n,s,	-2.333	398.3
R [mm]	1991	2020	-0.178	n.s.	-0.362	164.6
R [mm]	1931	2020	-4.224	***	-1.305	291.7

Z, Mann-Kendall test statistic; f(year) = A*(year-firstDataYear) + B
n.s, – Non-significant, +, Significant at 5%; *, Significant at 1%; **, Significant at 0.1%; ***, Significant at 0.01%

The highest runoff in the Krupinica River during the measurement period was in 1937 – 532 mm. The lowest annual runoff of 55.7 mm was in 2012. The runoff coefficient in the Krupinica River basin fluctuates from 9% to 56% with an average of 27%. A comparison of 30-year periods shows a significant decrease in the Krupinica outflow – from 231 mm to 144 mm, which was even more pronounced in the outflow coefficient. It fell from 0.32 through 0.27 to 0.21 in the last period 1991–2020.

The changes in percentiles (10-, 50-, and 90-) for annual precipitation series, air temperatures, and runoff for individual subperiods are visually compared in Fig. 2.

Table 3. **Krupinica River basin annual water balance for 4 periods 1931–1960, 1961–1990, 1991–2020, and 1931–2020. *P* – precipitation amount on basin, *R* – runoff depth, *ET* – yearly balance evaporation (*ET* = *P* - *R*), *Qa* – mean annual discharge, *q* – specific (unit) discharge, *k* – runoff coefficient, c_s – coefficient of asymmetry (decadal), c_v – variation coefficient (decadal), average annual air temperature in the Krupinica River basin**

Time period	*P* [mm]	*R* [mm]	*ET* [mm]	Q_a [m^3 s^{-1}]	*q* [l s^{-1} km^{-2}]	*k*	c_s	c_v	*T* [°C]
1931–1960	695	231	464	2.22	7.31	0.32	0.48	0.42	8.38
1961–1991	623	172	452	1.65	5.43	0.27	0.84	0.43	8.29
1991–2020	662	144	517	1.39	4.57	0.21	1.25	0.52	9.20
1931–2020	660	182	478	1.75	5.77	0.27	0.87	0.46	8.63

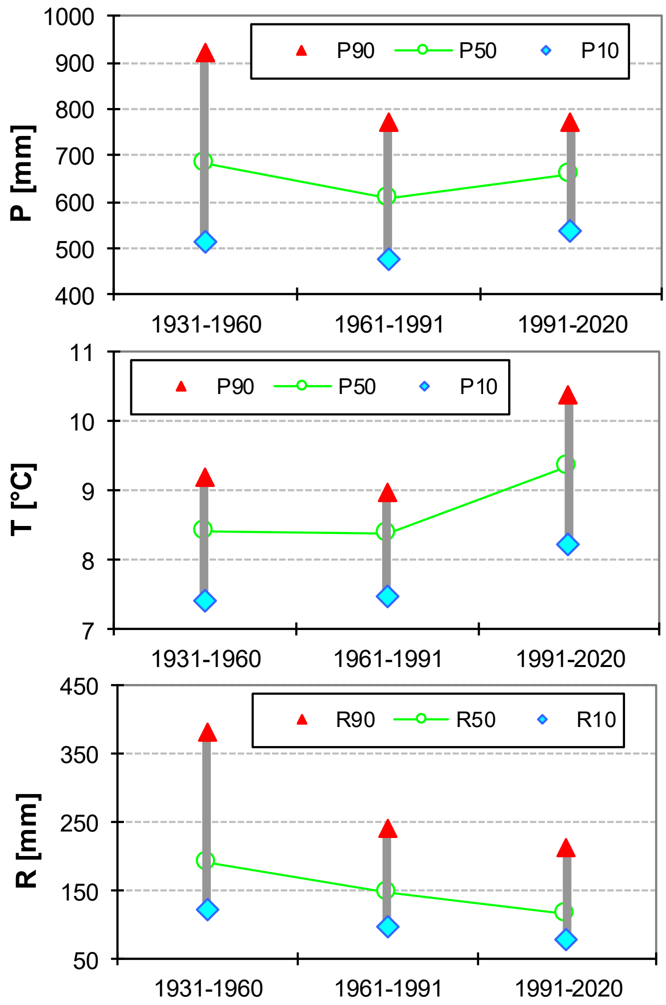


Fig. 2. The course of percentiles (10-, 50-, and 90-) for the series of annual precipitation P, air temperature T and outflow Krupinica R.

Long-term hydrological balance of monthly values in the Krupinica River basin

The Thornthwaite method was used to calculate the intra-annual distribution of potential evapotranspiration. The monthly PET, m values for the three subperiods examined are given in Table 4.
Maximum precipitation also occurs in the months with maximum evaporation and the availability of water should not be a factor modifying the annual distribution of the current evapotranspiration compared to the potential one. This fact makes it possible to assume that the annual course of potential and current evapotranspiration will be very similar in the studied river basin and the relations (2–5) can also be used for the intra-annual distribution of current evapotranspiration or balance evaporation.
Tables 5 a–c show the values of the monthly elements of the water balance equation, determined from the long-term monthly averages of measured precipitation and runoff for the periods 1930/31–1959/60, 1960/61–1989/90, and 1990/91–2019/20. Based on the percentage distribution of evaporation in the year according to PET in the Krupinica River basin, the monthly values of ET evaporation were calculated from the annual balance evaporation.

Table 4. Average monthly potential evapotranspiration PET, m in mm for the Krupinica River basin according to relations (2-5) for 3 periods 1930/31–1959/60, 1960/61–1989/90, and 1990/91–2019/20

PET,m mm	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X
1930/31–1959/60	11.5	1.6	0.3	0.8	13.3	45.7	87.7	113.0	128.8	112.5	74.2	41.7
1960/61–1989/90	11.7	1.2	0.4	2.2	15.8	47.1	87.5	110.8	124.0	109.1	72.2	43.5
1990/91–2019/20	13.3	1.2	0.7	3.3	16.9	49.8	89.9	116.7	131.7	116.6	70.5	40.8

Table 5. Long – term water (hydrological) balance terms time course, Krupinica, period *a*) 1930/31–1959/60; *b*) 1960/61–1989/90; *c*) 1990/91–2019/20

a	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	Year
P [mm]	70.3	53.4	37.2	45.2	51.7	47.7	73.1	77.6	68.6	60.9	45.7	63.2	695
R [mm]	21.6	21.9	18.7	28.8	55.2	30.5	19.7	12.0	8.4	4.7	4.1	4.9	231
ET [mm]	8.5	1.2	0.2	0.6	9.8	33.6	64.5	83.1	94.7	82.8	54.6	30.7	464
S=P-R-ET	40.2	30.2	18.3	15.8	-13.3	-16.4	-11.1	-17.4	-34.6	-26.5	-12.9	27.6	0
sum S	40	70	89	105	91	75	64	46	12	-15	-28	0	
ET [%]	1.8	0.3	0.0	0.1	2.1	7.2	13.9	17.9	20.4	17.8	11.8	6.6	100
ET+R	30.1	23.1	19.0	29.3	65.0	64.1	84.2	95.1	103.2	87.5	58.7	35.6	695
b	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	Year
P [mm]	60.5	53.4	41.9	43.1	39.1	44.9	63.5	76.2	54.1	54.5	47.9	41.0	620
R [mm]	10.8	14.6	11.7	20.8	37.7	25.7	14.9	11.7	5.2	4.4	4.8	9.3	172
ET [mm]	8.4	0.9	0.3	1.6	11.3	33.7	62.7	79.5	88.9	78.3	51.8	31.2	449
S=P-R-ET	41.3	37.9	29.9	20.7	-9.9	-14.5	-14.1	-15.0	-40.0	-28.2	-8.7	0.6	0
sum S	41.3	79.2	109.1	129.7	119.8	105.3	91.2	76.3	36.3	8.1	-0.6	0.0	
ET [%]	1.9	0.2	0.1	0.4	2.5	7.5	14.0	17.7	19.8	17.4	11.5	6.9	100
ET+R	19.2	15.5	12.1	22.4	49.0	59.4	77.6	91.1	94.1	82.7	56.6	40.5	620
c	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	Year
P [mm]	59.1	51.8	43.6	41.4	44.2	45.5	68.0	65.2	70.7	57.3	57.3	57.5	662
R [mm]	9.0	12.4	11.7	16.0	32.1	20.9	11.3	10.4	5.9	3.7	4.3	6.5	144
ET [mm]	10.6	0.9	0.6	2.6	13.4	39.6	71.4	92.7	104.6	92.6	56.0	32.4	517
S=P-R-ET	39.6	38.4	31.3	22.8	-1.3	-15.0	-14.7	-38.0	-39.8	-39.0	-2.9	18.6	0
sum S	39.6	78.0	109.2	132.1	130.8	115.8	101.1	63.1	23.3	-15.7	-18.6	0.0	
ET [%]	2.0	0.2	0.1	0.5	2.6	7.7	13.8	17.9	20.2	17.9	10.8	6.3	100
ET+R	19.5	13.4	12.3	18.6	45.5	60.5	82.7	103.1	110.5	96.4	60.3	38.9	662

The courses of the elements of the hydrological balance determined from the long-term monthly averages in the river basin are shown in Fig. 3.

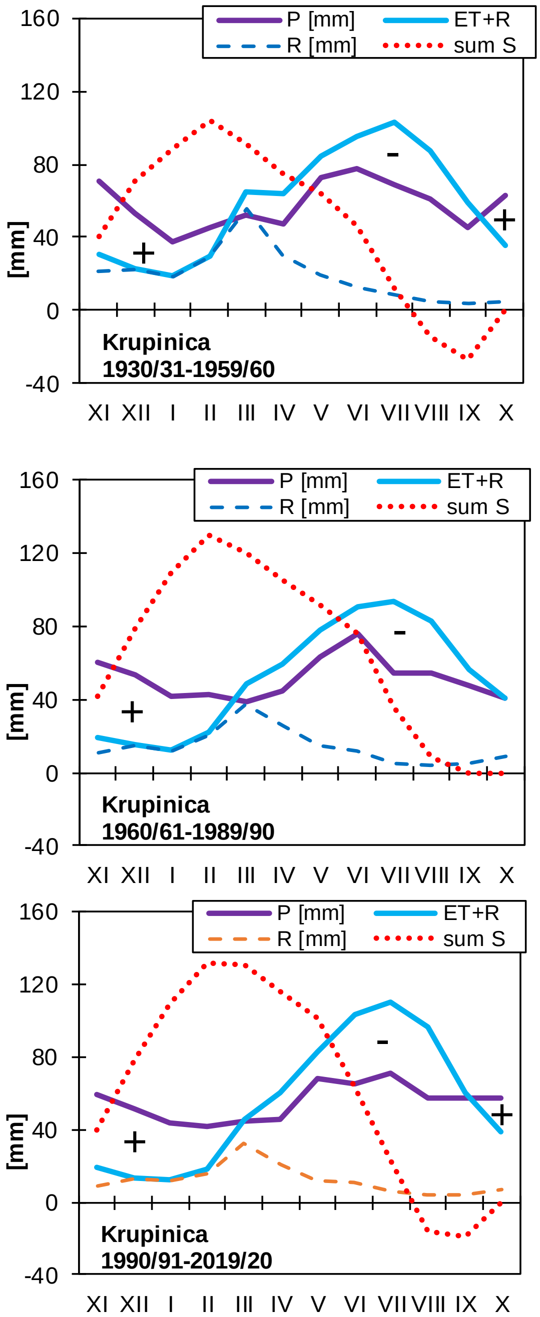


Fig. 3. Water (hydrological) balance components time course, determined from the long term monthly means in the river Krupinica basin up to Plášťovce, periods 1930/31–1959/60, 1960/61–1989/90, and 1990/91–2019/20.

Water resources (S) in the Krupinica River basin increased in the first and third periods from September to March, from April to August the accumulated water resources in the river basin were exhausted. In the second period 1960/61–1989/90, water resources increased from November to March, in the remaining period water supplies were exhausted. The largest fluctuation of changes in water resources (S) in the river basin was in the long term in the last period – 1990/91–2019/20, with a 30-year average of 150.7 mm. The hydrological balance compiled in this way makes it possible to set aside the average monthly changes in water resources in the river basin, and in a narrower sense in the soil and groundwater.

In terms of monthly precipitation totals, their long-term average (for the periods 1930/31–1959/60, 1960/61–1989/90, and 1990/91–2019/20) in the river basin is relatively balanced. The maximum precipitation fell in May-July, the minimum in January-March (Fig. 4a). The highest average monthly runoff in all three periods occurred in March – the period of melting snow (Fig. 4b) and highest long-term monthly balance evapotranspiration ET in July (Fig. 4c). During these months, almost 38% of the total annual outflow flows. The largest runoff is the month of March $c_v = 0.59$, the largest fluctuations in the runoff are recorded in August $c_v = 1.72$.

Dependence of annual runoff on precipitation and air temperature

A simple regression relationship between runoff, precipitation and air temperature can be used to estimate the future development of the annual runoff from the river basin (Fig. 5). Such relations were derived by Oto Dub in 1966 or Friga (Šipikalová et al., 2006), who determined several regional relations for different river basins.

For the Krupinica River basin, the following relationship was derived from the data of the time period 1931–2020:

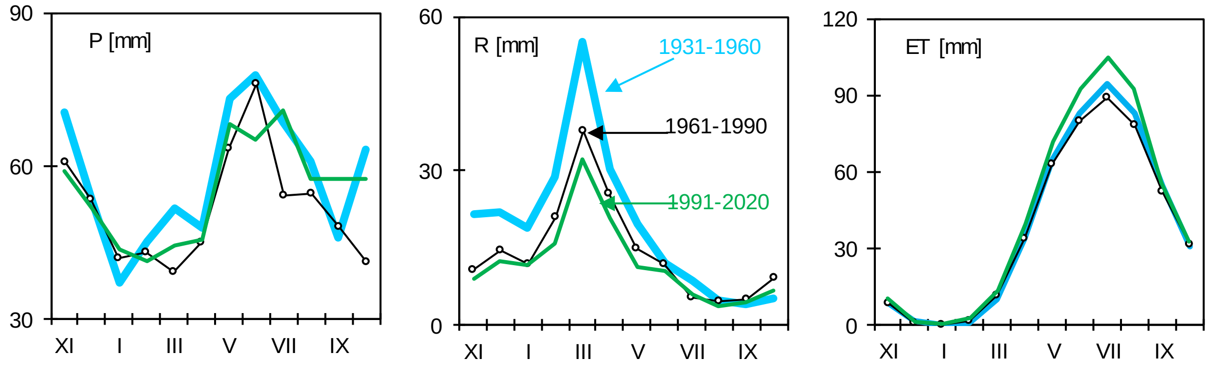
$$R = 0.519*P - 33.475*T + 131 \qquad (6)$$

where:

R – average annual runoff [mm],
P – average annual precipitation total [mm],
T – average annual air temperature [°C].

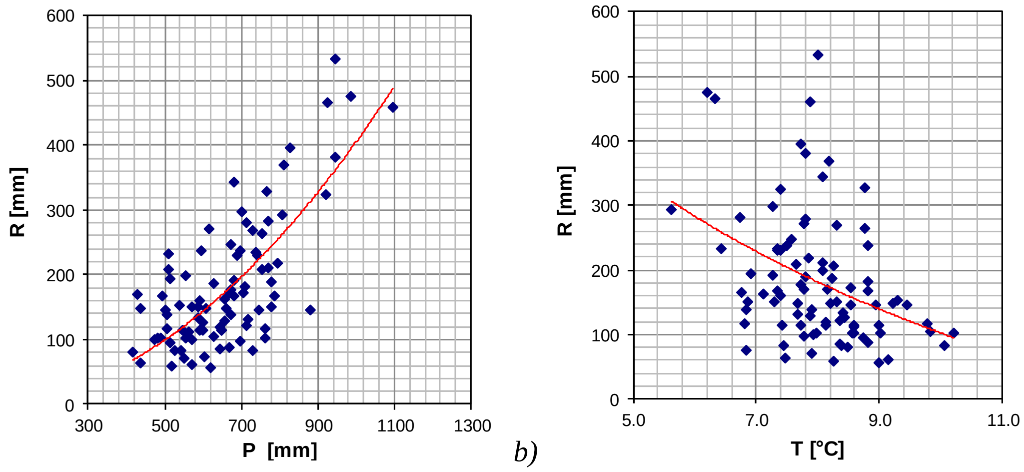
From relation (6) it follows that a decrease of precipitation in the Krupinica River basin by 100 mm will cause a decrease of runoff by 52 mm. An increase in the average annual temperature of 1°C results in a decrease of the runoff of 33.5 mm. By analogy, an increase in the average annual air temperature by 1°C results in an increase in evapotranspiration of 33.5 mm.

More accurate results for individual months and for other runoff components can only be obtained by mathematical modelling – using the precipitation-runoff balance model in a monthly (daily) step. Modelling procedures are gradually becoming a standard part of the solution and design optimization of water management systems in the world, mostly based on the observed hydrological series of flows, precipitation, temperatures, etc. Based on the information from these series, it is possible to determine the parameters of the system, such as e.g. water tank volume, dimensions of safety overflows, the height of the dam, required irrigation needs and others.



a) b) c)

Fig. 4. Water (hydrological) balance elements comparison, determined from the long–term monthly means of the river Krupinica basin up to Plášťovce, for three 30- years periods: 1930/31–1959/60, 1960/61–1989/90, and 1990/91–2019/20. a) Long-term monthly precipitation P, b) Long-term monthly runoff R, c) Long-term monthly balance evapotranspiration ET.



a) b)

Fig. 5. Dependence of a) annual runoff on the annual total precipitation in the Krupinica River basin; b) annual runoff at the average annual air temperature in the Krupinica River basin for the period 1931–2020.

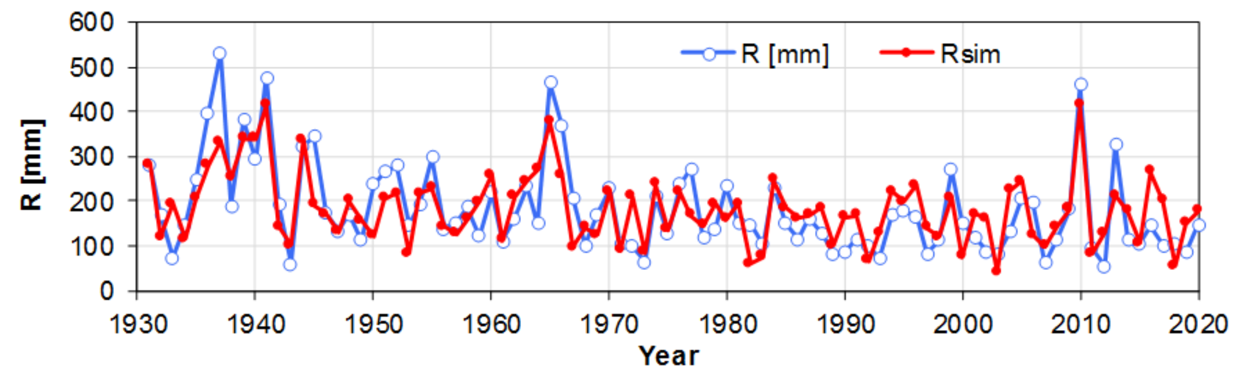


Fig. 6. The course of measured annual outflows R and simulated (Rsim) according to relation (6).

Conclusion

The analysis of the hydrological regime of the Krupinica River basin detected significant changes in the last 30 years (1991–2020). Even if this time period is relatively short, there is a need to closely observe and evaluate these changes. The changes in water balance need to be assessed in all significant catchments in Slovakia, while taking into the account also the level of anthropogenic influences. Due to climate changes, it is recommended to also assess the expected changes in rainfall and air temperature (Szolgay et al., 2007; Horvát et al., 2009; Földes et al., 2020; Sabová et al. 2021; Šipikalová et al., 2015). This task is needed and requires close cooperation between climatologists, hydrologist and water managers from different fields (governmental agencies, universities, research institutes). There is also a need for wider practical use of water balance models (Kožín et al., 2015; Fendeková et al., 2017) and special statistical methods for evaluation of changes in the runoff (Bačová Mitková and Halmová, 2021; Keszeliová et al., 2021)

The results of this study point to changes in the hydrological regime of Slovak rivers. This is also one of the reasons why are the hydrological characteristic of currently valid reference period in Slovakia (1961–2000) carefully revised and evaluated. One of the possible new reference periods is 1991–2020, which is recommended by the World Meteorological Organisation. During evaluation it also needs to be taken into the account, that the reference period should be selected and calculated based on type of application.

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