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Changes in the hydrological balance in the Litava river basin during the 90-years period 1931–2020

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During last twenty years, a number of extremely dry years have occurred in a number of European river basins. In Slovakia, the lowland streams of southern Slovakia have been particularly affected by drought. One of these streams is the Ipeľ River. In this basin we have three continuous observations of daily flows since 1931: from Krupinica at Plášťovce, Litava at Plášťovce, and from Ipeľ at Holiša station. The first part of the paper is devoted to the statistical analysis of the Litava flow series. In the second part, the hydrological balance in the Litava basin for the three subperiods (1931–1960, 1961–1990, and 1991–2020) in annual time step has been elaborated. The first thirty years 1931–1960 were the wateriest (runoff was 205 mm). In the last thirty years, the runoff coefficient was only 0.2 (runoff 131 mm) in Litava basin. In the final part of the study, the BILAN balance model (in a monthly step) was used to compute the contribution of several runoff components in the Litava basin during period 1930/31–2019/20. The long-term average baseflow accounts for 40.7% of the total modelled runoff, interflow accounts for 46.8% and direct runoff accounts for 12.5% of the total modelled runoff.

KEY WORDS: Litava River, hydrological balance, simulation, model BILAN

Introduction

In the last two decades, a decline in flows has been recorded in several streams in Slovakia. The hydrological balance in Slovakia did not change significantly until 2000. However, after 2000, we observe more significant changes in the hydrological balance (Fenkeková and Blaškovičová, 2018; Ďurigová et al., 2019; Halmová et al., 2022). Due to higher air temperature and higher precipitation, potential evapotranspiration and balance evaporation from the territory of the Slovak Republic are increasing. In eastern Slovakia, this trend is not as pronounced (Pavelková et al., 2016). In the period 1991–2015, annual precipitation in Slovakia increased overall by about 5% compared to the period 1961–1990, which amounts to almost 40 mm in absolute values. Despite higher rainfall totals, streamflows are decreasing. The decline in flows is most pronounced in the lowland streams of southern Slovakia.

In long-term water management planning, it is necessary (or at least advisable) to take into account the expected impact of climate change on the hydrological regime. For example, when permitting new abstractions (or increasing the capacity of existing abstractions), it is necessary to have information on water quantity. In view of this, it is recommended to include among the standard tasks of hydrology the study of the impact of climate change on the hydrological balance of river basins.

The hydrological balance of river basins in Slovakia has been addressed by a number of authors (e.g. Holko et al., 2001; Kostka and Holko, 2001; Majerčáková et al., 2004; Horvát et al., 2009; Pekárová et al., 2010; Porubská at al., 2012, 2013; Garaj et al., 2019; Keszeliová et al., 2021; Výleta et al., 2022).

The most comprehensive hydrological balance for the period 1961–1990 for 109 sub-basins in the entire Danube river basin was compiled by Petrovič et al. (2006, 2010). Sleziak et al. (2021) evaluate the possible climate change impacts on the runoff regime in eight selected basins located in the whole territory of Slovakia. The projected runoff in the basins they simulated using the HBV model.

For these reasons, we focused on assessing the long-term water balance in the relatively anthropogenically unaffected Litava river basin for the 90-year period 1931–2020.

The present study is divided into three parts.

1. The first part deals with a detailed statistical analysis of the Litava flows at the Plášt'ovce station;
2. in the second part we deal with the hydrological balance of the Litava in annual step;
3. the third part focuses on the modelling of the monthly water balance by the BILAN model.

Material and methods

River basin description

The Litava is an important left-side tributary of the Krupinica. It has a total length of 45 km. It rises in the Krupina plain, the spring lies at an altitude of about 650 m above sea level on the southern slope below the saddle between Kopaný závoz (775 m above sea level) on the western side and Jaseňový vrch (724 m above sea level) on the eastern side (Fig. 1). The area belongs to the upland-lowland region with a rain-snow type of runoff regime with accumulation in December-January, high water levels in February-April. There is a significant increase in water levels in late autumn and early winter. The Litava catchment area to Plášťovce gauging station is 214.27 km^2. 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 from the stations Krupina (latitude 48°22'51'', longitude 19°06'42''; 470 m a.s.l.), Bzovík (latitude 48°19'09'', longitude 19°05'38''; 355 m a.s. l.) and Senohrad (latitude 48°22', longitude 19°12'; 586 m a.s.l.), air temperature, and average monthly discharges from the gauging station Litava: Plášťovce for the 90-years period 1931–2020 were used to evaluate the hydrological balance.

Data

For the watershed balance, we need a measured series of discharge from the watershed and areal precipitation and mean temperature on the watershed. There is a problem in Slovakia with obtaining continuous series of daily precipitation and air temperature data for the period 1931–1960. From the point of view of protection of our country before floods there was build-up a network of precipitation stations at the end of the 19. century. The average monthly precipitation series from 203 stations (period 1901–1970) were published in the Collection of papers of the SHMI. Therefore, when processing the water balance, we only worked with stations published in Šamaj and Valovič (1978).
The following data were used in the analysis of the flows:

- Average daily discharge of the Litava at the station Plášťovce, 1931–2020;
- Average monthly air temperatures at Bzovik, and Banská Štiavnica stations (Petrovič and Šoltís, 1984);
- Monthly precipitation totals from stations Bzovík, Krupina, and Senohrad (Šamaj and Valovič, 1978).

Methods

Considerable attention has been paid to catchment hydrological balance methods. The hydrological balance quantifies the circulation of water in a closed catchment system with one concentrated outlet in the final profile on a watercourse. Assume that the only input to the watershed is atmospheric precipitation in the watershed and that there are no withdrawals or inflows from neighbouring areas. Then we can use a balance equation of the form:

$$P = R + ET + \Delta S \tag{1}$$

where:
P – mean annual precipitation depth [mm];
R – mean annual runoff depth [mm];
ET – balance evaporation [mm];
ΔS – change of water retention in the basin during the time Δt.

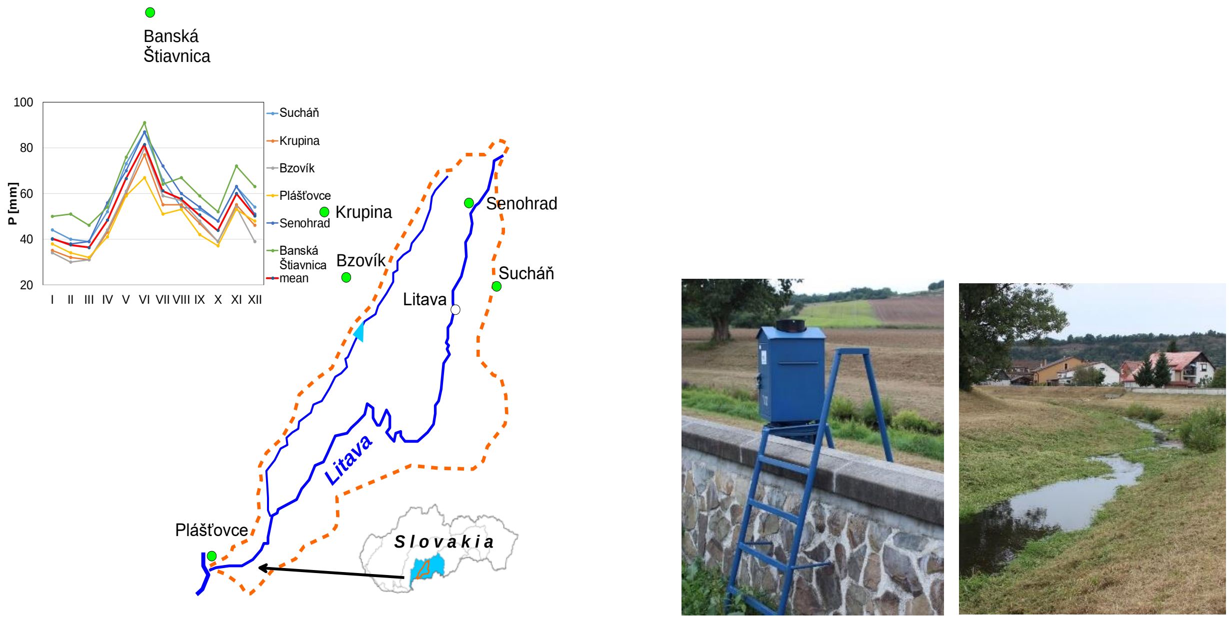


Fig. 1. Location and scheme of the Litava basin, precipitation stations (green points) and course of the monthly precipitation (1961–1990), Slovakia (left); water gauge of the SHMI at Plášťovce on Litava River. (Photo: J. Mészáros, 2021).

The difference in water storage in the saturated and unsaturated zones of the soil and in snow at the beginning (1 November) and at the end (31 October) of the balance period can be neglected for a sufficiently long period (e.g. 30 years) (Majerčáková et al. 2004). In that case, we can identify the annual actual evapotranspiration (AET) with the difference between precipitation and runoff, which is the annual balance evaporation (ET).

Over the last decades, hydrological rainfall-runoff models in a basin scale have become an important tool in the water management. The user has been able to choose the right model depending on the topic of study. The biggest problem remains the problem of getting high-quality, sufficiently long series of input data. After proper model selection and calibration, its subsequent use has irreplaceable contribution either in the water management or ex post evaluation of specific situations in river basins.

Among the conceptual models with lumped parameters there belong e.g. monthly water models BILAN, WBMOD, WatBal, or rainfall runoff models in daily time step HBV, SAC SMA Sacramento soil moisture model, HEC-HSM model or GLOBAL model (Garaj et al, 2019).

In this study, we used the hydrological model BILAN with a monthly time step to assess the individual components of the water balance of the Litava basin up to station Plášťovce. Model BILAN belongs to a group of conceptual models with lumped parameters (Tallaksen and van Lanen, 2004; Kašpárek and Novický, 1997, 2004a, b; Horáček et al., 2009; Vizina et al., 2015). The model schematizes (simplifies) catchment areas into three water reservoirs. The structure of the model consists of a system of relations describing the basic principles of water balance of the unsaturated and saturated zones, including the impact of vegetation cover and groundwater. Measured time series of monthly precipitation, air temperature and potential evapotranspiration, or relative humidity are the inputs into the model BILAN.

The aim of the model is to simulate monthly time series of hydrological variables and apply it to the entire river basin. Total runoff in the month consists of three components: base flow, interflow (hypodermic) and direct flow. Direct flow is considered as fast runoff component of total runoff, which does not affect the evaporation, and soil water balance. Hypodermic flow is considered as the water excess in the aeration zone. In winter, during snowmelt, this runoff component also includes direct runoff. The base flow is the slow component of the total runoff, the delay in the basin may be longer than one month. The model in the vertical direction distinguishes three levels, namely the surface, soil zone and groundwater zone. The size of the flows between the reservoirs is determined by the model algorithms, which are controlled by eight free parameters.

Time series of measured monthly discharges (runoff) in the closing profile Litava are used for model calibration. The model parameters include: soil water storage, direct flow, snow melt factor, factor to calculate the amount of water in liquid form in the winter, the parameter managing percolation distribution, hypodermic flow and groundwater recharge in terms of the melting snow in the winter and summer, parameter managing drainage from groundwater aquifer.

Eight free model parameters have to be identified to simulate the streamflow generation by the model:

Spa **–** capacity of soil moisture [mm],

Alf **–** parameter for rainfall-surface runoff equation (direct runoff),

Dgm **–** snow melting factor,

Dgw **–** factor for calculating the quantity of liquid water available on the land surface under winter conditions,

Mec – parameter controlling distribution of percolation into through flow (interflow) and groundwater; recharge under conditions of snow melting

Wic **–** parameter controlling distribution of percolation into through flow (interflow) and groundwater; recharge under winter conditions,

Soc **–** parameter controlling distribution of percolation into through flow (interflow) and groundwater; recharge under summer conditions,

Grd **–** parameter controlling outflow from groundwater storage (base flow).

Model parameters are identified (calibrated) by using an optimization algorithm. The optimization aims at attaining the best fit between observed and simulated runoff series.

The calibration of the parameters is executed in two steps. In the first step, *the standard error* of estimate (standard deviation between the observed and simulated runoff series) or *mean absolute error* (mean calculated from absolute deviations between the observed and simulated runoff series, where 'absolute' means that negative deviations are converted to positive values) is used as the optimization criteria to calibrate ***Spa, Dgm, Dgw,*** and ***Alf*** parameters that affect significantly the mean runoff.

The remaining four parameters (***Mec, Wic, Soc, Grd***) affecting the runoff distribution into its individual components are then calibrated by using the mean of absolute values of relative deviations (relative means that each deviation is divided by observed value).

The values of model parameters obtained from the optimization algorithm can be influenced by the maximum number of iterations performed by the algorithm. In case that we achieved the optimal model parameters, we can proceed to the simulation. Initial conditions in the basin can significantly influence the results of the simulation of water balance, especially in the first year. These conditions can be specified by the initial groundwater reserves setting. These conditions can be specified by setting the initial groundwater storage. The default initial groundwater storage is 50 mm. It can be changed based on the current state in the basin in the first month, or is derived from interim simulations.

Results and discussion

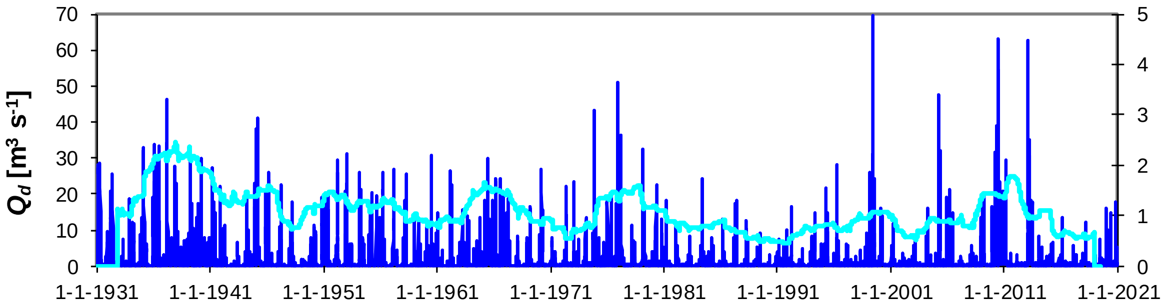
Statistical analysis of changes in the runoff regime of the Litava to station Plášťovce

The assessment of the hydrological regime of the Litava River was based on measurements of average daily discharge at the Plášt'ovce station for the period 1931–2020. Fig. 2a shows the course of the average daily discharge of the Litava. The average annual discharge of the Litava at Plášt'ovce for the period was 1.09 $m^3 s^{-1}$, the annual runoff depth was 160.5 mm. The highest average daily discharge was recorded on 22 June 1999 (69.48 $m^3 s^{-1}$). The wettest decade was 1931–1940, the driest 1981–1990 (Fig. 2b). Comparing the 30-year periods, the first period 1931–1960 was the wettest, the period 1961–1990 the most equable, and the last period 1991–2020 was marked by several floods and droughts.

The wettest month is April and the driest months are August-September (Fig. 2c). The highest flood flow of the Litava in Plášt'ovce was also recorded on 22 June 1999 Q_{max}=125.1 $m^3 s^{-1}$. The minimum flow Q_{min}=0.01 $m^3 s^{-1}$ was recorded on 1 September 1961 and on 13. July 1988. A water reservoir Kozí Vrbovok is built on a tributary of the Litava. As can be seen in Fig. 2d, the extreme peak discharges of the Litava in Plášt'ovce have increased significantly in the last 30 years. As a consequence, a flood dike has been built in Plášt'ovce (see Fig. 1).

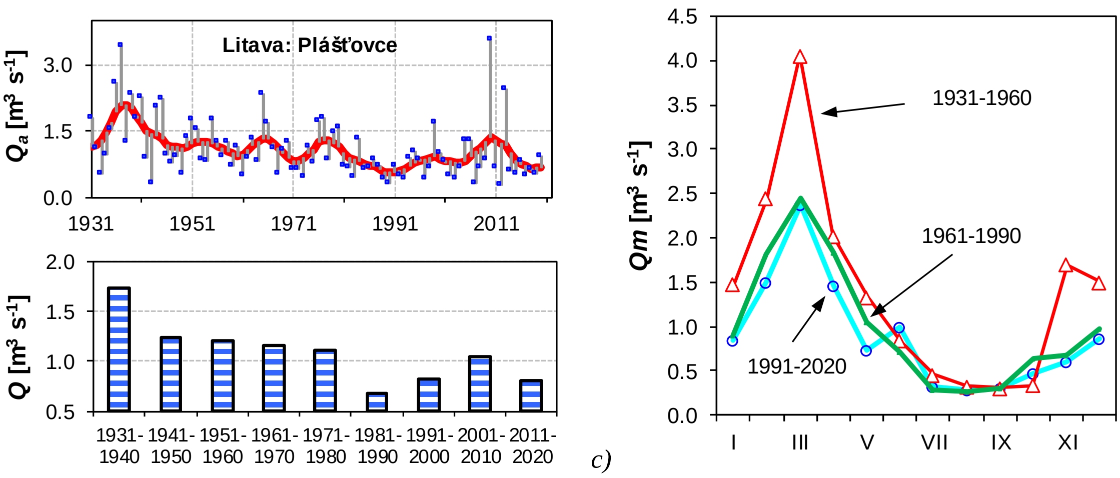
Hydrological balance in the Litava basin during three 30-years periods

The annual rainfall (per calendar year) for the Litava to Plášt'ovce catchment was determined from measurements at the Krupina, Bzovík and Senohrad stations in the period 1931–2020 (Fig. 3). Monthly precipitation totals were used to calculate the annual precipitation in the Litava basin, which were converted to the average elevation of the basin according to precipitation gradient (Petrovič et al., 2006). Basin air temperature was determined from stations Banská Štiavnica and Bzovík. The long-term average for the period 1931–2020 was 8.61°C. Fig. 3 shows the average annual values of the individual components of the hydrological balance, the air temperature in the basin, and the runoff coefficient (*k=R/P)* of the Litava River.



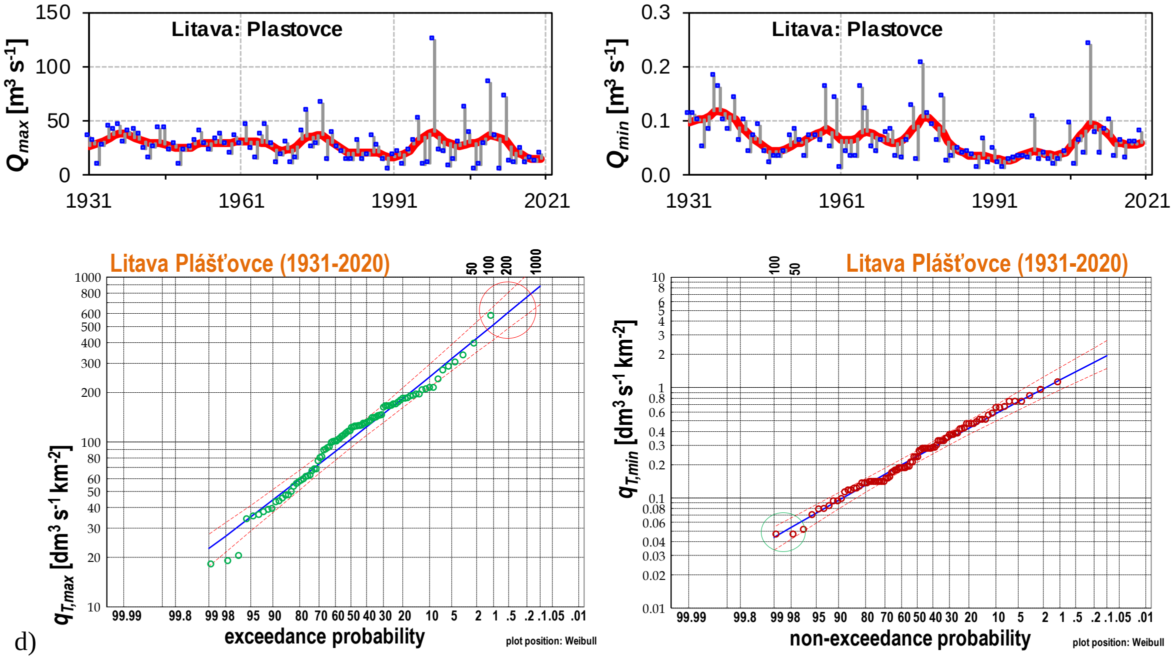
a)

Fig. 2. a) Mean daily discharge of Litava at Plášťovce station (dark blue line, left scale) and double 4-year moving averages of the daily discharge (light blue line, right scale).



b) c)

Fig. 2. b) Variability of the mean annual discharge (above) and 10-year mean values of the Litava discharge, period 1931–2020. c) Changes of the mean monthly discharge in three periods 1931–1960, 1961–1990, and 1991–2020.



d)

Fig. 2. d) Course of annual maximum Q_{max} (left) and minimum Q_{min} (right) discharge series of Litava, values of the maximum $q_{T,max}$ and minimum $q_{T,min}$ discharge per unit area (specific runoff) calculated according to log-Pearson type III distribution, Litava River at Plášťovce, 1931–2020.

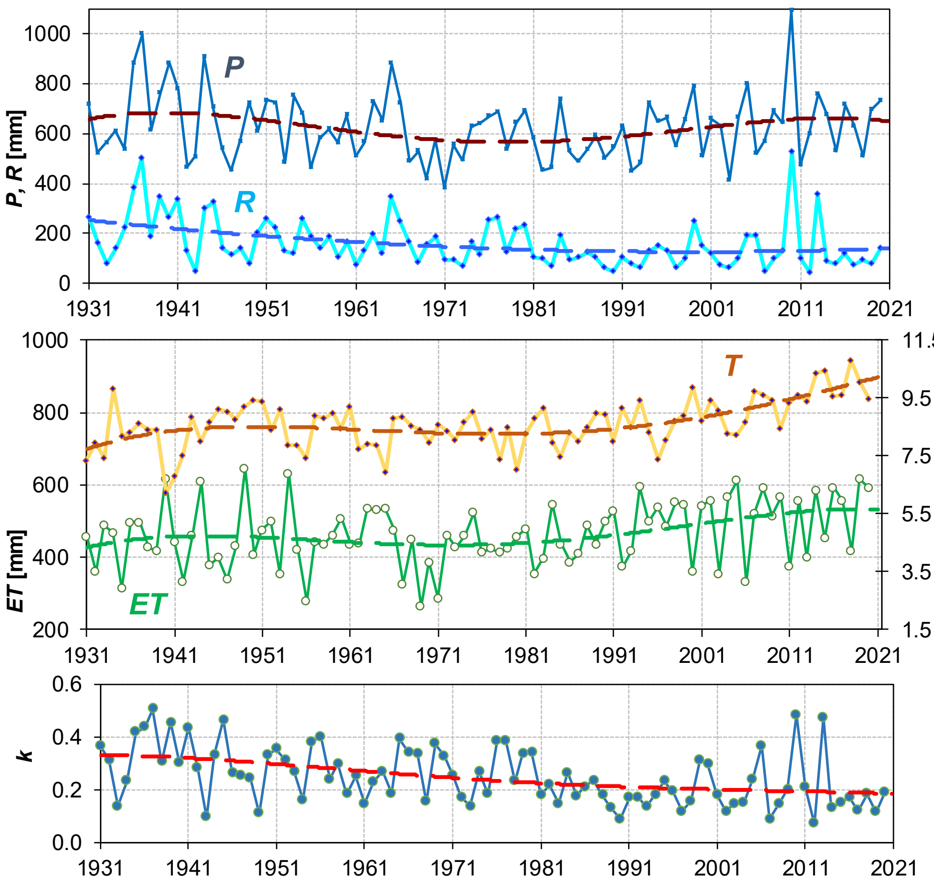


Fig. 3. Annual precipitation depth P and annual runoff R of the basin; annual balance evaporation ET, and the mean annual basin air temperature T; runoff coefficient k in the Litava basin up to Plášťovce, (period 1931–2020).

The values of the basic components of the water balance of the Litava basin for the three 30-year periods are presented in Table 1. The first thirty years 1931–1960 were the wettest, the runoff reached 205 mm, the runoff coefficient was 0.3. The years 1936–1940 were extremely wet, the average rainfall in this period reached 927 mm. The second thirty years had the lowest rainfall totals, 582 mm, but because it was the coldest, the balance evaporation was only 438 mm. The runoff coefficient dropped significantly – to 0.24. The 1990–2022 thirty-year period was the warmest, resulting in high evapotranspiration – 507 mm per year. Despite the higher rainfall, runoff fell to only 131 mm and the runoff coefficient fell to 0.2.

From the measured annual values over a 90-year period, a regression analysis was used to derive an empirical relationship for estimating the future development of runoff from the Litava basin (between runoff, precipitation and air temperature (Halmová et al., 2022):

$$Rmod = 23.38 + 0.522\ P - 22.01\ T \tag{2}$$

where:
Rmod – mean annual runoff from the Litava basin;
P – annual areal precipitation in the Litava basin;
T – mean annual air temperature in the basin.

A multiple correlation coefficient of 0.77 was obtained in the calculation. From relation (2), it can be seen that a 100 mm decrease in precipitation in the Litava basin causes a 52 mm decrease in runoff. A 1°C increase in annual mean temperature results in a 22 mm decrease in runoff.

More detailed runoff balance results for individual months and for several runoff components (base runoff, direct runoff) can only be obtained by mathematical modelling - using the balance model in a monthly (daily) step (Hanel et al., 2012; Sleziak et al., 2021).

Runoff balance by BILAN model in monthly step

Modelling of water balance components during the whole period 1930/31–2019/2020

We calibrated the BILAN model on data from the Litava to Plášťovce basin for the period 1930/31–2019/2020 (hydrological year). Table 2 shows the resulting model parameters for the whole period 1930/31–2019/2020. We can visually assess the success of the model calibration in Fig. 4a. The correlation coefficient between measured and modelled values is relatively low at 0.72 (R^2=0.51). This results from the fact that we calibrated the model over a long period of 90 years. Conditions – e.g. vegetation - have changed in the catchment. If we had chosen shorter periods, the results would have been better, but we would have had different sets of parameters. This way we have one set of parameters for the whole period, and we can compare different periods with each other – which is our goal.

Fig. 4b and 4c show the individual components of the hydrological balance from the Litava basin for the whole period – outputs from the BILAN model. The long-term average baseflow (*BF*) accounts for 40.7% of the total modelled runoff (*Rmod*), interflow (*I*) accounts for 46.8% and direct runoff (*DR*) accounts for 12.5% of the total modelled runoff (*Rmod*).

The long-term average monthly water storage in snow (*SS*) and soil (*SW*) was highest in February (35.9 mm / resp. 79.2 mm). In groundwater (*GS*), the highest retention was in the month of March – 30.9 mm. Cumulatively, the highest water retention in the basin was in the month of February (138.3 mm), the lowest in the month of August (20 mm).

Changes of the hydrological balance during the three 30-years periods

Changes in selected components of the hydrological balance of the Litava in monthly steps for three 30-year periods: I. 1930/31–1959/60; II. 1960/61–1989/91 and III. 1990/91–2019/20 are graphically presented in Figures 5 and 6. The first and second graph of Figure 5, top left, plot the measured (*Robs*) and modelled (*Rmod*) long-term average runoff depth for the three periods. The following graphs plot the monthly courses of the evapotranspiration (*ET*), base flow (*BF*), interflow (*I*), and direct runoff (*DR*) over the three periods.

A comparison of the three 30-year periods shows:

The first period 1930/31–1959/60 and the third 30-year period are overestimated by the model. In contrast, the second period is underestimated by the modelled runoff – the model gives lower runoff values on average. Table 3 shows the annual values of base flow (*BF*), hypodermic runoff (*I*) and direct runoff (*DR*) for the three periods studied in millimetres (and as a percentage of total runoff). The results of the BILAN model show that the percentage of base runoff decreases and soil – hypodermic runoff increases.

Table 1. The Litava river basin annual water balance for 3 periods 1931–1960; 1961–1990; 1991–2020. *P*– precipitation depth, *R* – runoff depth, *ET* – annual balance evaporation, *T* – average annual air temperature in basin, *k* – runoff coefficient

Year	*P* [mm]	*R* [mm]	*ET* [mm]	*T* [°C]	*k*
1931–1960	655	205	451	8.38	0.30
1961–1990	582	145	438	8.29	0.24
1991–2020	638	131	507	9.16	0.20

Table 2. **Model BILAN parameters for the Litava river basin, period: 1930/31–2019/2020**

Period	*Spa*	*Dgw*	*Alf*	*Dgm*	*Soc*	*Wic*	*Mec*	*Grd*
1930/31–2019/20	80.00	6.674	0.001	14.441	0.383	0.465	0.742	0.327

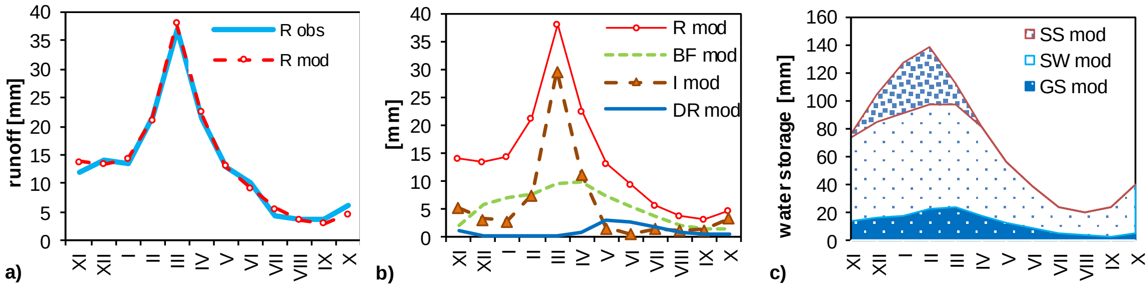


Fig. 4. a) Comparison of the long-term mean monthly runoff R (measured) and Rmod (modelled); (b) Long-term modelled mean monthly runoff Rmod, base flow BF, interflow I, and direct runoff DR; c) snow water storage SS, soil water storage SW, and groundwater storage GS; period 1930/31–2019/2020.

Table 3. **The Litava river basin long term annual water balance for 3 periods. *Robs*– observed runoff depth, *Rmod* – modelled runoff depth, *BF* – base flow, *I* – interflow; *DR* – direct runoff**

Period	*Robs* [mm]	***Rmod*** [mm]	*BF* [mm]	*BF* [%]	*I* [mm]	*I* [%]	*DR* [mm]	*DR* [%]
1930/31–2019/20	161	**171**	70.07	*40.7*	80.44	*46.8*	21.45	*12.5*
1930/31–1959/60	206	**226**	95.58	*42.2*	103.04	*45.58*	27.92	*12.3*
1960/61–1989/90	145	**129**	51.61	*39.9*	61.20	*47.3*	16.67	*12.9*
1990/91–2019/20	130	**159**	63.01	*39.4*	77.07	*48.2*	19.75	*12.4*

Discussion and conclusions

1. Statistical analysis of the daily flows of the Litava River shows:
   - The first thirty years 1931–1960 were the wateriest in the Litava basin. In the last thirty years, although the runoff coefficient was only 0.2 (runoff of 131 mm), the average daily flows of the Litava in Plášťovce reached the highest values. This is evidence of either more extreme rainfall events or poorer drainage conditions in the catchment (or a combination of both). To estimate future runoff trends from the basin, we used a simple regression relationship between runoff, precipitation, and air temperature, derived from the 90-year period 1931–2020, *Rmod = 23.38 + 0.522 P - 22.01 T*. This relationship shows that a 100 mm decrease in precipitation in the Litava basin causes a 52 mm decrease in runoff. A 1°C increase in mean annual temperature results in a 23.4 mm decrease in runoff. The results of the balance of the Litava: Plášt'ovce catchment are very similar to the results from the neighbouring Krupinica: Plášt'ovce catchment (Halmová et al., 2022).
2. The modelled results of the components of the hydrological balance for the whole period 1930/31–2019/20 by the BILAN model show:
   - Long-term average baseflow accounts for 40.7% of the total runoff, hypodermic runoff accounts for 46.8% and direct runoff accounts for 12.5% of the total runoff of the Litava in Plášťovce.
   - Cumulatively, the highest water retention in the basin was in the month of February (138.3 mm), the lowest in the month of August only (20 mm).
3. The results of the BILAN model for each 30-year period show that:
   - In absolute terms, soil water, snow and ground-water supplies in the Litava basin have declined.
   - In relative numbers, the percentage of base runoff decreases and soil - hypodermic runoff increases.

In this paper, we focused on the assessment of the long-term balance over a 90-year period with the BILAN model. Such a long period in Slovakia was first treated by a unified balance sheet model in Halmová et al. (2022). It should be noted that it is difficult to collect the necessary homogeneous input data for 90 years from the same location and with comparable instruments.

In addition, the assessed catchment must not be significantly anthropogenically influenced. There are only a few such catchments left in Slovakia. It is therefore necessary to focus on the assessment of changes in the hydrological balance in these catchments.

Acknowledgement

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