The Changes of Water Balance in the Eastern Slovakia

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Abstract. The paper deals with assessment of the changes of the hydrological balance in the Topľa River basin (Eastern Slovakia) up to the hydrological gauge Hanušovce nad Topľou during the period 1961/62–2014/15. Firstly we compared changes of hydrological balance of the Topľa River basin in two separated periods: 1961/62–1987/88 and 1988/89–2014/15. From the 54-years annual data we derived the empirical relationship for the estimation of runoff on precipitation amount and air temperature. From it follows, that if precipitation amount will decrease by 100 mm then runoff will decrease by 50 mm. But if air temperature will rise by 1°C it will bring the decrease of Topľa River runoff by 25.5 mm. Then we applied calibrated water balance model BILAN to assess the share of individual runoff components in monthly step. Base flow creates 50.38%, interflow 28.16% and direct runoff 21.48% from total Topľa River runoff. Finally we used the BILAN model for simulation of runoff volume according to the four incremental scenarios – increasing air temperature and decreasing/increasing precipitation. The simulated mean monthly runoff volumes from the Topľa River basin are the outputs of the model. If precipitation depth decreases by 100 mm, then runoff decreases by 77 mm. If air temperature will rise by 1°C it will bring the decrease of Topľa River runoff by 29 mm. These values are higher than those from empirical equation. The worst scenario (increased air temperature by 1°C and decreased precipitation depth by 100 mm) indicates that the runoff from the Topľa River basin will be reduced by 44% in comparison with actual status.

1. Introduction
An average consumption of water in Slovakia is 670 million m³ per year. It consists of 48% of underground water (water wells, alluvial deposits) used as potable water and 52% of surface water sources (water bodies, reservoirs, streams) mainly for industry and agriculture. The spatial distribution of water sources in Slovakia is unequal. Even actually, potable water supply is insufficient in the eastern part of Slovakia. Generally, in Slovakia, 85% of population has access to drinkable water (in 2014). For example, in the district of Vranov nad Topľou just 41.6% inhabitants have access to public water tap. No big changes appeared in hydrological balance in Slovakia until the year 2000 [1]. Nevertheless, after the millennium the change has started. The mean annual precipitation depth for the whole territory of Slovakia increased by 5% in the period 1991–2015 in comparison with the period 1961–1990. That phenomenon has spatial disparities, because it is not so obvious in the eastern part of Slovakia [2]. In terms of climate change, the mean annual air temperature is rising in the territory of Slovakia (figure 1). It enhances potential and even actual evapotranspiration amounts in Slovakian catchments. Despite of continuously increasing precipitation amount, the runoff from Slovakian basins is decreasing. If we consider all the mentioned facts, it is necessary to predict possible scenarios.
Prediction is useful for the mitigation of climate change impacts and preparation of adaptation strategies for the future. Very important tools in that are the rainfall–runoff models [3–8]. There is a long tradition in hydrological modelling and forecasting in Slovakia with various models [9–11].

Figure 1. The 30–years moving averages of the air temperature at the Hurbanovo station (T); The 30-years moving averages of precipitation on the territory of Slovakia (P); The 30-years moving averages of water balanced evaporation (ET); The 30-years moving averages of runoff (R); runoff coefficient from the territory of Slovakia during the periods 1961–2017 or 1931–2017, (e.g. value in 1960 is average of 1931–1960).

This paper is focused on analysis on the changes of hydrological balance components on the example of the Topľa River basin by BILAN model.

2. Description of the Topľa River basin
The spring of the Topľa River is located at the foothill of peak Minčol (930 m a.s.l.) in mountainous massif of Čergov in eastern part of the Slovakia (figure 2). The length of the Topľa stream is 115 km, area of its catchment reaches 1506.4 km². With those attributes it is the biggest tributary of the Ondava River. The catchment shape is strictly longitudinal in north–south direction with the mean altitude of 440 m a.s.l up to the Hanušovce water gauge. The density of streams in the Topľa River basin is 1.84 km.km⁻² and forest area covers 55.4%. The geology conditions built flysch rocks, especially sandstones and claystones. The springs have low yields in that basin, usually from 0.1–1.0 l.s⁻¹. The main factor influencing the yields of the springs is precipitation. Water gauges of the Slovak Hydrometeorological Institute (SHMI) are situated in Gerlachov, Bardejov, Bardejovská Dlhá Lúka, Kľušov, Marháň, Giraltovce and Hanušovce nad Topľou (figure 2).

Data on discharge we obtained from water gauge Hanušovce nad Topľou (river kilometre 47.5). Meteorological stations of SHMI are located in Bardejov (305 m a.s.l., 49°17’05”, 21°16’14”) and Čaklov (140 m a.s.l., 48°54’09”, 21°37’52”). The wettest period on record appeared between the years 1971–1980 and the driest one between 1991–2000. During the year, the highest flows are in March and April and the lowest ones in September and October (figure 3, 4). The long–term mean annual precipitation depth in the Topľa River basin is 725 mm and the mean annual air temperature is 8.4°C. During the period of hydrological years 1961/62–2014/15, the highest precipitation depth occurred in July (121 mm) and the lowest one in March (40 mm). In term of air temperature, the warmest month is July and the coldest one is January (figure 4). Anthropogenic influence on streams
in the Topľa River basin is low and there are almost no reservoirs, dams or power stations. That is why hydrological balance could equal to water balance. The annual precipitation depths in the Topľa basin have stable or slightly increasing trend in the period 1961/62–2014/15. Moreover, the mean annual runoff volume has decreasing trend. The mean annual air temperature has increasing trend therefore balanced evapotranspiration has increasing trend as well.

Figure 2. Topľa River basin orography and location of water gauges up to the Hanušovce nad Topľou water gauge. Photo – water gauge Topľa: Bardejov, (Pekarova, september 2018).
Figure 3. Monthly precipitation depths $P$, mean monthly air temperature $T$ and runoff $R$ of Topľa at Hanuľovce station.

Figure 4. The long-term mean monthly precipitation depths $P$ [mm] and air temperature $T$ [$°C$] in the Topľa River basin, the period of hydrological years 1961/62–2014/15.

3. Methods

Hydrological balance quantifies the water circulation in a closed system with one concentrated runoff in the final profile of the catchment. The atmospheric precipitation over the basin is the only input to the basin hydrological balance. The difference in soil water content at the beginning and at the end of period can be neglected for a sufficiently long period. In that case, we can identify total annual evapotranspiration with a difference of precipitation and runoff. The simple water balance equation has the following form:

$$P = R + ET + \Delta S$$  \hspace{1cm} (1)

where:

$P$ – annual precipitation depth [mm];
$R$ – annual average runoff depth [mm];
$ET$ – annual evapotranspiration depth [mm];
$\Delta S$ – average total losses that have a higher significance in shorter time intervals $\Delta t$. 

For the long-term hydrological balance this component might be neglected and replaced by $\Delta S = 0$. For the long-term monthly balance, if we determine the monthly total evapotranspiration in independent manner, we are able to determine the change in water storage in the basin according to the water balance equation. Precipitation, as the input to the hydrological cycle in basins, plays the most important role in its hydrological balance. At the second position there is air temperature, which influences evapotranspiration.

4. Description of the Water Balance Model BILAN

Over the last decades, hydrological rainfall–runoff models, in a basin scale, have become an important tool in the water management. The user must be able to choose the right model depending on the topic. The biggest problem remains the problem of getting high quality, sufficiently long series of input data [12, 13]. After proper model selection and calibration, its subsequent use has irreplaceable contribution either in the water management or in ex post evaluation of specific situations in river basins. Among the conceptual models with lumped parameters there belong, for example monthly water models BILAN, WBMOD, WatBal, or rainfall runoff models. In daily time step, there are HBV, SAC SMA Sacramento soil moisture model and HEC – HSM model. In the study we used the hydrological model BILAN [5, 6] in a monthly time step to assess the individual components of the water balance of the Topľa River basin up to station Hanušovce nad Topľou.

BILAN model belongs to a group of conceptual models with lumped parameters. The model simplifies catchment areas using 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. The model simulates hydrological variables, such as potential evapotranspiration, actual evaporation and infiltration into the zone of aeration, percolation into groundwater aquifers, water storage in snow cover, soil and aquifer. Total runoff ($R_{mod}$) of the month ($i$) consists of three components (2): 1. Base flow ($BF$); 2. Interflow – hypodermic flow ($I$); 3. Direct runoff ($DR$).

$$R_{modi} = DR_i + I_i + BF_i$$  \hspace{1cm} (2)

Direct flow is defined 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 [3]:

- **Spa** – capacity of soil moisture storage (mm)
- **Alf** – parameter for rainfall – surface runoff equation (direct runoff)
- **Dgm** – snow melting factor,
- **Dgw** – factor for calculating the quantity of liquid water 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 (baseflow)
5. Results

5.1. Comparison of changes in hydrological balance components in the Topľa River basin between periods 1961/62–1987/88 and 1988/89–2014/15

In the first step we divided observing period (1961/62–2014/15) into two periods 1961/62–1987/88 and 1988/89–2014/15. It is interesting what serious changes we detected. We calculated the mean annual values of particular components of hydrological balance. The analysis revealed that the mean annual air temperature increased by 0.9°C between periods together with increased actual evapotranspiration by 71 mm (table 1). Precipitation increased by 27 mm. On the other hand, runoff decreased by 46 mm together with runoff coefficient. The accuracy of results depends on the quality of meteorological measurements and evaluating of daily discharges [13]. Values might be a little bit different, however it gives reliable information about processes in the catchment.

| Period           | P [mm] | R [mm] | ET [mm] | T [°C] | k   |
|------------------|--------|--------|---------|--------|-----|
| 1962–1988        | 712    | 267    | 446     | 5.97   | 0.37|
| 1989–2015        | 739    | 221    | 517     | 6.96   | 0.30|

It is possible to derive regression for the estimation of relationship between runoff, precipitation amount and air temperature in the Topľa River basin. According to 55 years period available data, we derived simple empirical equation:

$$R_{comp} = 43.78 + 0.50365 P - 25.55 T,$$

(3)

where: $R_{comp}$ – mean annual runoff depth from the Topľa basin; $P$ – annual precipitation depth in the Topľa basin; $T$ – mean annual air temperature in the Topľa basin.

On figure 5, there are compared observed ($R_{obs}$) and computed ($R_{comp}$) according Eq. (3) annual runoff depths. The coefficient of determination was $R^2 = 0.47$. The consequence from equation (3) is that if precipitation amount will decrease by 100 mm then runoff will decrease by 50 mm. But if air temperature will rise by 1°C it will bring the decrease of runoff by 25.5 mm in the Topľa River basin.

![Figure 5](image_url)
5.2. Modelling of particular components of runoff in the Topľa River

In the second step we tried to get results that are more precise by BILAN water balance model. We provided BILAN calibration procedure based on monthly data from Topľa River basin up to the Hanušovce nad Topľou water gauge for the period 1961/62–2009/2010. The eight parameters of the model were identified by using an optimization algorithm (table 2). The optimization aims at attaining the best fit between the observed and modelled runoff series. The calibration of the parameters is executed in two steps, the standard error of estimate or mean absolute error.

**Table 2.** BILAN model parameters for the Topľa River basin for the period: 1961/62–2014/15.

| Period          | Spa  | Dgm | Dgw | Alf | Soc  | Mec  | Wic | Grd |
|-----------------|------|-----|-----|-----|------|------|-----|-----|
| 1961/62-2014/15| 86.15| 197.8| 6.808| 0.00135| 0.2207| 0.9892| 0.1445| 0.1749|

The coefficient of determination between annual modelled and measured data equals 0.64. The BILAN model shows better coincidence than empirical equation (3) mentioned above. On figure 6, there are compared observed \((R_{obs})\) and by model BILAN modelled \((R_{mod})\) annual runoff depths. Despite some changes made in the Topľa basin, such as deforestation, urban area spreading and other land use changes, the long-term mean monthly values of runoff modelled \(R_{mod}\) and runoff measured \(R_{obs}\) show an appropriate coincidence.

After the finishing of the optimization, it is possible to display time series of particular components of water balance in monthly step: \(P\) – Precipitation (mm.month⁻¹); \(R\) – Runoff (observed) (mm.month⁻¹); \(RM\) – Runoff (modelled) (mm.month⁻¹); \(BF\) – Base flow (modelled) (mm.month⁻¹); \(B\) – Base flow (derived) (mm.month⁻¹); \(I\) – Inter flow (mm.month⁻¹); \(DR\) – Direct runoff (mm.month⁻¹); \(PE\) – Potential evapotranspiration (mm.month⁻¹); \(E\) – Catchment evapotranspiration (mm.month⁻¹); \(SW\) – Snow water storage (mm); \(SS\) – Soil water storage (mm); \(GS\) – Groundwater storage (mm); \(RC\) – Recharge (mm.month⁻¹); \(T\) – Air Temperature (°C); \(H\) – Air Humidity (%).

As it can be seen on figure 7a, the BILAN model just underestimates runoff in May and July and overestimates a little in September and October. The model simulates particular components of runoff from the Topľa basin. Base flow creates 50.38%, interflow 28.16% and direct runoff 21.48% from total runoff (figure 7b). Figure 7c demonstrates the long-term changes in water storage during hydrological year. The highest amount of water stored in snow is usually in February (figure 7c). It is the same for water stored in soil and groundwater storage. The minimum water storage is on the end of August and at the beginning of September.

![Figure 6](image-url)  
**Figure 6.** Annual observed \((R_{obs})\) and modelled by BILAN \((R_{mod})\) runoff depths, Topľa River at Hanušovce water gauge, period 1961/62–2014/15.
5.3. Simulation of runoff according to the potential scenarios of climate change

Finally, we present four potential scenarios modelled by the BILAN model in comparison with modelled data according to the empirical equation (3). The first scenario is increased air temperature by 1°C (figure 8), second one is decreased precipitation depth by 100 mm, the third one is increased air temperature by 1°C and increased precipitation depth by 100 mm, and the fourth one is increased air temperature by 1°C and decreased precipitation depth by 100 mm.

Figure 7. a) The long-term mean monthly values of runoff modelled $R_{mod}$ and runoff observed $R_{obs}$ at the Hanušovce nad Topľou water gauge, period 1961/1962–2014/15. b) Simulated long-term mean monthly values of total runoff $R_{mod}$ and its separation to base flow $BF$, interflow $I$, and direct runoff $DR$ for the period 1961/62–2014/15. c) Output of the BILAN model (Topľa river basin, closing profile – Hanušovce station, period 1961/62–2014/15). Average monthly modelled values: $SW_{mod}$ – snow water storage, $SS_{mod}$ – soil water storage, $GS_{mod}$ – groundwater storage.

Figure 8. Scenarios of the change in mean monthly discharge in case of: 1. increase of air temperature by 1°C; 2. decrease of precipitation depth by 100 mm per year; 3. increase of precipitation by 100 mm and increase of air temperature by 1°C; 4. decrease of precipitation by 100 mm and increase of air temperature by 1°C.
Runoff decreased by 29 mm according to the first scenario. If precipitation depth decreases by 100 mm (scenario 2), then the runoff decreases by 77 mm. These values are higher than those from empirical equation (3). The third scenario results in runoff decrease by 51 mm. The worst scenario 4 indicates that the runoff from the Topľa River basin will be reduced by 44% in comparison with actual status. It is approximately more than 100 mm. It could cause a serious damage to ecosystems, human health, agriculture, etc.

6. Discussion and conclusions
The aim of this paper was to analyse the change in the runoff regime in the Topľa River basin and to simulate possible future runoff changes under new climate conditions. Hydrological rainfall – runoff models are very important tool for integrated water management in basins. Conceptual models with lumped parameters use to be applied for particular basins. We used water balance model BILAN for simulation in the Topľa River basin for the period 1961/62–2014/15. The BILAN water balance model seems to be useful for runoff modelling although it underestimates peak values of runoff. Hydrological regime of the Topľa River has changed over the last 50 years. Double mass curve methods can confirmed the existence of certain changes in runoff trends in the Topľa River basin during last fifty years. On figure 9 you can see that significant change in runoff occurred in year 1984.

Figure 9. Double mass curve of annual discharges $R$ (%) and precipitation $P$ (%), 1962–2015.

It is very important to pay attention to the results of this research. It would be efficient to re – evaluate the reference time series 1961–2000 for hydrological characteristics in Slovakia [14–17]. It is necessary to implement expected climate change to evaluation procedure in Slovakia [18]. It demands cooperation between hydrologists, climatologists from different sectors. Moreover, it is time to start using rainfall – runoff models and sophisticated statistical apparatus for discharge evaluation in practice.

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