



Changes in Runoff Distribution in River Basins on Territory of Slovak Republic

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Abstract

Water is one of the pre-eminent factors among environmental concerns critical to societal well-being. As the global population grows and the demand for water increases, so does the importance of effective and sustainable management of water resources. To provide that, we need to know well the distribution of water resources, their variability, and the assumption of their development in the foreseeable future. Continuous and irreversible changes related to global warming are also reflected in Slovakia. A significant regional increase in air temperature in individual regions is accompanied by rapid changes in other climatic elements, especially in precipitation conditions (Markovic et al. in Change of the temperature a precipitation regime in Slovakia, pp. 18–23, 2019). Not only the seasonal precipitation that changes but also their temporal and spatial distribution (an increase of precipitation in mountain areas in the north and decrease in the south) or the proportion of liquid and solid precipitation in the cold half of the year (significant increase of liquid part of precipitation in winter) (Fasko et al. in Decadal changes in snow cover characteristics in Slovakia over the period 1921–2020, 2020). This study aimed to show some of the results of detection and to analyze changes in runoff distribution in river basins on the territory of the Slovak Republic (Poorova et al. in Evaluation of Hydrological Drought, The annual runoff and the changes of runoff distribution during the year, 2019). In addition, the intention was to identify possible changes in the hydrological regime of surface waters and groundwater. Therefore, analyses have been provided on the data series of natural monthly

discharges (surface water) and spring yield (groundwater) of national monitoring points of the Slovak Hydrometeorological Institute.

Keywords

Mean monthly discharges · Spring yield · Water regime changes · Low flow characteristics

1 Introduction

The uneven spatial and temporal distribution of water resources is evident not only on a global scale but also significantly within a small territorial unit such as Slovakia. This issue forces us to know the regime of water balance in nature, at least to the extent that we can protect water resources, create strategic plans for their rational use, and protect society from the consequences of extreme hydrological situations. The geographical location of Slovakia on the Black Sea watershed and the Baltic Sea, alongside the natural conditions of the territory, determines the type and distribution of the outflow from the Slovak territory. Water from 96% of the territory flows through the Danube and its tributaries (Morava, Vah, Hron, Ipel, Slana, Bodva, Hornád, and Bodrog) to the Black Sea, and only the remaining 4% flows through the Vistula tributaries (Poprad and Dunajec) via Poland to the Baltic Sea. Overall, in the long-term average, $2.869 \text{ m}^3 \text{ s}^{-1}$ of water flows from the territory of Slovakia to the four neighboring countries (Hungary, Poland, Ukraine, and the Czech Republic). Only 13% of this surface water rises in the Slovak territory (Markovic et al., 2019; Poorova et al., 2019; Fasko et al., 2020). Therefore, only this amount can be considered available from surface waters. The usability of the remaining surface water resources is subject to agreements on trans-border waters with the neighboring states.

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Natural groundwater sources for Slovakia's territory were determined at the level of 140 to $150 \text{ m}^3 \text{ s}^{-1}$. These sources represent dynamic sources of groundwater, replenished and drained in natural conditions. Given the technical and financial possibilities, only part of this amount can be used for water management. At the national level, this amount suitable for usage is called usable groundwater resources. For the territory of Slovakia, they amount to $78.67 \text{ m}^3 \text{ s}^{-1}$. The volume of these resources fluctuates during the year according to the filling and emptying of hydrogeological structures. Therefore, knowledge of the year-on-year changes in the hydrological regime of the usable sources of groundwater is a crucial issue for water management.

The regimes of surface waters, groundwater levels, and spring yields during the year are influenced by a set of climatic factors, ultimately determining the year's nature. In addition to the climatic factors, the regime is significantly influenced by the geological and hydrogeological conditions and the territory's physical–geographical characteristics (Negm et al., 2020). The streams in Slovakia have different characters, ranging from the alpine type (Poprad) through the middle mountain and highland type (Váh, Hron, Slaná, Bodva, Hornád) to the lowland type

(tributaries of Morava, Ipeľ, Bodrog). For this reason, the water resources rising in Slovakia are characterized by high fluctuation in time and space. Based on long-term observation of the regime of Slovak rivers, the maximum runoff is typical for the spring period (the months of March to April). Only on the main streams of the Danube, the Poprad, and the Dunajec the maximum runoff occurs approximately two months later. Minimum flows arise either in the summer–autumn period or in the winter months (January–February).

2 Input Data

To identify changes in the hydrological regime of surface flows, a series of average monthly discharges and average monthly yields from the objects of the state observation network with an unaffected regime were used (Fig. 1). Eighty-nine gauging stations with the beginning of observation in the period of 1961 to 1970 and 94 spring observation objects with the start of observation from 1974 have been chosen. For comparison, the representative period of 1961–2000, or the period from the beginning of the observation until the year 2000 (springs), was used.

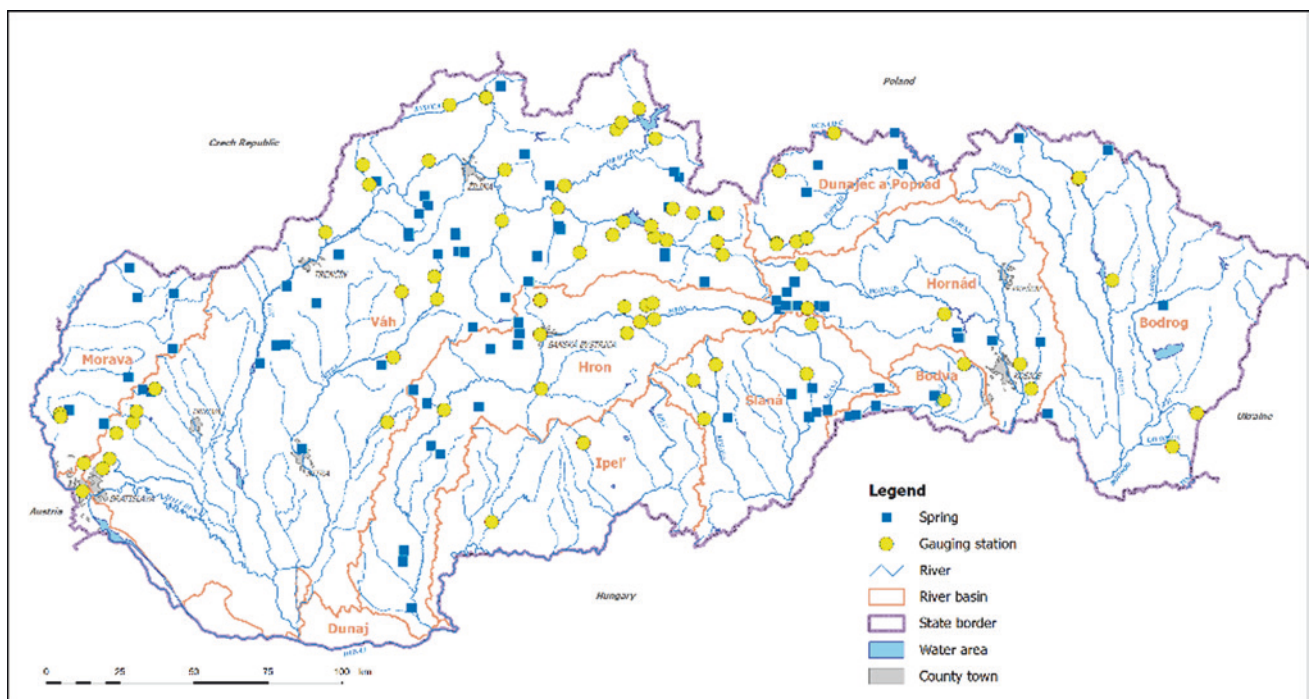


Fig. 1 Objects of the state observation network with the unaffected regime

3 Results and Discussion

3.1 Average Deviation (%) of Monthly Flows

To identify changes in the distribution of flows in the period 2001–2015, the average values of individual deviations (%) of monthly flows from 2001 to 2015 from individual gauging stations compared to the reference period 1961–2000 have been evaluated. In addition, regarding the shorter data series for springs, the average values of individual deviations (%) of monthly spring yields for 2001–2015 compared to the reference period 1974–2000 have been evaluated.

The results indicate some changes in the surface runoff distribution. Changes were noted in all the months. The increase was detected in 5 months, January to March, August, and September (5.4–19.7%), which, apart from March, are classified as low-flow months. For the other months, a decrease in the values of monthly flows was detected (from –19.23 to –4.3%). These results are very global; therefore, deviations of up to 10% cannot be considered significant. However, significant deviations (above 10%) already indicate relevant deviations. They were recorded in January (+19.7%), April (–14.1%), May (–10.23%), August (+11%), September (+10.7%), and October (–19.23%). A positive deviation in January indicates an increase in runoff due to warming, which subsequently causes earlier snowmelt and its runoff or sublimation, which results in the reduction of spring runoff (April and May). These changes indicate that we can expect problems with water scarcity already in the near future, especially in agriculture, for growing our conventional crops.

Similar changes have also been documented for the groundwater, indicating a certain degree of modifications in the filling and emptying of hydrogeological structures. Although the overall documented average annual change is not significant (–1.49%), the observed changes in average monthly yields for the respective months of the year are negligible. The most significant increases in groundwater yields have been documented for August (+8.18%) and January (+7.27%). The most significant decreases in the average monthly yields have been documented for October (–12.54%) and November (–9.83%). The results of the groundwater assessment correspond surprisingly well with the results for the surface waters. The comparison of the overall surface course and groundwater changes in the individual months of the year has also shown an obvious match.

In the individual river basins of Slovakia, the results of the evaluation of monthly values are more significant. The most significant difference was recorded in the Morava, Nitra, and Vah river basins, where the importance of the

average monthly runoff decreased in 11 or 10 months. In the Nitra river basin, the runoff value increased only for January but insignificantly (+1.9%) and for September (+13.2%). If we focus on the growing period, which in Slovakia is typically from April to September, a decrease in runoff has been recorded in almost all the spring months of this period (IV.–VII.). The outflow increased only at the end of the growing season (IX.). This fact not only significantly impacts the growth of crops but can also harm the course of harvest.

As for the same assessment of groundwater related to individual river basins, the results were essentially in compliance with those for the surface waters. The most significant decrease in the spring yield values was recorded for the Nitra basin, the Vah river basin, and the Poprad river basin. A minor reduction in the spring yield values was recorded for the Hornad, Hron, Slana, and Morava river basins. The largest number of months with the most significant decreases in spring yields was documented for the Nitra, Slana, and Poprad river basins.

The results for the Poprad river basin are completely inconsistent with the surface waters, and the cause of this discrepancy needs further analysis. However, in the other sub-basins (of the Danube river basin), a clear interaction between the changes in the hydrological regime of the surface waters and the groundwater could be stated (Markovic et al., 2019; Poorova et al., 2019; Fasko et al., 2020).

3.2 Frequency of Low-Flow Months (Below 40% of the Relevant Q_{ma} , 1961–2000)

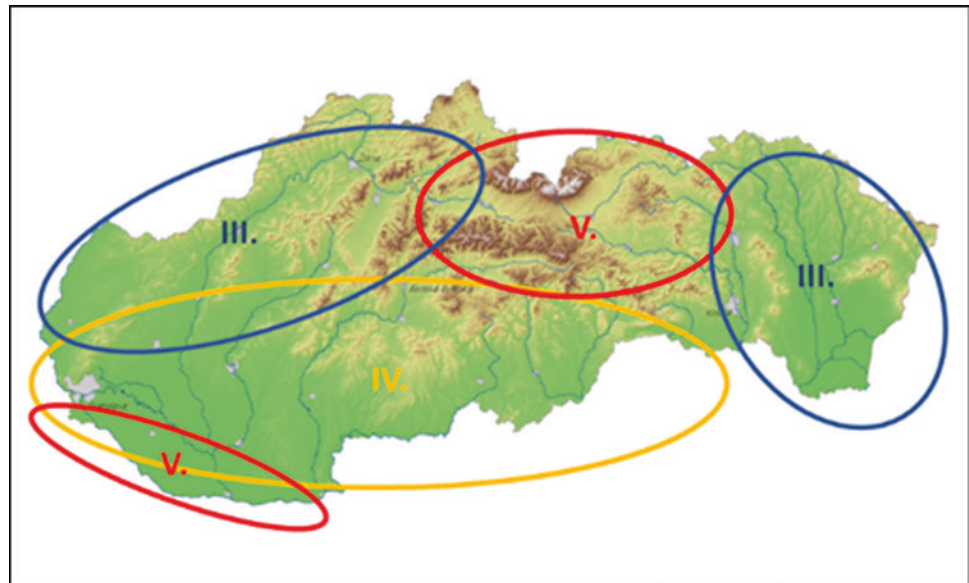
In the following evaluation, we focused on the frequency of occurrence of low-water months in the reference period 1961–2000 and 2001–2015 and their subsequent comparison. This assessment was carried out only for the surface waters.

The following scales have been used as the limits:

$$\begin{aligned} Q_m &< 20\% Q_{ma}, \\ 20\% Q_{ma} &< Q_m < 40\% Q_{ma}, \\ Q_m &< Q_{364d}, \\ Q_{364d} &< Q_m < Q_{355d}. \end{aligned}$$

To evaluate the changes, the results of the occurrence of low-flow months in both periods were divided into four groups. Probability analyses were used to determine these groups. We considered an increase when the evaluated number of occurrences of monthly flows for the period 2001–2015 was included in one step higher group. A significant increase meant that the evaluated number of events of monthly flows for the period 2001–2015 was included in

Fig. 2 Regionalization of the distribution of runoff within Slovakia



two steps higher group, or the evaluated number of occurrences was directly included in the fourth group.

The evaluation showed an increase in the occurrence of low-flow months, even in the spring period, i.e., the period of increased runoff. The review also showed the event of average monthly flows with values less than $Q_{364d}^{1961-2000}$ in the objects, where such values of average monthly flows were not recorded at all in the reference period. To illustrate the results, from April 2001–2015, almost in the whole territory, a significant increase in the number of occurrences of low-flow months was recorded, in some cases even in the upper parts of the river basins (Fig. 2).

3.3 Change in the Distribution of Monthly Runoff

The changes in the runoff distribution in the year were investigated in 42 long-term gauging stations (used for monitoring at least since 1961) with a natural regime. The distribution of runoff within Slovakia is different and regionally divided according to the maximum long-term outflow: March (north-west and east of Slovakia), April (central and southern Slovakia), and May (north and the main flow of the Danube) (Fig. 2). For individual stations, the distribution of runoff in the year was expressed in % of runoff volume for the periods 1961–2000 and 2001–2015, and the differences were examined.

In the stations with the most significant monthly outflow in March in the reference period, we recorded a change mainly because while in the reference period, many of these stations had maximum secondary runoff in April, in

2001–2015, the maximum runoff is more concentrated in March. We also recorded the increased outflow in January.

In many stations with the largest runoff in April in the reference period, the maximum runoff in April decreased from 2001 to 2015. However, in some stations, it moved from April to March, and a noticeable increase in January was also identified. For the stations with the maximum runoff in May in the reference period (mostly flows from the mountainous areas of the Tatras Mountains and the main stream of Danube), a decrease in total runoff in May and an increase in other months were also identified.

4 Conclusion

The results indicate changes in the surface runoff distribution from 2001 to 2015. Significant deviations (above 10%) compared to the reference period indicate relevant deviations and were recorded in January, April, May, August, September, and October, including in groundwater. The positive deviation in January suggests an increase in runoff due to warming, which subsequently causes earlier snowmelt and its runoff or its sublimation, which results in the reduction of the spring period runoff. At the same time, the redistributions of the maximum runoff were documented, which were more concentrated at the beginning of the spring period (March). In the individual river basins, it is possible to state a clear connection between the changes in the hydrological regime of surface waters and groundwater. If we add the trend analysis results (Blaškovicova et al., 2019), it is evident that there are changes in the hydrological regime of Slovakia's water resources. These changes

may cause water supply problems soon. The identified differences in the hydrological regime of surface water and groundwater may help to adopt the necessary measures in the currently prepared national strategy and the management of water resources in the Slovak Republic.

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