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Long-term dynamics of the underground feeding of the Horyn River Basin rivers

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**SUMMARY**

The paper considered the algorithm and the results of the amount of underground rivers feeding estimation by the hydrograph separation method. On the example of the Horyn River Basin rivers, the long-term dynamic of the amount of underground feeding of its water flow was analyzed. The key principles of determining the indicators of the rivers underground feeding, the graphic and geometric components of the application of the hydrograph separation method were outlined. Examples of the use of computer software for solving similar problems were considered. Calculations of the amount of the rivers underground feeding of the Horyn River Basin for a long-term period were performed for two representative periods of climatological standard normals - 1961-1990 and 1991-2020. Changes in temporal dynamics of the underground feeding share in terms of annual flow were analyzed. The increased trends in the amount of the rivers underground feeding of the Horyn River Basin in the current period were revealed. An increase of 3.1-10.3% in the underground feeding share of water flow in the Horyn Basin was recorded for the period 1991-2020, compared to the period 1961-1990.
Introduction

Determining the quantitative characteristics of different river feeding types is one of the most important issues in the study of its hydrological regime. The sources of river feeding determine the general nature of the river’s hydrological regime as well as the water regime periods, the river waters chemical composition regime, the water temperature regime, the ice phenomena, etc. The dynamics of water flow feeding is primarily appeared due to fluctuations in water levels and changes in water discharges. Corresponding changes in water flow are indicated on the hydrograph shape, in particular as sudden high peaks of water levels during floods, or long low water discharges during low periods when the water flow is only ground feeding.

This issue is especially relevant in the current climate change, especially in the context of integrated water resources management. Understanding the processes of water flow formation and the conditions of the rivers feeding contributes promote to the effective use of water resources and the development of water-dependent sectors of the economy.

For the Ukrainian rivers, the following types of river feeding are distinguished: rain, snow, and ground. In turn, the ground feeding is divided into soil water and underground. Determining the rivers feeding amount of snow and rain is carried out by taking into account the characteristics of precipitation and its relationship with the characteristics of water flow. The ground feeding indicators, in particular underground feeding, is defined by the analytical (calculation) method.

Method and Theory

The Horyn River is a typical plain river of the Polesian Lowland, flowing through the territory of two countries - Ukraine and the Republic of Belarus. The Horyn is a second-order tributary of the Dnieper (5.55% of the Dnieper Basin area) and the largest tributary of the Pripyat (23.1% of the Pripyat Basin area). The Horyn River flows through three physical-geographic zones: the mixed forest zone (the Volyn and Zhytomyr Polesia), the deciduous forests zone (the Volyn Opillia, the Male Polesia, and the Eastern Podilia region), and a small part in the forest-steppe zone (the Dnieper Upland).

The Horyn River Basin borders the Styr River Basin in the west, the Stvyha, the Ubort, the Uzh, and the Teteriv River Basins in the east, and the Southern Bug and the Dniester Basins in the south (Basin management ..., 2022, Vishnevsky and Kosovets, 2003).

The basin of the Horyn River is located in two geomorphological regions: the upper part (the south) is located on the Volhynian-Podolian Upland, the middle and lower parts (the north) are located on The Polesian Lowland.

The main rocks within the Volhynian-Podolian Upland are the Cretaceous sands, marls, limestones, and chalk that come to the surface in the river valleys. They are underlain by ancient crystalline rocks, mainly granites, which are overlain by a layer of Tertiary sands, clays, marls, and limestones. The Quaternary sediments are represented by glacio-fluvial sediments, loams, and loess, on which fertile alfisols and chernozem soils are developed.

The Moraine sediments (which are usually represented by loams with varying content of boulders), the glacio-fluvial sediments and loess-like loams (with a surface cover of sod-podzolic soils) are common within Polesia. A significant part of the Polesia area is occupied by peatlands.

Hydrogeologically, the Horyn River Basin is located within two groundwater basins: the Volyn-Podillya artesian basin and the region of fracture waters of the Ukrainian Shield, which differ in geological structure and lithofacies composition. Confined to the Devonian and Cretaceous deposits, groundwater in the basin within the Crystalline Massifs is associated with the fissures in crystalline rocks. Within the boundaries of Polesia, the groundwater depth is insignificant. It can vary from 0,0 m to 14,0 m in river valleys floodplain areas, more often its amount can be 2,0-5,0 m (Surface water resources of the USSR, 1971).

The proximity of ground waters to the Earth’s surface within the Horyn Basin river valleys definitely affects the nature of the water regime. Taking into account the relevance of the considered in the research issue, the principle of determining the amount of the river underground feeding was
presented. The results of the underground feeding calculations of the river’s water flow of the Horyn River Basin were presented. To determine the amount of the underground feeding share in the general river feeding, the hydrograph separation method was used as the most suitable method.

This is an exclusively hydrological approach, which was developed in the first half of the last century by Evgeniy Heinz. According to this approach the amount of the rivers ground feeding was determined based on river flow data without quantitative groundwaters (which entered to the river from aquifers) consideration (Grebin and Vasylenko, 2010).

Determining the underground feeding share during the hydrograph separation was carried out by drawing a straight horizontal line through the point that corresponds to the minimum water discharge value of the specific year. At the same time, the underground feeding was considered as a quasistationary process. That was possible only for the conditions of water flow, which was established. However, the underground feeding process is heterogeneous and unstable. In particular, this is due to the filtration properties of rocks that form the basis of river basins. Taking this into account, the underground feeding during the hydrograph separation should also be considered as a dynamic characteristic that, despite certain inertia of the process’s course, has its own annual and long-term variability.

The water flow of each specific day, month and year is determined by the flow formation conditions of the previous day, month and year, and also determines the water flow of the next day, month and year. Determining the underground feeding share on the hydrograph, it is necessary to take into account not only the minimum water discharge of each specific year, but also the previous and, if it is possible, of the next year. To solve this problem, we suggest interpolation between the minimum discharge values of neighboring years for the entire period (Figure 1). This makes it possible to determine the values of the underground feeding closer to the real values for each specific day.

![Figure 1](image-url)  
*Figure 1 The interpolation between the minimum water discharge values of the neighboring years for the hydrological gauge the Horyn River - Ozhenyn*

At the same time, the numerical expression of the underground feeding share of the general water flow was calculated by the difference in the areas of the figures - the general hydrograph and the figure of the lower part of the hydrograph. That was limited by the conditional line of the underground feeding and the abscissa axis. In order to increase the accuracy and efficiency of calculations, computer software with an open license – Graph was used in the research.
Taking into account that the climatic conditions also directly affect the rivers water feeding, it was decided to consider the dynamics of the rivers underground feeding share of the Horyn Basin for two equal periods - 1961-1990 and 1991-2020. For these periods it was determined the values of the climatological normal air temperature and the amount of precipitation in the basin. Thus, there was an opportunity to compare the characteristics of the underground feeding indicators dynamics with the variability of meteorological characteristics. The average annual air temperature in the basin was 7,1°C for the period 1961-1990 and the average annual precipitation was 647 mm, according to our research. The average air temperature was 8,3 °С and the average amount of precipitation was 628 mm for the period of the climatological normal 1991-2020. According to the assessment of meteorological indicators, an increase in the average annual air temperature by 1,2°C and a decrease in the average annual amount of precipitation by 19 mm were recorded in the basin.

Results

The Graph tools were used to calculate the areas of hydrograph figures of the Horyn Basin rivers water flow. The shares of the rivers water flow feeding types and the annual values of the rivers underground feeding were determined, based on the data of eight hydrological gauges in the basin. A total of 480 hydrographs were analyzed for the period 1961-2020. It was recorded a slow trend of growth in the amount of the underground feeding (Figure 2) over the long-term period (1961-2020) for the Horyn Basin rivers. In particular, the trends of annual growth in the underground feeding amount were noted for the period 1961-1990. However, in the period 1991-2020, the dynamic of a gradual decrease of the underground feeding indicators was observed. The exception was the long-term underground feeding indicators dynamics of the Horyn - Derazhne data. The hydrological gauge was characterized by the maintaining growth trend of the Horyn River underground feeding share of water flow for 1991-2020 compared to the 1961-1990 period. Probably, a similar trend can be connected with the Stubla and Putylivka rivers flow, which is significantly regulated by ponds and networks of reclamation channels.

![Figure 2](image-url)

**Figure 2** The chronological chart of the underground feeding share of the river general feeding for the period 1961-2020: a – the Horyn - Derazhne, b – the Horyn – Ozhenyn

The average value of the underground feeding share of the Horyn Basin rivers for the period 1961-1990 was 6,0-42,6%, and for the 1991-2020 period it was 9,9-49,9% (Table 1). The minimum values of the underground feeding can be explained by the size of the river catchments, whose base level of erosion is at insufficient depths. Therefore, for such rivers, the manifestation of other types of the river feeding is more intense.
Table 1 The main characteristics of the underground feeding amount of the Horyn River Basin in the percentage of the general river feeding

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Period</th>
<th>Volynych</th>
<th>Horyn - Kotylyan</th>
<th>Sarny</th>
<th>Shish - Derazhne</th>
<th>Horyn - Odeshyn</th>
<th>Shish - Derazhne (Runner)</th>
<th>Brezhny</th>
<th>Trya</th>
<th>Sary</th>
<th>Shev</th>
<th>Vida</th>
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<tr>
<td>Max</td>
<td>1961-1990</td>
<td>60.7</td>
<td>42.1</td>
<td>66.1</td>
<td>72.1</td>
<td>30.3</td>
<td>27.1</td>
<td>21.1</td>
<td>34.8</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Year</td>
<td>1990</td>
<td>1900</td>
<td>1900</td>
<td>1900</td>
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<td>1972</td>
<td>1989</td>
<td>1990</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>1991-2020</td>
<td>59.8</td>
<td>57.3</td>
<td>61.9</td>
<td>64.4</td>
<td>35.6</td>
<td>26.5</td>
<td>22.1</td>
<td>29.9</td>
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<tr>
<td>Min</td>
<td>1961-1990</td>
<td>20.1</td>
<td>7.9</td>
<td>27.9</td>
<td>20.3</td>
<td>5.7</td>
<td>1.4</td>
<td>0.3</td>
<td>0.7</td>
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</tr>
<tr>
<td>Min</td>
<td>1991-2020</td>
<td>21.8</td>
<td>8.7</td>
<td>35.6</td>
<td>35.5</td>
<td>13.2</td>
<td>5.4</td>
<td>3.3</td>
<td>4.9</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Averaged</td>
<td>1961-1990</td>
<td>35.1</td>
<td>21.8</td>
<td>42.6</td>
<td>39.5</td>
<td>16</td>
<td>11.2</td>
<td>6</td>
<td>14.2</td>
<td></td>
<td></td>
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<tr>
<td>Averaged</td>
<td>1991-2020</td>
<td>38.2</td>
<td>25.2</td>
<td>49.9</td>
<td>49.9</td>
<td>23.7</td>
<td>15.6</td>
<td>9.9</td>
<td>19.9</td>
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<tr>
<td>Difference</td>
<td></td>
<td>3.1</td>
<td>3.4</td>
<td>7.3</td>
<td>10.3</td>
<td>7.7</td>
<td>4.4</td>
<td>3.8</td>
<td>5.7</td>
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</table>

For the studied basin, the underground feeding share increased in the range from 3,1% to 10,3%. The volume of runoff and the average annual amount of precipitation decreased by 14,6% and 2,9% respectively in the current period. It can be assumed that the increase in the underground feeding share occurs due to the redistribution of moisture between the different feeding types.

Conclusions

The amount of the rivers underground feeding estimation algorithm for the hydrograph separation method was considered. According to the data of eight hydrological gauges of the Horyn River Basin rivers, a comparison of the river underground feeding share dynamics for the period of the climatological normal 1961-1990 and 1991-2020 was made.

According to the analysis of chronological charts of the underground feeding share changes, it was revealed a slow growth trend of these characteristics in the period 1961-1990. However, it was established that the average values for 1961-1990 and for 1991-2020 had different trends. In the first case there was an increasing trend of the underground feeding share and in the second - decreasing for almost all hydrological gauges. An exception was the Horyn – Derazhne, where an increasing trend was observed in both cases.

The underground feeding share of the Horyn River Basin increased in the range from 3,1% to 10,3%, the volume of runoff decreased by 14,6% on average. The average annual amount of precipitation decreased by 2,9% in the current period. The increase in the underground feeding share occurs due to the redistribution of moisture between the different feeding types.

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