Introduction

The Borzhava River is one of the largest rivers in the Tisa River basin within the Transcarpathian Region. It plays an important role in providing water supply for the local population, agriculture, industry, etc. Long-term agricultural development of the territory and growing urbanization of the basin are causing environmental problems to escalate due to interference with the hydrological regime of rivers, artificial changes in the morphology of watercourse channels, environmental pollution by hazardous substances and deterioration of river water quality (Melnyk, 2009, 2011). Therefore, it is important to study the structure and metrication of the hydrographic network of the Borzhava river basin, which contributes to the determination of the spatial features of its development and the organisation of the river system. The study of the hydrographic network of the Borzhava River also allows us to identify areas vulnerable to channel deformations, which are mainly prone to erosion and flooding, which is important for planning environmental protection and risk management measures.

Method

The study of the structure and spatial organization of the hydrographic network of the Borzhava River basin is based on the use of a set of methods of geoinformation analysis and geospatial data processing. (Karabiniuk et al., 2020). The first step in our research was to identify the current boundaries of the Borzhava River basin in the specialized software environment ArcGIS 10.4.1. based on publicly available and proprietary digital geospatial data for the territory of the Transcarpathian region. After that, a spatial reference was set for raster images of a number of topographic maps at a scale of 1:50 000 (sheets M-34-130-H; M-34-131-A, B, V, H; M-34-142-A, B, V, H; M-34-143-A, B, V) and all elements of the hydrographic network of the study river, namely permanent and temporary watercourses, ditches, canals, etc. were vectorized. Our study also used geospatial data from the modern digital topographic database of the SOE “Zakarpatgeodeskcenter”, which updated information on the location of watercourses, morphometry and morphology of their channels, etc.

Using semi-automated tools for processing and analyzing linear geospatial data in the ArcGIS software environment, the elements of the hydrographic network of the Borzhava river basin were structured, resulting in the identification of 11 types of network objects. Based on the geographic information analysis of the river hydrographic network structure using the R. Horton (Horton, 1937), a total of 7 orders of permanent watercourses were identified, which indicates the progressive development of the river system. Important elements of the Borzhava River hydrographic network are also temporary watercourses, ditches, canals, as well as canalized sections of watercourses and ditches, the latter of which are directly related to the economic development of the basin. As a result, using the tools of the geoinformation environment, a geospatial data base was formed and the quantitative parameters of the elements of the Borzhava River hydrographic network were determined, on the basis of which the features of its internal organization were analyzed and the corresponding cartographic material was compiled. To present the orographic features of the river basin, as well as to detail the spatial and ordinal organization of the hydrographic network, we developed hypsometric maps separately for the upper, middle, and lower parts of the Borzhava River basin using digital geospatial data using Spatial Analyst tools. Another important task of our study of the hydrographic network of the Borzhava River basin was to collect published scientific works of a literary and cartographic nature, stock and other materials to establish the peculiarities of the formation, current stage of development and functioning of the river system. The analysis of scientific literature shows the intensive development of floods, mudflows, floodings and other dangerous water and gravity processes in the Borzhava River basin, which significantly affect the formation and development of the modern hydrographic network of the river system (Ivanik, 2007; Horbachova & Bibik, 2012; Khomyn, 2014; Velychko & Dupliak, 2019).

Examples

The practice of using geoinformation technologies to map natural processes in river basins and analyze environmental objects demonstrates the importance of developing mapping materials (Fekete,

Vörösmarty & Lammers, 2001; Karabiniuk et al., 2020; Burianyk et al., 2021). As the main result of the scientific research and geoinformation analysis, we have developed a map of the hydrographic network of the Borzhava river basin, which expresses its ordinal structure (Fig. 1).

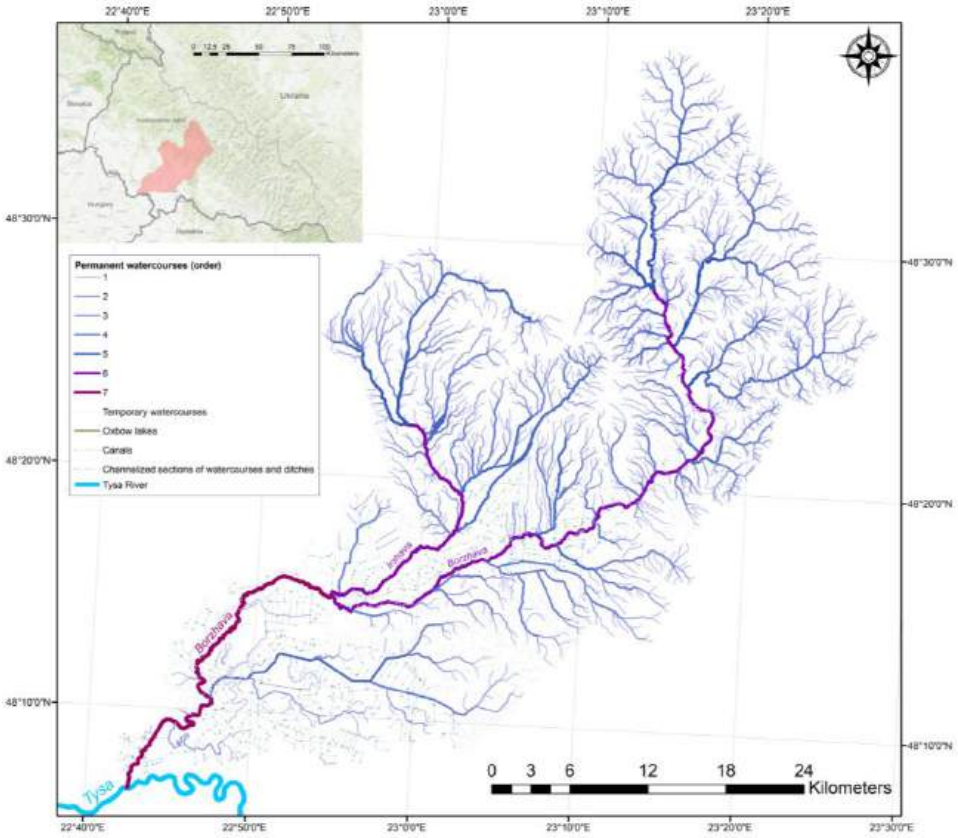

Figure 1 *Ordinal structure of the hydrographic network of the Borzhava River basin system*

Results

The Borzhava River is entirely located within the Transcarpathian Region and is confined to the southwestern macro-slope of the Ukrainian Carpathians. It crosses the main structural units of the mountain system and belongs to the Tysa River basin. The middle reaches and the mouth part of the river were formed in the conditions of flat relief and are stretched in the southwestern direction to the confluence with the Tysa River. The maximum length of the river basin from its extreme points is 70,8 km, and its width is 34,7 km. The geographic information analysis of the Borzhava River basin hydrographic network revealed that it is formed by permanent and temporary watercourses, oxbows, canals and canalized sections of watercourses and ditches with a total length of 3 374 km. The basis of the Borzhava hydrographic network is formed by permanent watercourses, which form a complex system of watercourses of 1 to 7 orders. Their total length is 2123,3 km, which is more than 60 % of the hydrographic network. The river system is dominated by watercourses of the 1st order in terms of length and number. They form the basis of the river network and account for more than 48 % of the total number of permanent watercourses in the river system under study. The total number of 1st order watercourses is 1 611 units with a total length of 1 035,6 km.

The gradual merger of watercourses contributes to the development and consolidation of elements of the Borzhava River hydrographic network, which is generally accompanied by a decrease in the number of watercourses as their order increases. In the structure of the hydrographic network, the number of watercourses of the 2nd and 3rd order decreases sharply to 451 and 117 watercourses, respectively, with a total length of 300-475 km. The largest number of them is characteristic of the upper and widest middle part of the river system. They are the main centers of formation of powerful

mudflows, floods, and deep erosion and are characterized by deep embeddedness in steep catchment slopes, mostly covered with forests (Fig. 2). These orographic elements are also mainly associated with watercourses of the 4th order, which differ significantly from the previous types in terms of water content and mainly separate large mesoforms within the catchment. As a result of the geographic information analysis, 35 4th order watercourses with a total length of 155,5 km were identified.

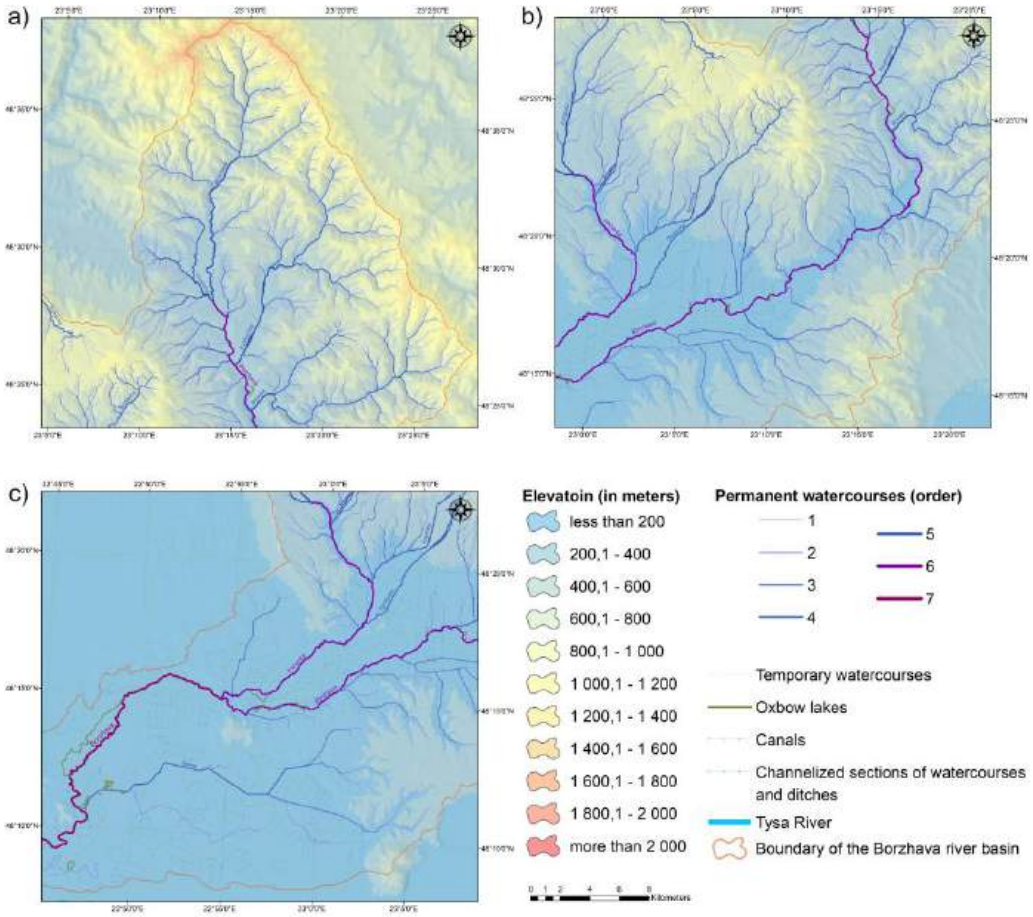

Figure 2 *Fragments of the hypsometric map of the Borzhava River catchment: a – upper reaches of the basin with mountainous terrain; b – middle foothill part of the basin; c – mouth of the basin*

The major elements of the hydrographic network of the Borzhava River are 6 watercourses of the 5th order, which unite the river network of its largest tributaries – the Irshavka, Kushnytsia, Bronka, Kryvulia, etc. These watercourses are characterized by a significant expansion of the river valley and intensive erosion and accumulation processes in full-flowing channels with an average width of 3-4 m to 8-9 m. Watercourses of the 5th order are a link in the river system between small watercourses with fast flow on steep slopes and powerful, full-flowing watercourses of the largest 6th and 7th orders with a leveled channel and a much slower flow. Therefore, powerful floods are formed and intensively flow down the river system. The confluence of the main stream and the Prokholodnyi tributary within the village of Keretsky contributes to the formation of a 6th order watercourse with a total length of 54,9 km, which is the longest element of the Borzhava River hydrographic network. It cuts through the mountain range of the Vyhorlat-Hutynskyi Range of hard volcanic rocks and directs the flat part of the river basin, which is characterized by an increase in alluvial and accumulative processes in the channel (Mykyta et al., 2022; Nazarevych, Bairak & Nazarevych, 2023). The second watercourse of the 6th order is the mouth of the Irshavka River, which is the largest tributary of the Borzhava River. The confluence of these two watercourses between the villages of Velyki Komiaty and Verkhni Remety forms the most abundant watercourse of the Borzhava River of the 7th order. It is characterized by intense lateral erosion and associated meandering of the riverbed. As a result, oxbows are widespread here, and the wide river valley of the main channel is deeply embedded in the

sediments of the Zakarpattia Lowland. The total length of this watercourse is 33,4 km and culminates in its confluence with the Tisa River near the village of Vary.

Conclusions

The conducted geoinformation analysis shows a significant development of the hydrographic network of the Borzhava River basin, which is mainly represented by 7 orders of permanent and temporary watercourses. As the order of watercourses increases, the capacity of the river system increases and the hydrological features and morphological characteristics of watercourses, the intensity and nature of water and gravity processes, etc. change significantly. Also, as a result of long-term economic development of the territory, a significant part of the hydrographic network has been transformed. As a result, it now comprises 380,6 km of canals and 151,4 km of canalized sections of watercourses and ditches, which perform important irrigation, drainage, water supply, and other functions. In the context of increasing anthropogenic pressure, it is important to study the ecological state of the hydrographic network elements and the Borzhava River basin.

References

Burianyk, O., Karabiniuk, M., Gostiuk, Z. & Terletska, Ya. (2021). Mapping of the forest pathological processes in landscape complexes (on the example of the Rybnyk Maidanskyi river basin in Skole Beskids). *International Conference of Young Professionals, GeoTerrace 2021*, 2021, 1–5 (In English).

Fekete, B. M., Vörösmarty, C. & Lammers, R. (2001). Scaling gridded river networks for macroscale hydrology: Development, analysis, and control of error. *Water Resources Research*, 37 (7), 1955–1967 (In English).

Horbachova, L. & Bibik, V. (2012). Temporal homogeneity of water flow characteristics in the Borzhava river basin. *Scientific works of the Ukrainian Research Hydrometeorological Institute*, 262, 177–188 (In Ukrainian).

Horton, R. (1937). Determination of infiltration-capacity for large drainage basins. *Transactions, American Geophysical Union*, 18, 371–385 (In English).

Ivanik, O. (2007). Structural and tectonic control of the development of water-gravity processes within Svalyava and Volovets districts of Transcarpathian region. *Geological Journal*, 3, 81–86. (In Ukrainian).

Karabiniuk, M., Markanych, Y., Burianyk, O., Hnatiak, I. & Gostiuk, Z. (2020). Methodical aspects of geoinformation analysis of landscape differentiation of modern negative geological and geomorphological processes in natural territorial complexes of the highlands of Chornohora (Ukrainian Carpathians). *International Conference of Young Professionals, GeoTerrace 2020*, 2020, 1–5 (In English).

Khomyn, Ya. (2014). Values and dynamics of the total sediment run-off in the different order stream systems of the Borzhava River basin. *Problems of geomorphology and paleogeography of the Ukrainian Carpathians and adjacent territories*, 165–172 (In Ukrainian).

Melnyk, T. (2009). Improving the calculation of flood zones on the Borzhava River floodplain along the Zarichchia-Vilkhivka highway. *Water management in Ukraine*, 6, 82–98 (In Ukrainian).

Melnyk, T. (2011). Hydroecological situation of the Borzhava river basin (problems and ways of optimization). *Physical geography and geomorphology*, 3(64), 56–63 (In Ukrainian).

Mykyta, M., Salyuk M., Slavik, R., Karabiniuk M. & Leta, V. (2022). Characteristics of volcanic mountains morphostructure of Transcarpathia, Ukraine. *Forum geografic*, 21(2), 97–108 (In English).

Nazarevych, A., Bairak, H. & Nazarevych, L. (2023). The relief features of the middle reaches of the Borzhava River and their connection with geodynamics and seismotectonics. *Problems of geomorphology and paleogeography of the Ukrainian Carpathians and adjacent territories*, 1(15), 78–103 (In Ukrainian).

Velychko, S. & Dupliak, O. (2019). Determination of the Irshava River flow parameters in the absence of observations in the design reach. *Problems of water supply, sewage and hydraulics*, 31, 1–10 (In Ukrainian).