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PARTNERSHIP
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ENVIRONMENTAL ISSUES OF ZAKARPATTIA

Manual

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The manual contains scientific materials devoted to the coverage of contemporary environmental issues of Zakarpattia. Considerable attention is paid to the peculiarities of its natural conditions. Emphasis is placed on the preservation of biodiversity in the face of climate change. While devising this textbook, the authors resorted to the analysis of literary sources as well as the findings of their own research. It will benefit school teachers, students and postgraduates of higher educational institutions majoring in natural sciences, employees of the nature reserve fund, and representatives of the authorities.

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CONTENTS

days. Moisture levels vary across the district, with the northern areas experiencing sufficient moisture, moderate levels in the south, and intermittent droughts in some years. Precipitation during the period with an average daily temperature above 10°C ranges from 380-460 mm, with a yearly total of 530-700 mm.

The foothills area encompasses the entire foothills region, the southern section of the Vyhorlat-Hutyn ridge, as well as the Irshava and Khust valleys. Due to the diverse terrain within this area, climatic conditions exhibit a notable degree of diversity. In general, it represents a warm region, with temperatures ranging from 2700-3000°C. However, the thermal regime of the Irshava and Khust basins exhibits more pronounced continental characteristics compared to the foothills. The duration of the period with an average daily air temperature above 10°C in the foothills extends for 180-185 days, and temperatures exceeding 15°C persist for 115-130 days. The frost-free period spans an average of 170-175 days. Furthermore, the foothill area is classified within the zone of excessive moisture.

The mountain area encompasses the largest portion of the region's territory, spanning almost the entire Vyhorlat-Hutyn ridge, excluding its southwestern part, as well as all other mountainous areas situated to the northeast of it. Climatic conditions in the mountainous region undergo significant changes with increasing altitude above sea level. In January, there is a decrease in air temperature by 0.4°C for every 100 meters of vertical elevation, and in July, a decrease of 0.7°C occurs. Valleys represent the warmest locations within the mountainous region. In specific valleys, particularly those situated on the bottom, southern, and western slopes, the sum of active temperatures (SAT) ranges from 2400-2470°C. The annual atmospheric precipitation in the mountainous area totals approximately 1000 mm on open slopes and up to 800 mm in valleys. The climate of the middle zone is characterized as moderately cold, with temperatures spanning between 1000-1600°C, and a period of active vegetation lasting 90-100 days. In the upper zone, the climate is cold, with a period featuring temperatures exceeding 10°C lasting only 60-88 days, with temperatures in this period ranging from 600-1000°C. The average annual rainfall in the upper zone reaches 1500 mm.

1.2. NATURAL CONDITIONS AND ANTHROPOGENIC FACTORS AFFECTING THE HYDROECOLOGICAL STATE OF THE UPPER REACHES OF TISZA RIVER BASIN *(V. Leta, M. Karabiniuk)*

The Tisza River is the main watercourse of Zakarpattia Region and the largest tributary of the Danube (Fig. 1.2.1). The total length of the river is 966 km, of which 2658 km is within Ukraine (Zakarpattia Region). The total area of the Tisza basin is 157.2 thousand km^2, including 13.8 thousand km^2 within Ukraine. The basin is formed on the territory of five countries: Serbia, Slovakia, Hungary, Romania and Ukraine. Within Ukraine, the Tisza basin occupies the administrative boundaries of Zakarpattia Region, which makes the basin unique and its borders with neighboring countries transboundary (NPMTRB, 2012).

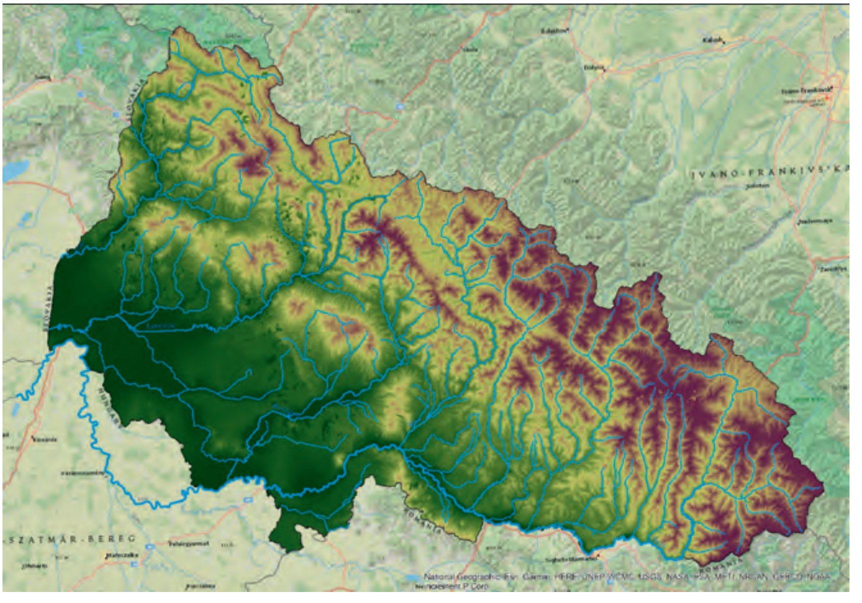

Figure 1.2.1. River Network of Zakarpattia Region (compiled by the author)

The peculiarity of the Ukrainian part of the Tisza basin is that it is located in the headwaters, where both the flow and the chemical composition of the water are formed. These factors are important to consider when conducting various studies, both within Ukraine and downstream of the Tisza. In particular, it is necessary to account for the flood regime of the waters of the Tisza River and its tributaries within Zakarpattia Region. Additionally, the presence of volcanogenic deposits in the explored polymetallic deposits and ore occurrences in this region, owing to the high solubility of sulfate compounds of heavy metals (such as chromium, cadmium, copper, etc.), is one of the reasons for the increased concentrations of these elements in the surface waters of the Tisza river basin system within Ukraine.

Surface runoff within Zakarpattia Region is formed by the following right tributaries of the Tisza River: Teresva, Tereblia, Rika, Borzhava, which flow into the Tisza river, as well as the Uzh and Latorytsia rivers. The latter flow into the Laborec and Bodrog rivers in the Slovak Republic, and then into the Tisza River in Hungary.

Transit surface runoff comes from Romania, the main rivers Viseu and Iza (flowing into the Tisza river above the Tyachiv city) and from Slovakia, the Ulichka and Ubl'a rivers (flowing into the Uzh river above the Zarichevo village).

In the Tisza basin of Zakarpattia Region, there are approximately 9,426 rivers and streams with a total length exceeding 16.1 thousand km, and the river network density averages 1.7 km/km^2. Most watercourses in the region have an average length of about 2 km and a catchment area of 1.2 km^2. Only 152 rivers are longer than 10 km, of which 4 exceed 100 km in length: Tisza, Latorytsia, Uzh, and Borzhava (NPMTRB, 2012).

The Ukrainian part of the Tisza basin includes both the Upper Tisza (from the source of the Black Tisza to the village of Badalovo, 7 km downstream from the mouth of the Borzhava) and the Middle Tisza (the basins of the Latorytsia, Uzh, and Tisza rivers from the village of Solovka to the village of Solomonovo). From its source to its outlet on the territory of Hungary, the Tisza River either flows entirely through Ukraine or forms the state border with Romania.

The total length of the Tisza River in Ukraine is 265 km. From the source of the Black Tisza to the village of Dilove in the Rakhiv district, the Tisza flows through the territory of Ukraine and then forms the state border between Ukraine and Romania for 61 km. Below the town of Tyachiv the river flows through Ukraine again to the village of Vylok. Downstream, the river forms the state border between Ukraine and Hungary for 25 km, and below the village of Badalovo, the Tisza flows through Hungarian territory for 77 km. From the village of Solovka to the villages of Solomonovo and Zahony, the Tisza serves as a border. The length of this section is 19 km. Downstream, the river forms the state border between two European countries – Slovakia (right bank) and Ukraine, with a total length of about 5 km. The river then flows through the territory of Hungary and Serbia.

The results of the water quality analysis and assessment presented below pertain to the surface waters of the Upper Tisza River basin, encompassing the transboundary section of the Tisza River, commencing at the confluence with the Romanian tributary of the Tisza, the Viseu River, and extending from the village of Dilove in Rakhiv district. The transboundary section of the Tisza River traverses the Ukrainian-Romanian border in Rakhiv and Tyachiv districts, spanning a total length of 64 km (NPMTRB, 2012).

Within Ukraine, the tributaries of Tisza in the border area consist of the following rivers: Kosivska and Shopurka in the Rakhiv district, and Apshytsia, Teresva, and Tyachivskyi in the Tyachiv district. The Romanian tributaries of the Tisza, on the other hand, include the rivers Viseu, Iza, and Sepince. The identification of the surface water massif was undertaken by Ukrainian and Romanian hydrological experts as part of international cooperation between the water management basin authorities of Ukraine and Romania. This collaborative effort resulted in the determination of the average length of the cross-border section of the Tisza River, which currently stands at 64 km.

The Tisza River originates at an altitude of approximately 460 m due to the confluence of two mountain rivers, namely the Black Tisza and the White Tisza (Table 1.2.1). These headwaters of the Tisza are situated in close proximity to Rakhiv, the highest mountain town in Ukraine. The Tisza basin encompasses a total area of 157,186 km², constituting 19.2% of the Danube basin, rendering it the largest tributary in this regard. The primary focus of our study pertains to the upper reaches of Tisza region, which encompasses the cross-border area within the Rakhiv district, extending from the upper reaches of the Black Tisza river basin to Velykyi Bychkiv.

The study area encompasses the entirety of Rakhiv district and a substantial portion of the Tyachiv district within Zakarpattia Region, Ukraine. This region's intricate morphometry is characterised by the presence of the Chornohora and Svydovets mountain ranges, as well as a segment of the Marmarosh massif, encompassing the Yasinia and Solotvyno depressions. The topographical complexity of this mountainous terrain also exerts an influence on the density of the river network, prominently featuring the Black Tisza and White Tisza Rivers. These two rivers converge near the town of Rakhiv, situated at an elevation of 460 m, giving rise to the Tisza River. Additionally, a multitude of tributaries, including the significant Kosivska, Shopurka, Apshytsia, Teresva, and others, contribute to the Tisza's flow. The degree of relief fragmentation diminishes downstream from the origin point of the Black Tisza. The study area covers approximately 3420 km², and the Tisza River section stretching from Rakhiv to Tyachiv spans 80 km, with around 60 km forming the state border between Ukraine and Romania.

Table 1.2.1.

The main morphometric parameters of the rivers studied in the upper reaches of the Tisza within Ukraine (compiled from data provided by the Zakarpattia Regional Hydrometeorological Centre).

River	Length, km	Area, km²	Slope, m/km
Black Tisza	49	567	19
White Tisza	28	489	10
Tisza	80/265	3420/12777*	3.6/1.4*

Notes. * – within the study area / within the entire Zakarpattia Region of Ukraine

The territory of the studied upper reaches of the Tisza river basin area is characterised by a significant distribution of aquifers within the structure of Paleogene sediments in the Ukrainian structural-folding system. Sandstone aquifers are also prevalent within shale strata, providing water for domestic and drinking water purposes. In relatively developed alluvial complexes, hydrocarbonate waters are concentrated in river valleys, which contribute to river flow during low water periods and serve various economic needs.The hydrogeological conditions of the area are marked by the presence of a single quaternary aquifer, composed of hard sandy loam with up to 40 % gravel and pebbles. Groundwater is free water (gravitational water) and is replenished by the infiltration of precipitation. Groundwater levels in this aquifer vary from 0.5 m to 4.0 m (NPMTRB, 2012).

In the context of climate change, the examination of the current state and alterations in the quality of surface waters holds considerable significance. This is due to the profound modifications in the characteristics of the natural environment, which, in turn, engender changes in the broader framework of environmental protection, the resilience of natural resources to anthropogenic exploitation, conservation principles, and more. Within the Tisza river basin, there is a notable prevalence of intensive developments related to a complex of contemporary physiographic processes. The manifestations and extents of these developments may undergo alterations in the face of climate change. Similarly, the upper Tisza river basin region is marked by the vigorous evolution of a complex of contemporary physiographic processes, the appearances and scopes of which could also shift in response to climate change. Concerning the environmental scenario and surface water contamination, processes such as landslides, mudflows, floods, and others exert the most significant impact on water quality and its primary hydrochemical parameters. These processes contribute to substantial quantities of solid runoff (soil) enriched with elements such as iron (Fe), manganese (Mn), and heavy metals including copper (Cu), zinc (Zn), chromium (Cr), and lead (Pb). Furthermore, these processes influence turbidity, water transparency, nutrient levels, and the oxygen regime of the surface water in the studied rivers.

The hydrological regime of the rivers within the upper reaches of the Tisza basin

The Tisza River is recognized as the source of the Black Tisza, which boasts a greater length and catchment area in comparison to the White Tisza (see Table 1.2.2). The river basin is entirely situated within the southwestern macro-slope of the Ukrainian Carpathians. Upon the confluence of the Black Tisza and White Tisza rivers above the city of Rakhiv, the water content of the Tisza increases, and its narrow river valley takes a southward orientation towards the Romanian border. Subsequently, below the village of Dilove, located at the border with Romania, the river alters its course from the left bank of the Viseu River and flows through a narrow gorge in a northwesterly direction, eventually reaching the village of Velykyi Bychkiv.

Table 1.2.2.

Hydrographic characteristics of the main rivers in the Tisza River basin (compiled from the data provided by the Tisza River Basin Water Resources Management).

River Name	Falls into	Distance from the mouth of the main river, km	River Length, km		Catchment Area, km^2	
			Entire	within Ukraine	Entire	within Ukraine
Tisza (with Black Tisza)	Danube	1218	966	265	157186	12777
Black Tisza	Tisza	913.5	50	50	567	567
Bila Tisza	Tisza	913,5	26	26	489	489
Viseu	Tisza	886,1	79,1	0	1580	0
Kosivska	Tisza	876,6	43,1	43,1	157	157
Shopurkra	Tisza	871,9	41,4	41,4	286	286
Iza	Tisza	856,5	80,0	0	1300	0
Sepyntsya	Tisza	838,5	18,0	0	149	0
Teresva	Tisza	835,4	56	56	1220	1220
Tereblya	Tisza	818,1	91	91	750	750
Rika	Tisza	793,0	92	92	1240	1240
Borzhava	Tisza	729,3	106	106	1360	1360
Latorytsya	Bodroh	90	191	144	7860	2900
Uzh	Laborets	-	133	106	2750	2010

The Black Tisza stands as one of the primary watercourses in the Rakhiv district, and it serves as the source of the Tisza river near the city of Rakhiv. Given the mountainous terrain that encompasses the entire Black Tisza basin, commencing with its origin in the Svydovets mountain range, the river valley exhibits a distinctly mountainous regime and structure. The elevation drop from the source to the mouth amounts to 800 m, resulting in the presence of rapids and waterfalls throughout the entire course of the Black Tisza. The river also maintains a rapid flow, particularly registering speeds of up to 1.5 m per second during low-water periods and up to 4.5 m per second during floods. Characterized by a V-shaped valley, the river valley width varies from 50 m in the upper reaches to 300 m downstream, accompanied by steep and at times precipitous banks, which can reach heights of up to 10 m (Khilchevskyi, 2016).

The subsequent major tributary of the Tisza within the Rakhiv district is the White Tisza. This river originates on the slopes of Chornohora, where the Stohivets and Balzatul Rivers converge. Similar to the Black Tisza, the White Tisza exemplifies a characteristic mountain river, measuring a mere 28 km in length and featuring a narrow, gently winding V-shaped valley. The river's channel seldom widens beyond 20 m. Owing to its swift flow, the elevated banks are frequently subjected to erosion, necessitating additional measures for reinforcement (Khilchevskyi, 2017).

The Shopurka River serves as a right tributary of the Tisza River and is formed through the confluence of the Mala Shopurka and the Serednya Rika. The Shopurka stands out from other Tisza tributaries due to the unique characteristics of its lower valley, which can extend to a width of up to 300 m, featuring a meandering and branching channel that, in certain sections, reaches up to 40 m in width. The slopes exhibit steep gradients of 20-40 degrees in the upper reaches, gradually lessening downstream. Along the course of the Shopurka, one can frequently encounter rapids and islands. Notably, the Shopurka basin encompasses the villages of Kobyletska Poliana and Velykyi Bychkiv, which, in comparison to other settlements in the Rakhiv raion, have shown more advanced economic activities (Leta, 2016).

The Kosivska (Kisva) river also serves as a right tributary of the Tisza River. It runs parallel to the Shopurka River and originates on the slopes of Svydovets, which, in turn, defines the mountainous characteristics of the river's hydrological regime and the morphometric parameters of its basin. The river valley exhibits a slightly winding course, resembling a gorge in some sections with a width of up to 4 m. The floodplain of the Kosivska River is present only in specific areas along its course (Leta, 2019).

The Lazeshchyna river originates in the Petros and Hoverla intermountain area and represents a left tributary of the Black Tisza. Similar to previous instances, the hydrological regime and the V-shaped valley structure classify this river as a mountain river, characterized by extremely steep slopes and a rapid flow. The Lazeshchyna's channel features slight meandering, branching, and rapids, with a floodplain primarily observed in the lower reaches of the river (Leta et al., 2019).

The Tisza river serves as the primary body of surface water within the Rakhiv district and is partitioned into two segments, distinguished by variations in the river valley's characteristics and the river's water regime parameters. The first segment commences at the confluence of the Black Tisza and the White Tisza, terminating at the village of Velykyi Bychkiv. In this segment, the Tisza River exhibits hydrological and morphometric characteristics typical of mountainous regions. Here, the Tisza courses through a narrow and deep valley, flowing southward until it meets the Romanian tributary, Viseu, near the village of Dilove. Beyond this point, the river undergoes a transformation, unveiling a broad floodplain, extending up to 500 m in width, and changing its course to the northwest. The Tisza riverbed is slightly sinuous, sometimes empties, and occasionally forms islands, while the banks rise to heights of up to 6 m. The river itself reaches widths of up to 40 m. Notably, the river's depth increases significantly downstream, ranging from 0.5 m on the rifts in the upper reaches to 5 m within the backwaters. Additionally, it's of significance that the border demarcating Romania and Ukraine originates in the village of Dilove, near the confluence of the Viseu, following the course of the Tisza River. This aspect enhances the scientific appeal of any studies related to the Tisza including those focusing on hydroecology (Leta, 2017; NPMTRB, 2012; Technical Report, 2009).

Table 1.2.3.

Information on the composition of observations at hydrological stations within Rakhiv district (compiled by the Zakarpattia Regional Hydrometeorological Centre)

№	The river is a hydropost	Periods for which data on the main elements of the water body regime are provided			Catchment area, km^2	Mark "0" of the post schedule, m BS
		characteristic water levels	characteristic water discharge rates	characteristic sediment flow rates		
1	Black Tisza – Yasinia	1947-2018	1956-2018	-	194	648,5
2	Black Tisza – Bilyn	1946-1988	1946-1988	1968-1988	540	492,12
3	White Tisza – Lugy	1947-2018	1955-2018	-	189	602,05
4	White Tisza– Roztoky	1955-1988	1955-1988	1968-1988	473	482,93
5	Tisza – Rakhiv	1946-2018	1947-2018	1951-2017	1070	431,73
6	Tisza – Dilove	1946-1988 2010-2018	1956-1988	-	1190	345,96
7	Kosivska – Kosivska Polyana	1963-2018	1963-2018	-	122	406,77
8	Shopurka – Kobyletska Polyana	1947-2018	1954-2010 2017-2018	-	240	389,06
9	Tisza – Velykyi Bychkiv	1946-2018	2017-2018	-	1700	294,78

In the mountainous terrain of Rakhiv and Tyachiv districts, several factors, including the amount of precipitation, geological structure (characterised by a lack of aged aquifers, high rock fracture, rock infiltration capacity, substantial debris, and limited soil cover), surface fragmentation, steep slope gradients, and the low catchment accumulation capacity, play a decisive role in shaping the river runoff of the Tisza and its tributaries (Lukianets, 2004). According to Lukianets' research, the average annual runoff has been increasing over the past decades (Lukianets, 2004).

The Tisza river and its tributaries in the mountainous part of Zakarpattia Region are characterised by a pronounced flood regime. The most powerful floods in the region are triggered by intense (heavy) rains between May and October, as well as during the winter snowmelt, brought on by warm Atlantic air masses and thaws. Flooding can also result from a substantial overall rise in springtime air temperatures and accelerated snowmelt, further exacerbated by significant rainfall (Vyshnevsky, 2003; Water Fund, 2007; Schwebs, 2003).

Nevertheless, determining the time interval of spring floods in the upper Tisza River's rivers is challenging due to significant variations in the hydrological regime and meteorological features from year to year. An analysis of the period 1981-2016 reveals distinct patterns, with some years characterised by clear high spring floods and low floods (1986, 2000, 2002, 2013), others marked by low floods and sharp fluctuations (1997, 1998, 2001, 2008, 2014, 2015), and still others showing alternating high floods throughout the year (1985, 1987, 2004, 2011, 2016) (refer to Figures 1.2.2 to 1.2.4) (Leta, 2021).

The hydrological regime of the rivers, which includes spring floods, summer-autumn low water, and winter low water, significantly influences the sources of river feeding, resulting in variations in the chemical composition of water. In essence, the hydrological regime plays a crucial role in shaping the hydrochemical regime.

The rivers in the upper reaches of the Tisza are characterised by flooding resulting from snowmelt during winter thaws, frequent spring rains, and intense precipitation in the summer and autumn (May-October). At the Tisza-Rakhiv hydrological station, covering a catchment area of 1070 km^2, the average long-term water discharge is 25.4 m^3/s. The highest recorded water discharge was 938 m^3/s on 5th March 2001, while the lowest was 1.14 m^3/s on 2nd February 1963 (Leta, 2021).

During periods of low summer and autumn water levels, as well as low spring floods, the Tisza River experiences minimal water levels. Paradoxically, the most catastrophic floods also transpire in the summer and autumn, primarily driven by intense rainfall. It's worth noting that the amplitude of level fluctuations can vary from 3.1 m to 6.8 m (Leta, 2021). In contrast, water levels in the Tisza River and its tributaries exhibit instability during the winter period due to frequent thaws and rains.

The mountainous region of Zakarpattia Region experiences intensive snowmelt, often accompanied by periodic rains, resulting in elevated river water levels. Consequently, spring flooding typically occurs during the latter half of March and early April, sometimes unfolding in multiple stages. During high floods, water levels can surge by 150-200 cm per day, while low floods lead to more gradual increases of 5-15 cm per day (Zakarpattia Regional Hydrometeorological Centre). At the Tisza River hydrological station in Rakhiv, the highest recorded water level during the period from 1950 to 2016 was 575 cm, observed on 5th March 2001 (Zakarpattia Regional Hydrometeorological Centre). Notably, even in years with average water conditions, the spring season consistently witnesses elevated water levels (Leta, 2021).

Floods in the basin's rivers primarily result from frequent precipitation events (165-175 days annually). However, flood formation typically commences when daily precipitation exceeds 20 mm. During exceptionally heavy downpours, characterised by rainfall exceeding 100 mm, floods reach catastrophic levels. In such instances, water levels surge in mountainous areas by 2-4 m, in foothill regions by 5-6 m, and in the Tisza River, by 6.5-9.5 m. Consequently, floodwaters rapidly drain from mountain watercourses into river valleys, leading to extensive flooding. This inundation spans a 15-60 m width in the mountainous zone, 115-500 m in the foothill zone, and extends to 2500 m in the plains. The steep terrain profiles contribute to flash floods, during which water levels can elevate by 1.5-2.5 m within just 3-4 hours (Leta, 2021).

An analysis of long-term data on precipitation and the hydrological regime in the Tisza River basin reveals that the most significant increases in water levels and flows are characteristic of autumn and winter floods (refer to Figures 1.2.2 to 1.2.4). These floods, which typically constitute 20-30% of the total annual flood count, have a mixed origin and primarily occur during the colder months. In addition to these cold-season floods, there are warm-season floods, spanning from April to November, resulting from sudden heavy rainfall.

Minimum water flows occur in both warm and cold seasons. The first minimum typically transpires in September-October and is linked to a significant reduction in precipitation. The second minimum emerges in January-February when surface runoff is absent, and groundwater reserves are depleted. In mountain rivers across the basin, stable summer low water conditions are observed in 20% of cases, while stable winter low water conditions prevail in 40% of cases. The summer low water phase commences in June and July and extends into early November, lasting on average for 100-160 days. On the other hand, the winter low water phase concludes in February-March, with an average duration of 45 to 80 days.

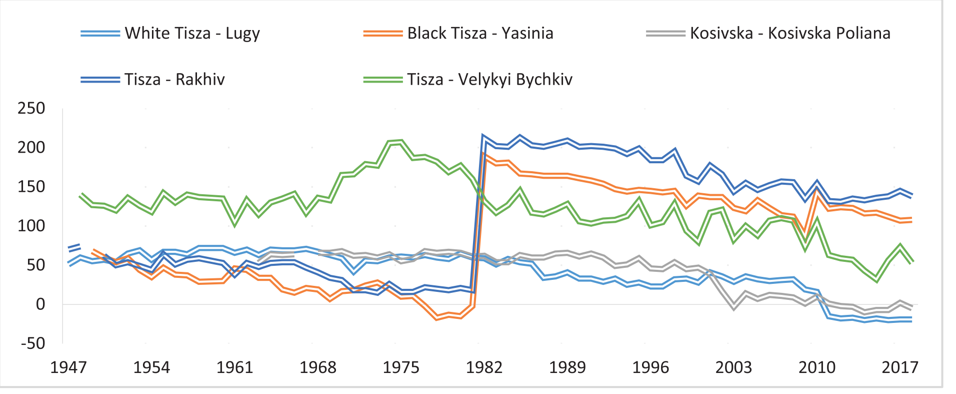

Fig. 1.2.2. Dynamics of water levels by annual averages, cm (compiled by the Zakarpattia Regional Hydrometeorological Centre)

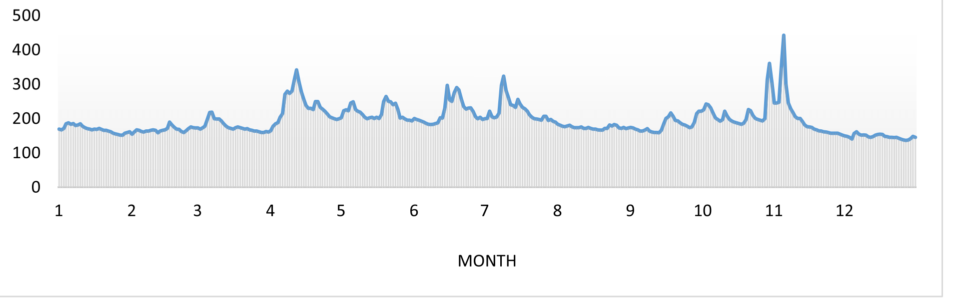

Fig. 1.2.3. Dynamics of water levels in the Tisza River (Rakhiv) during 1998 (high-water year), cm (compiled by the Zakarpattia Regional Hydrometeorological Centre)

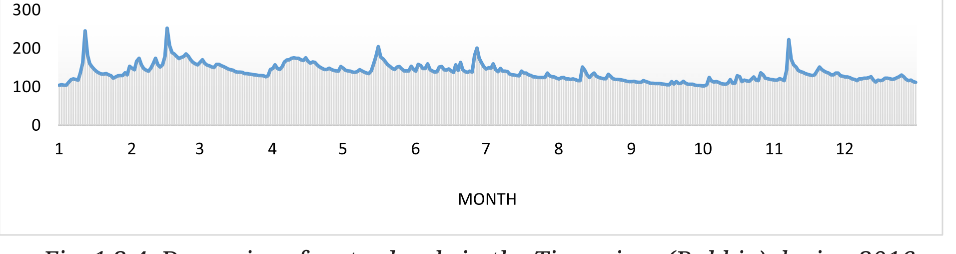

Fig. 1.2.4. Dynamics of water levels in the Tisza river (Rakhiv) during 2016 (average water year), cm (compiled from the materials of the Zakarpattia Regional Hydrometeorological Centre)

The minimum flow characteristics are the average monthly flow (30-day periods with the lowest flow) and the minimum average daily flow in summer, autumn and winter. The minimum average monthly flows of 95%

availability are mainly used as a reference for the design of hydroelectric power plants, reservoirs, and ponds, and the minimum average daily flows of 95% availability are used for the design of water supply facilities for settlements and industrial enterprises.

Similar to the water level indicator, water discharge exhibits a consistent pattern in the observation series (see Figure 1.2.5). Minor variations can be attributed to differences in precipitation, topographic characteristics, and underlying surface conditions. Over the period spanning 1946-2017, the highest water discharge was documented during the March 2001 flood, reaching a peak of 938 m^3/s, while the average long-term discharge remained at 25.4 m^3/s.

The highest average long-term runoff levels in the studied part of the Tisza basin for the period 1981-2017 are observed in the Kosivska river (Kosivska Poliana village) and the Shopurka river (Kobyletska Polyana village). This can be attributed to elevated precipitation levels and the catchment area's height. It's also noteworthy that there has been an increase in the average long-term values of water discharge and the water flow module compared to previous studies (NPMTRB, 2012; Obodovsky, 2017). The only exceptions are the data from the hydrological stations on the Black Tisza river (Yasinia village) and the Kosivska river (Kosivska Poliana village), which indicate a slight decrease in average annual water discharge and runoff module over the past decades.

Table 1.2.4.

Average flow characteristics of the rivers in the upper reaches of the Tisza river basin (for the period 1981-2017) (compiled from the materials of the Zakarpattia Regional Hydrometeorological Centre)

№	River – Hydropost	Average long-term values	
		$Q_{average}$ m^3/s	$M_{average}$ $l/s\ km^2$
1	Black Tisza – urban-type village Yasinia	4,68	24,14
2	Black Tisza – village Bilyn*	13,1	24,3
3	White Tisza – village Lugy	5,25	27,8
4	White Tisza – village Roztoky*	14,5	30,7
5	Tisza – city of Rakhiv	26,06	24,35
6	Tisza – village Dilove*	32,7	27,5
7	Kosivska – village Kosivska Polyana	4,59	37,65
8	Shopurka – village Kobyletska Polyana*	8,51	35,5

*-1981-1988 pp.

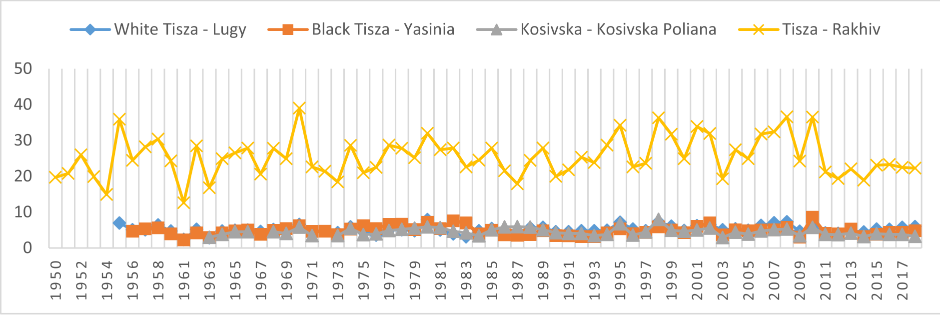

Fig. 1.2.5. Dynamics of water discharge by annual average, m³/s (compiled from the materials of the Zakarpattia Regional Hydrometeorological Centre)

In the high-water year of 1998, except for the White Tisza River (Lugy village), autumn runoff predominated, with maximum values occurring in November. Conversely, in 2016, the influence of spring flooding on the flow distribution is notably evident. The allocation of runoff between warm and cold periods also exhibits variations. For instance, the mild winter and April floods in 2016 resulted in a prevalence of runoff during the cold season. In 1998, the period of the lowest winter low water mark with the least runoff was distinctly discernible, whereas in 2016, we observe a more balanced intra-annual distribution of runoff (refer to Tables 1.2.5 to 1.2.6).

Table 1.2.5.

Intra-annual distribution of runoff (by months of 1998) in the Tisza basin rivers, % (compiled from the materials of the Zakarpattia Regional Hydrometeorological Centre)

River – Hydropost	Months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Tisza – city of Rakhiv	3,43	2,76	4,57	15,50	11,22	11,66	12,58	4,08	4,93	12,19	14,24	2,85
Black Tisza – village Yasinia	2,04	2,09	2,36	16,33	13,31	11,72	11,09	5,30	7,26	12,35	13,76	2,40
White Tisza – village Lugy	3,20	3,21	3,58	16,08	14,71	12,60	14,55	3,57	4,31	8,27	12,60	3,33
Kosivska – village Kosivska Polyana	3,36	2,88	5,09	15,24	8,82	8,26	8,95	3,40	5,15	11,53	24,43	2,89

Table 1.2.6.

Intra-annual distribution of runoff (by months and seasons in 2016) in the rivers of the Tisza basin, % (compiled from the materials of the Zakarpattia Regional Hydrometeorological Centre)

River – Hydropost	Months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Tisza – city of Rakhiv	7,93	15,97	9,72	13,03	11,44	11,19	7,43	5,11	2,67	3,83	8,46	3,22
Black Tisza – urban-type village Yasinia	7,79	13,93	8,69	12,89	12,95	13,94	8,58	4,72	2,58	3,40	8,39	2,15
White Tisza – village Lugy	5,08	12,13	9,15	15,24	11,93	12,47	7,68	5,85	3,50	5,03	8,07	3,87
Kosivska – village Kosivska Poliana	9,21	17,03	10,84	15,51	12,04	10,51	5,46	3,91	2,04	2,36	7,55	3,54

Riverbed processes and deformations

An essential aspect of river network functioning and development, under the influence of varying external environmental factors, including climate, involves riverbed processes such as erosion, sediment transport, and accumulation. The vigorous evolution of these processes in different parts of the river valley leads to modifications in the river channel's configuration, resulting in alterations to its morphology and morphometric parameters. Riverbed processes in the mountain river basins of Zakarpattia Region exhibit unique manifestations, which arise from the complex geological and geomorphological characteristics of the region, as well as the distinctive features of the hydrological regime, river feeding, and other natural and anthropogenic factors (Hydrometeorological conditions, 2005).

The primary driver behind the occurrence and progression of riverbed deformations is the dynamic structure of water flow, which induces riverbed erosion, sediment transport, and accumulation (Hydrometeorological conditions, 2005). The water content of the stream and its carrying capacity are contingent on the moisture regime of the area. In certain mountainous of the Zakarpattia Region, annual precipitation surpasses 2,000 mm. Moreover, during cyclonic periods, a two-month rainfall equivalent can precipitate in a single day, with up to 200 mm of rainfall occurring within 2-3 days. This gives rise to rapid and destructive floods, which, in plains, result in inundations causing substantial harm to the local population and accumulating significant quantities of river material. During severe floods, the riverbanks undergo active erosion, leading to profound channel deformities and the transportation of substantial alluvial sediments to lower hypsometric levels of the river network. These processes coincide with the degradation of hydraulic structures, road infrastructure, residential buildings, communications, and more.

The most severe floods in Zakarpattia Region occurred in 1998 and 2001, resulting in the destruction of numerous bridges, deforestation, disruption of power lines, and washouts in some of the region's mountain rivers. Beyond inflicting significant economic damage on the region's economic infrastructure and exacerbating the overall geo-environmental situation in Zakarpattia Region, these high floods pose a threat to the population. They also contribute to an increase in water flow capacity, accompanied by bank and riverbed erosion, as well as overall deformations (Karabiniuk, 2021; Obodovskyi et al., 2002).

Riverbed processes and deformations are also influenced by the orographic characteristics of the region, where steep mountain slopes contribute to rapid runoff and the formation of high floods. Sudden shifts in the configuration of river valleys and the presence of erosion-resistant rocks, including sandstones, gneisses, and shales, lead to the creation of specific rapids within river channels. These natural transverse barriers impact the dynamics and progression of riverbed processes. The manifestation of riverbed processes is significantly influenced by the outcrops of metamorphic rocks on the riverbed surface, which greatly enhance the riverbed's resistance to deformation. Such outcrops of hard bedrock are observed in Zakarpattia Region, particularly in the channels of the Black Tisza, Shopurka, Kosivska, and others. Rock formations traversing the riverbed can alter the kinematic forces of the flow during floods, giving rise to supports and hydraulic jumps (Hydrometeorological conditions, 2005; Obodovsky et al., 2002).

Generally, the sediment transport pattern in the mountain rivers of Zakarpattia Region follows the following sequence (Obodovsky and others, 2002):

✓ in the upper reaches, there is active erosion and sediment transport.

✓ in the middle reaches, a combination of erosion and accumulation processes occurs alongside sediment transport.

✓ in the lower reaches, accumulative processes and meandering become prominent.

Within the complex river network of Zakarpattia Region, sediments prevail in various sections of the riverbed-floodplain complex.

Under the influence of water runoff, alluvial sediments accumulate in widening areas of river valleys, with the accumulation intensity increasing downstream. In these locations, the riverbed consists of pebble, pebble-boulder sediments, mixed with gravel, sand, and clay, and may branch out when the channel's stability against scour is poor (Hydrometeorological Conditions, 2005). This phenomenon of river valley expansion and alluvium accumulation is most commonly observed in the mountainous rivers of Zakarpattia Region, particularly in regions with a concave topography and a geological base of mudstone flysch, which is susceptible to erosion by water. For instance, within the Jasinia Basin in the Black Tisza River valley, pebble-boulder alluvial deposits accumulate along a substantial portion of the river's course, flowing through the Krosnenska geological zone predominantly composed of argillites (Figure 1.2.6). As the river exits the Yasinia Basin, the Tisza river channel significantly narrows and cuts through the hard sandstone rocks of the Porkulets Cover, resulting in reduced sediment accumulation and a riverbed marked by rapids often devoid of alluvial deposits.

Fig. 1.2.6. Accumulation of alluvial sediments in winter in the Black Tisza riverbed within Yasinia, 2021 (Photo by the author)

The manifestation of riverbed deformations in the mountainous areas of Zakarpattia Region is characterised by the predominance of deep erosion, resulting in the active incision of riverbeds. This is evident in several basins, including Black Tisza, Shopurka, Kosivska, Latorytsia, and others, where narrow river valleys lack terraced sides and feature straight stony channels with multiple rapids. In areas where the river valley widens and the drop in the riverbed decreases, weakly sinuous meanders form. The most significant lowering of water levels is observed after destructive floods, leading to the transportation of a substantial amount of sediment and the development of deep erosion (Hydrometeorological Conditions, 2005; Leta et al., 2019).

Other significant factors influencing the development of riverbed processes in Zakarpattia Region include the ongoing anthropogenic impacts, such as excessive ploughing of catchment surfaces, unauthorised riverbed quarrying and pebble mining, expansion of development into floodplain and water protection zones, and the construction of hydraulic structures.

Based on its genesis, the river valley comprises several sections, with the riverbed and the first floodplain terraces being the most dynamic (Obodovskyi, 2013). Geometric features of the riverbed, such as its tortuosity and width, influence the river's flow characteristics. We conducted in-depth studies of channel processes and deformations in the mountainous region of Zakarpattia Region, using the Black Tisza river as an example, known for its dynamic flood regime. The Black Tisza River crosses significantly different geological areas along its course, impacting the morphology of the riverbed and the feasibility of hydrotechnical structures. Within the Yasinia Basin, the widest segment of the river valley exhibits pronounced meandering and minimal transformation of the main riverbed. This area has experienced the most substantial anthropogenic impact on the riverbed, particularly in the Jasinia settlement. In the early 21st century, the Black Tisza river was dammed along a significant portion of its length within the central part of the settlement. Special attention was also given to fortifying the section where the Black Tisza river meets its tributary, the Lazeshchyna river.

Downstream of the Black Tisza River, the orographic features of the terrain, coupled with the steep spurs of the Chornohora and Svydovets massifs, have given rise to the formation of an exceedingly narrow river valley, extending from the village of Keveliv to its confluence with the White Tisza River near Rakhiv. The anthropogenic impact on this stretch of the river valley, including the floodplain, has experienced a significant upsurge. This escalation can be attributed to the presence of the nationally important motorway H09, which has witnessed the construction of numerous engineering bank protection structures along the Black Tisza river valley in recent years. These constructions have had notable effects on riverbed processes and riverbed deformation (refer to Figure 1.2.7).

Figure 1.2.7. Anthropogenic pressure on the valley and riverbed of the Black Tisza river in the area from the village of Kvasy to the village of Yasinia (fragment of Google Earth image)

Active bank protection structures on the Black Tisza river perform the main function of protecting the banks from active erosion processes that disrupt the landscaping of the territory, destroy infrastructure, and contribute to the development of slopes and landslides in mountainous terrain (Fig. 1.2.8). In practice, river dams and riverbed transformation often reduce the natural tortuosity of the river, which creates optimal conditions for increasing the speed of river masses during periods of rising river water levels. This results in a greater potential destructive capacity of water masses, which is associated with changes in the characteristics of solid material transport, development of channel deformations, etc. Engineering unjustified construction within floodplains contributes to artificially induced accumulation of alluvial sediments, riverbed deformation and further changes in river flow.

Figure 1.2.8. Dumping and development of low terraces in the Black Tisza river valley within the village of Kvasy (fragment of Google Earth image)

To regulate floods and mitigate flood risks, a considerable 14.6 km of dams and nearly 18 km of bank protection were constructed in the Rakhiv raion, as reported by Leta in 2021. However, this extent of hydraulic infrastructure falls short in providing sufficient protection to the local population against the ramifications of hydrological hazards and the progression of riverbed deformations. In the Zakarpattia Region, the majority of river basins fail to meet the stipulated criteria for coastal protection zones within river valleys, and related standards.

The ecological well-being of rivers and the morphology of riverbeds within the Zakarpattia Region is imperiled by the obstruction of river channels with solid household waste. A substantial number of spontaneous dumpsites are observed in this area. Notably, within the Black Tisza river basin, the authorized landfill near the town of Rakhiv raises the greatest concern, with the garbage layer attaining heights of up to 10 m (Leta, 2021). The lack of proper waste segregation results in the contamination of water bodies with municipal solid waste (MSW), with quantities during flood events in the Tisza river reaching hundreds per minute, including waste products and household chemicals, among others. A similar situation is observed with unauthorized dumpsites located along the banks of rivers such as Lazeshchyna, Borzhava, Latorytsia, Teresva, and more (Leta, 2021; Obodovsky, 2013). Conversely, the prevalent illicit gravel extraction practices in Zakarpattia Region's rivers lead to the formation of unnatural depressions and riverbed deformations, thereby disrupting the natural cycle of erosion and sediment accumulation processes within the riverine system.

Economic activity affect on surface waters

Economic activity in the upper Tisza basin has experienced profound transformations over the past centuries, manifesting in the region's socio-economic development and environmental conditions. This encompasses the rapid growth of mining and manufacturing industries, light industry, food processing, transportation and social infrastructure, agriculture, among other sectors. It is inherent that economic activity within the Tisza basin yields not only economic but also environmental repercussions, one of which pertains to its influence on the hydroecological conditions of watercourses.

The analysis of economic activity as a factor impacting the hydroecological state of rivers entails an examination of the territorial and sectoral composition of the industry. Distinctive natural conditions and substantial natural resource potential have fostered the growth of the wood processing industry, construction materials sector, and food industry. At certain points in time, the Rakhiv district witnessed active development in timber and chemical, pulp and paper, as well as light and metal processing industries. Following the disintegration of the Soviet Union, major industrial establishments experienced a decline and eventually ceased their operations, with the proliferation of small and medium-sized private enterprises.

Routine surveys of the Black Tisza, White Tisza, and Tisza Rivers along the Ukrainian-Romanian border have enabled the identification of the impact of agriculture, household waste and wastewater, illegal landfills, manure storage facilities, and summer animal camps within the coastal protection zones and floodplains on river water quality.

The analysis of economic activity within Rakhiv and Tyachiv districts has revealed a list of primary enterprises and institutions whose activities during the study period presented a direct or indirect threat of polluting the waters of the Tisza River or its tributaries. These include municipal enterprises in Rakhiv, Kobyletska Polyana, Solotvyno, and Tyachiv; marble mining operations in Trybushany and Bilkam; wood processing facilities such as VGSM, Karpaty, Velykyi Bychkiv Timber and Chemical Plant, and Rakhiv Cardboard Factory; in addition to Kozmeschyk tourist resort, Dragobrat resort, and Hirska Tisza sanatorium (Rakhiv District State Administration). It is noteworthy to emphasize the risk of water pollution in the Tisza River area downstream from Rakhiv, resulting from solid household waste, organic and synthetic substances that emanate from the landfill situated directly on the left bank of the river.

The popularity of Rakhiv and Tyachiv districts in the tourism sector has been steadily increasing year by year, evident from the rise in direct railway connections with other regions of Ukraine. This growth holds particular significance for the development of both domestic and international tourism. However, tourist and recreational facilities, including those situated in the upper reaches of the Tisza River basin, represent a direct threat to surface water quality. Foremost among these threats is the absence of a centralized water supply and sewerage system, a consequence of the uncoordinated expansion of recreational complexes and the absence of effective water usage monitoring.

Forest management indirectly poses a threat to the deterioration of surface water quality, specifically in relation to water turbidity and the presence of specific heavy metals. An instance of this is observed in the upper reaches of the Tisza river basin, where clearcutting leads to accelerated runoff during heavy rainfall, subsequently resulting in a swift escalation of floodwater levels in the Tisza river and its tributaries within the study area.

Figure 1.2.9. Deforestation in the Black Tisza River Basin

Fig. 1.2.10. Deforestation in the Lazeshchyna River Basin

The orographic and climatic conditions in the Rakhiv and Tyachiv districts, combined with distinctive features of economic development and a range of historical factors, have fostered a particular form of subsistence farming characterized by cattle breeding (dairy and meat), sheep farming, poultry husbandry, and various other agricultural activities. These practices significantly dominate over crop production, the expansion of which is predominantly constrained by specific natural and geophysical conditions.

Private subsidiary plots and farms account for more than 95 % of livestock production in Rakhiv district. In particular, there are 19,800 private subsidiary plots and 55 farms within the raion (Rakhiv District State Administration). The functioning and efficiency of these entities are directly related to the level of sales and market demand for their products, which is associated with the level of trade relations between territorial communities at the Raion and Oblast levels. The main livestock products in this region include meat, milk, eggs, and cheese. An analysis of the number of livestock indicates a decline in livestock numbers and a general decline in agriculture, primarily attributed to lower production costs and intense competition in the market for inexpensive factory food. The absence of systematic state support in the form of programs, limited awareness among the population regarding the opportunities and procedures for receiving subsidies, and other factors also negatively impact the economy.

Among the agricultural products, potatoes and vegetables are most commonly cultivated in limited quantities, providing the annual required amount for a portion of the local population. At the hypsometrically lowest levels of the study area, there is limited cultivation of crops such as corn, barley, and legumes. The flat south-western part of the raion, known as the Solotvyno Plain, is most suitable for gardening and horticulture. In the Tisza River valley near Velykyi Bychkiv and the villages of Luh and Bila Tserkva, collective farms used to be prevalent in the past, but now they primarily focus on cultivating technical grape varieties. The development of viticulture in the mountainous part of the study basin is hindered by unfavorable climatic conditions and low grape yields (Leta, 2021).

Given the limited availability of land in Rakhiv district, the cultivation of sloping and steep slopes in narrow river valleys and along riverbanks is prevalent. The use of organic fertilizers and pesticides on arable land, combined with intensive surface runoff in conditions of ample precipitation, heightens the risk of surface water pollution and the development of erosion, among other processes, especially during floods (Leta, 2021). Consequently, agriculture is characterized by its impact on surface water and its quality in the upper reaches of the Tisza river region. This impact is notably associated with:

- the application of organic and mineral fertilizers in arable land cultivation; the utilization of coastal strips and river floodplains for agricultural purposes;
- the construction of manure storage facilities and summer livestock camps in close proximity to rivers;
- the discharge of water from fish farm ponds into rivers; the absence of sewage treatment facilities and centralized water disposal at livestock facilities and enterprises.

An important factor influencing the quality of surface water in the cross-border section of the Tisza River is the water usage within Rakhiv and Tyachiv districts. This usage has undergone several structural changes, which, in turn, have impacted specific quantitative indicators. Over the analysed period from 1990 to 2019, a 20-fold reduction in the volume of water withdrawn can be observed. This reduction is primarily attributed to the decline of water-intensive industries, including those related to chemicals, forestry, food production, and more. It is worth noting that the ratio between water abstraction from surface and groundwater sources has also shifted, contingent on the purpose of water usage. In recent years, a preeminence of water withdrawal for drinking and sanitary purposes has been noted, thus making groundwater abstraction the predominant source.

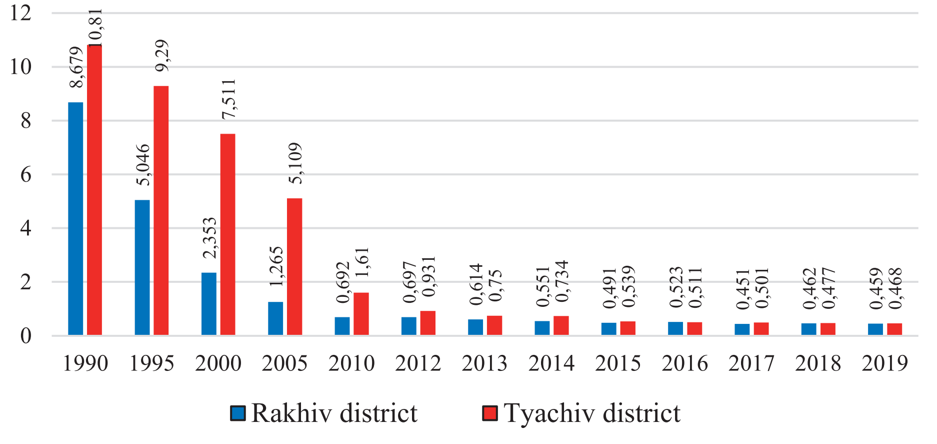

Fig. 1.2.11. Dynamics of Water Intake in 1990-2019, Million m³, Rakhiv district Tyachiv district (compiled by the Tisza River Basin Water Resources Management Authority)

The reduction in water withdrawal also leads to a decrease in wastewater volumes, thus impacting the hydroecological status of the Tisza (Figure 1.2.12). For instance, as a result of structural changes in water usage, the volume of industrial wastewater from enterprises within the Tisza study area's sub-basin decreased by a factor of 15. In recent years, municipal wastewater has come to dominate, leading to organic pollution of the Tisza river waters.

The greatest threat of pollution in the transboundary section of the Tisza River is posed by biogenic nitrogen-containing substances (ammonium, nitrite, nitrate) and phosphates, as well as synthetic detergents, which serve as a source of synthetic surfactants in the river. Another concerning source of pollution is associated with wastewater treatment plants, particularly due to their inadequate condition, outdated equipment, and limited treatment capacity. For instance, mechanical treatment methods tend to prevail over biological treatment at wastewater treatment plants in Rakhiv and Tyachiv districts, resulting in an increase in chemical water quality indicators such as BOD_5, ammonium nitrogen, nitrite nitrogen, nitrate nitrogen, COD, and so forth. It is crucial to note that in recent years, the category of “polluted” water, or at the very least "insufficiently treated" water, has become predominant among the classifications of wastewater discharged into the riverbed.

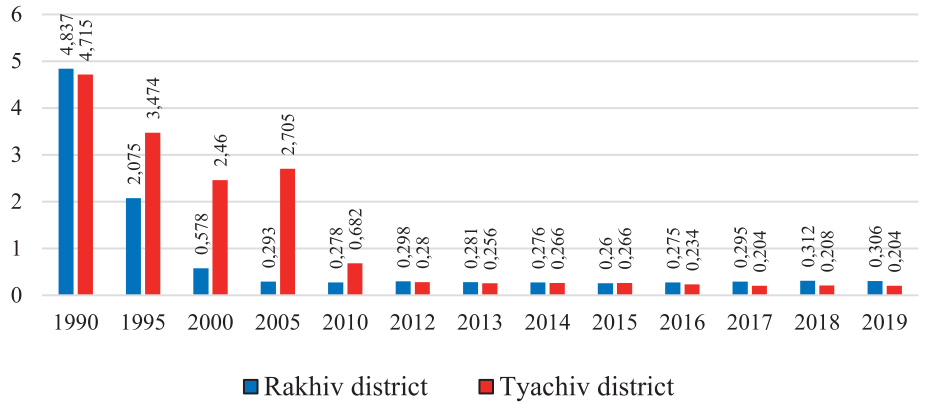

Fig. 1.2.12. Dynamics of wastewater discharge in 1990-2019, million m^3, Rakhiv district, Tyachiv district (compiled by the Tisza River Basin Water Resources Management Authority)

Fig. 1.2.13. Sewage Treatment Facilities in Tyachiv

The most substantial water users and consequently the primary sources of pollution in the transboundary section of the Tisza River include the extractive industry enterprises located in Dilove village, such as Trybushany Marble Quarry PJSC, Sauliak LLC, Bilkam LLC. Additionally, woodworking enterprises in Velyky Bychkiv, namely VGSM LLC and Karpaty LLC, as well as food processing companies like Canning Plant ALC, and municipal enterprises in Solotvyno and Tyachiv, significantly contribute to water pollution. For instance, in 2018, 20% of the abstracted water was allocated for production needs, marking a twofold increase compared to previous years. However, it's important to note that the volume of water utilized for production purposes in 2018 was 50 times less than in 1990. Presently, wastewater from industrial enterprises primarily consists of treated drinking and sanitary water after undergoing biological treatment.

1.3. HYDROECOLOGICAL STATE OF THE UPPER REACHES OF THE TISZA RIVER BASIN *(V. Leta)*

The hydroecological state represents a spatiotemporal combination of quantitative hydrological, hydrochemical, and physical characteristics that provide insights into the regime, water quality, and the degree of pollution within a surface water body or its segments. It also elucidates the interplay with the environment and the impact of economic activities (Leta, 2021). The dynamics and variability of hydroecological conditions in river waters can be examined through data collected from a single river reach, specific points, surface water bodies (river sections), or an entire basin, spanning various timeframes (such as a day, month, season, year, or long-term period) (Leta, 2021). The study of hydroecological conditions in rivers serves the following purposes:

- analysis of the anthropogenic load on the aquatic geosystem;
- hydroecological monitoring of surface waters;
- development of management decisions;
- forecasting environmental changes due to the impact of anthropogenic activities;
- development of plans and schemes for integrated use and protection of water resources;
- optimisation of the water management complex;
- development of recommendations for the preservation of the ecological balance of hydrogeosystems (Leta, 2021).

There are numerous methods available for determining and classifying the hydroecological conditions of surface waters. Within the Ukrainian scientific geographical community, the most commonly employed methods include the Comprehensive Water Pollution Index (CWPI) and the Integral Environmental Index (I_E).

To ascertain the hydroecological states of waters, their seasonal variations, and long-term dynamics, it is essential to consider the relationship

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The manual contains scientific materials devoted to the coverage of contemporary environmental issues of Zakarpattia. Considerable attention is paid to the peculiarities of its natural conditions. Emphasis is placed on the preservation of biodiversity in the face of climate change. While devising this textbook, the authors resorted to the analysis of literary sources as well as the findings of their own research. It will benefit school teachers, students and postgraduates of higher educational institutions majoring in natural sciences, employees of the nature reserve fund, and representatives of the authorities.

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Manual

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