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GROUNDWATER OF VOLYN REGION: CONDITIONS OF LOCATION, FEATURES OF USE, WAYS OF PRESERVATION AND IMPROVEMENT

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Water is a vital resource that sustains life on our planet. However, its distribution is uneven, leading to water scarcity in some areas and excess in others. Human activities further exacerbate the reduction of usable water volume. It is predicted that water scarcity may become a significant factor in conflicts of the 21st century.

Groundwater serves as a primary source of water and is classified as an exhaustible renewable natural resource. However, the replenishment of groundwater occurs at a slow rate. Given the global water scarcity issue, there is a pressing need for comprehensive research on groundwater, particularly at local and regional levels. Therefore, this article focuses on investigating the underground water resources in the Volyn region, including their occurrence, and analyzing their utilization by the local population and regional economy.

The article provides a detailed description of aquifers of various geological ages in the Volyn region, including their occurrence patterns and distribution boundaries. The study examines the specific locations of each aquifer in relation to the geological structure of the area, following a geochronological sequence. Additionally, the article investigates mineralized underground waters, noting that the most prevalent types are chloride-sodium, sulfate, sodium, and hydrogen carbonate-chloride calcium waters.

The study focused on the period from 2015 to 2020 to assess the current status of groundwater and identify trends in water resource utilization. The research revealed a consistent increase in the proportion of underground water in overall water usage. Surprisingly, however, the actual volume of water extracted from underground sources has been decreasing. The study examined the dynamics of water usage by various industries. It was determined that the housing and communal sector was the largest consumer of water during the study period, mainly due to the region's limited economic development and correspondingly low water demands from other sectors. Analysis showed that, on average, 25.8% and 21.3% of the total water withdrawals were utilized for industrial and agricultural purposes, respectively. Irrigation and fisheries represented the smallest water-consuming activities, accounting for 9.5% and 6.5%, respectively. Notably, a significant portion of water intake, approximately 13%, was attributed to transportation purposes.

To ensure the rational utilization, preservation, and enhancement of groundwater quality, several measures have been recommended. These measures include the implementation of water-saving and water-free technologies in industrial processes, adopting reversible water usage practices, and upgrading water supply systems to improve efficiency. To safeguard and improve the quality of underground water, it is essential to upgrade treatment facilities in communal enterprises, implement rainwater and sewage treatment systems, promote the responsible use of pesticides and fertilizers in agriculture, among other practices. These actions aim to optimize water usage, mitigate pollution, and enhance the overall management of groundwater resources.

The article represents a significant contribution as it provides a comprehensive description of the characteristics of underground aquifers in relation to the geological structure of the Volyn region. It establishes the distribution boundaries of underground waters of different geological ages within the region, offering valuable insights. The creation of a modern geochronological scale during the research adds further value to the study. The article also sheds light on the utilization of water resources by various economic sectors during the specified period (2015–2020), highlighting important trends. The proposed measures for preserving water resources and improving their quality demonstrate a practical approach. The research findings can serve as a valuable resource for the Department of Ecology and Natural Resources of the Volyn Regional State Administration in their efforts to develop regional environmental programs.

Key words: underground water, geological age, aquifer, mineral water, water intake, water supply, rational water use, conservation measures.

Formulation of the problem. Water is a vital and indispensable natural resource that holds paramount importance for humanity. Experts studying future prospects have raised concerns about the heightened likelihood of conflicts arising from water scarcity, considering it as a primary economic resource. The term «water wars» was initially introduced by former UN Secretary-General Boutros Boutros-Ghali in 1985 and has since become part of the political discourse [19]. Forecasts from the Food and Agricultural Organization of the United Nations and the United States Agency for International Development suggest that by 2025, approximately 3 billion people (over 40% of the global population) could face water scarcity, with two-thirds of the population experiencing a severe lack of access to clean drinking water [20, p. 45].

Groundwater serves as the primary source of water resources, constituting 99% of all available liquid freshwater. It supplies approximately half of the water utilized for domestic purposes by the population, including drinking water [21]. Underground water resources are formed through processes such as mantle degassing and the infiltration of surface water, representing a replenishable but exhaustible natural resource. However, their replenishment rate is relatively slow, averaging around 0.1–0.3% per year [18, p. 98].

In order to address the issue comprehensively, it is crucial to conduct in-depth investigations of groundwater at the local level. Therefore, this study focuses on examining the underground water resources of the Volyn region, which includes analyzing the geological structure of the area, studying the occurrence patterns of aquifers, assessing the dynamics of water extraction, and understanding the overall structure of water usage.

Review of previous publications and studies. The study of underground water resources in the Volyn region has involved numerous scientists specializing in geography, geology, and economics. These experts have examined various aspects, including the formation and occurrence of aquifers, as well as the assessment of their resource potential. Notable contributions to the understanding of underground water features have been made by researchers such as K.I. Gerenchuk [11], F.V. Zuzuk, L.K. Koloshko, Z.K. Karpiuk [6], and others. The emergence of groundwater through springs has been studied by O.V. Mishchenko [10], V.O. Fesiuk [15], and additional researchers. L.M. Trush and Y.O. Molchak [14] have focused on the ecological and economic aspects of water usage. Statistical data regarding the state of groundwater is regularly published by the Department of Ecology and Natural Resources of the Volyn Regional State Administration, the State Geology and Subsoil Service of Ukraine, and the State Scientific and Production Enterprise "State Information Geological Fund of Ukraine".

Identification of previously unidentified parts of the general problem. Despite previous research on underground water in the Volyn region, there has been a lack of comprehensive studies regarding their occurrence, current status, utilization, and conservation measures. Therefore, this article provides a detailed description of the occurrence of underground aquifers, considering the geological structure of the region. It also establishes the approximate boundaries for the distribution of underground water from different geological periods within the Volyn region. Additionally, a modern geochronological scale has been developed during the course of this study. The article emphasizes the specific water usage patterns within different economic sectors during the period from 2015 to 2020. Furthermore, efforts to preserve and enhance the quality of water resources in underground aquifers are given significant attention and further advancements are proposed.

Formulation of the purpose of the article. The main objective of this study is to assess the present condition of groundwater in the Volyn region, considering the geological structure of the area. To achieve this goal, the following tasks were addressed:

– Establishing the relationship between the underground water conditions in the Volyn region and its geological structure, along with characterizing the primary aquifers in the region.

– Evaluating the level of underground water resources available for the region's economic sector.

– Suggesting measures to optimize the utilization of groundwater and proposing methods for enhancing its quality.

Methods. The research employs various scientific and geographical approaches, including the problematic, comparative, systemic, territorial, constructive, and comprehensive approaches. The comprehensive approach was particularly utilized to study underground waters in the Volyn region, considering their interconnections with other elements of the geographical environment and society. Furthermore, a constructive approach was employed to thoroughly analyze the present condition of underground aquifers and to identify strategies for their sustainable utilization and conservation.

The following formula was used to estimate the annual reserves of groundwater per inhabitant of the region:

$$AR = \frac{BS}{P} \times 365,$$

where: BS is the balance reserves of underground water, expressed in m^3 per day; P is the population of the region.

Results. The Volyn region is situated entirely within the Volyn-Podillia region of the East European Platform. From a geological perspective, the region falls within the Baltic-Transnistrian zone of pericratonic subsidence. The key geological structures within the region include the northern portion of the Lviv Paleozoic Depression (LPD), the Volyn Paleozoic Uplift (VPU), the Lviv-Ratniv Horst Zone (LRHZ), and the southern part of the Brest Depression.

The region has undergone a complex geological history, characterized by multiple stages and cycles of formation of its basement and platform cover. Its geological structure is highly diverse and heterogeneous, encompassing both Cryptozoic and Phanerozoic formations.

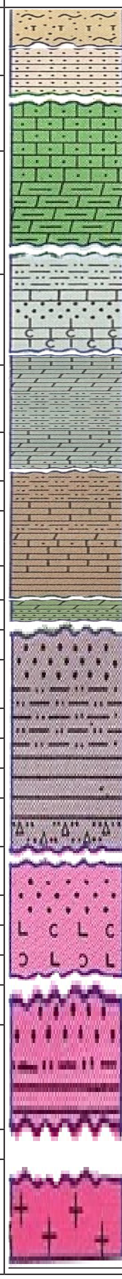
The basement is predominantly composed of granites, granodiorites, slates, gneisses, and other crystalline rocks. However, the study of the basement is limited and based primarily on core samples from a few wells. The crystalline basement, dating back to the Archaean-Proterozoic era, has been identified in reference and parametric wells such as I-Berestechko, I-Volodymyr-Volynskyi, I-Horokhiv, I-Lutsk, and I-Ovadne. Absolute age determinations suggest that most of these rocks belong to the lower and middle Proterozoic. Mineral deposits associated with the crystalline basement rocks have not been discovered within the region. This is primarily due to the significant depths at which these rocks occur, ranging from 150 meters in the tectonic blocks of the Lviv-Ratne Horst Zone (LRHZ) to 3.5 kilometers in the Lviv Paleozoic Depression (LPD), as well as the limited extent of exploration and study.

The sedimentary cover of the region consists of deposits from the upper Proterozoic, Paleozoic, Mesozoic, and Cenozoic eras. It is comprised of a thick layer of volcanic and sedimentary rocks, reaching depths of 3–3.5 kilometers in the southwestern part of the region, specifically in the Lviv Paleozoic Province (LPP).

To conduct a detailed study of the sedimentary cover in the region, it is recommended to utilize the geochronological scale that aligns with the International chronostratigraphic chart [17]. This standardized scale provides a framework for understanding the chronological sequence and relationships of the various rock formations and geological events within the region (table 1).

Table 1

Consolidated Geologic time scale*

Erathem	System	Stage, series	Horizon, formation	Lithological composition	Thickness, m	Brief lithological characteristics of rocks
Cenozoic	Quaternary				Up to 40	Peat, sand, loam, clay
	Paleogene				Up to 20	Glauconite sands, clays
Mesozoic	Cretaceous	Maastrichtian Campanian Santonian Coniacian Turonian Cenomanian			Up to 400	Carbonate rocks
Paleozoic	Carboniferous	Bashkirian Namurian Viséan Tournaisian			Up to 1000	Limestones, argillites, coal, siltstone
	Devonian	Famennian Frasnian			Up to 2000	Carbonate rocks with admixtures of terrigenous material
		Givetian Eifelian				Terrigenous carbonate rocks
	Silurian	Skal	Skal		Up to 730	Clay-carbonate rocks
			Malynovets			
		Ludlow	Bahovytsya			
		Wenlock	Kytaihorod			
	Ordovician				Up to 90	Limestones, sandstones
	Cambrian	Upper and Middle			90–265	Limestones, sandstones
		Berezhky series	Svitiaz		285–500	Sandstones, siltstones, argillites
			Liuboml			
			Dominopol			
		Baltic series	Stokhid		150–245	Sandstones, siltstones, argillites
			Rivne			Siltstones, sandstones, argillites
Proterozoic	Ediacaran (680-570 million years ago)	Valday	Kotlyne		Up to 200	Sandstones, siltstones, argillites
			Gdov			
		Volyn	Berestovets		Up to 186	Sandstones, siltstones, argillites, phosphorites
			Gorbashi			
	Paleoproterozoic – Neoproterozoic (1650–680 million years ago)	Polissia			Up to 900	Sandstones, argillites, siltstones in the form of layers. There are bodies of igneous rocks up to 100 m thick
	Paleoproterozoic					Crystal foundation. Amphibolites, gneisses, granites, granodiorites, granosyenites
Archean						

*made by authors based on the [1, p. 4].

Aquifers are found within the Upper Proterozoic, Cambrian, Silurian, Devonian, Carboniferous, Paleogene, and Quaternary sediments (Fig. 1). To conduct a comprehensive study of the sedimentary cover and the distribution of groundwater, it is recommended to examine each geological period or system separately. This approach allows for a detailed analysis of the specific characteristics and properties of aquifers associated with each geological period.

Proterozoic Erathem

Polissia series (1650–680 million years). The sedimentary cover of the southwestern edge of the East European platform includes the ancient formations known as the Polissia series, which are found in a discordant relationship over the crystalline basement. According to the International chronostratigraphic chart [17], the Polissia series is classified as Paleoproterozoic-Neoproterozoic in age. These rocks are overlain by younger Ediacaran, Paleozoic, and Mesozoic formations. The Polissia series occupies the linear graben-like Volyn-Orsha depression and represents the auvlacogenic stage of development in the sedimentary cover of the southwestern edge of the East European Platform. It serves as a transitional complex situated between the folded Archean-Proterozoic basement and the actual platform cover.

Fig. 1. Hydrogeological map of the Volyn region

*made by authors based on the [2, p. 8].

In the Volyn-Podillya region, the deposits of the Polissia series consist of sandstones, siltstones, and argillites. Among these, the sandstones are predominantly fine-grained quartz and feldspar-quartz varieties. Siltstones and argillites are present as thin layers within the sandstones, occupying a subordinate position in the sedimentary section. In certain areas such as Horochiv, Lutsk, Berestechko, Ovadne, etc., bodies of igneous rocks with a thickness of up to 100 m can be found within these deposits. These igneous rocks comprise dark green and black gabbro, gabbro-diabase, and gabbro-dolerite. The thickness of the Polissia series sediments varies, with an increasing trend towards the central part of the Polissia basin. The maximum recorded thickness of these sediments, reaching 870 m, was observed in the Lutsk area.

Proterozoic and Cambrian fractured sandstone deposits in the region contain an aquifer with a high groundwater pressure. This aquifer is widely distributed in the northeastern part of the region and is utilized for various economic purposes, including water supply for the urban-type settlement of Manevychi.

Ediacaran (680–570 million years ago). Rocks of this age, which are part of the Baltic series of the Cambrian, are found throughout the entire territory of Volyn-Podillya. These rocks consist of sedimentary and volcanogenic-sedimentary formations, with a maximum thickness reaching up to 950 meters. They discordantly overlie the sediments of the Polissia series and are themselves overlain by younger geological formations.

In the Ediacaran section, two distinct strata, known as the Volyn and Valdai series, can be identified. These series are positioned in a discordant manner, with one overlaying the other. The Volyn series comprises the Gorbashi and Berestovets formations. The Gorbashi formation consists of multigrained, multicolored sandstones and gravelites predominantly composed of arkose. This rock layer, with a thickness of up to 46 meters, is easily distinguishable on well log diagrams and serves as a reliable reference for cross-plane correlation.

The Berestovets formation, which is up to 465 meters thick, consists of volcanic rocks including effusive, pyroclastic, and partially intrusive formations. In the northern part of Volyn-Podillya, the Berestovets region can be divided into three parts based on rock composition: the lower and upper parts consist of effusive rocks, while the middle part comprises tuffogenic rocks, indicating the cyclic nature of volcanic activity. Thin layers of tuffs and tuffites can be found within the thick basalt covers. The basalts are predominantly dark gray with a dark shade and have a massive texture. The tuffs exhibit greenish-gray and brownish-lilac colors, lack distinct layering, and possess a fine fragmental structure. Red-brown argillites and siltstones are occasionally present as lenticular layers within the tuffs. The thickness of the basalt layers decreases from north to south, primarily due to the subsidence of rocks in the lower section. Adjacent to the traps in the Berestovets formation, intrusive rocks such as picrite gabbro-dolerites can be found. These rocks are dark in color, displaying shades of green and brown, and possess a fine-grained structure. An example of such an intrusive rock is observed in Well I-Berestechko.

The Valday series is characterized by sediments that overlie the eroded formations of the Volyn series and, in some areas, directly rest on the rocks of the crystalline basement. Above the Valday series, there are deposits of the Baltic series from the Lower Cambrian, as well as Cretaceous and Quaternary deposits. The Valday series can be further divided into two parts: the lower part, known as the Gdov horizon, and the upper part, referred to as the Kotlyne horizon. In the reference sections of Podillya Transnistria, the lower part of the Valday series is represented by the Mohyliv, Yaryshiv, and Nahoryany formations, while the upper part is represented by the Kalynivka formation.

The Lower Valday sediments, specifically the Gdov horizon, consist of irregularly grained quartz-feldspar sandstones with interbedded layers of siltstones of varying thickness. Among the argillites, phosphorite concretions can be found, particularly in the Nahoryany formation.

The maximum thickness of the Lower Valday formations, reaching 186 meters, was encountered in the eastern part of the region. Towards the western direction, the thickness gradually decreases as the lower part of the section thins out.

The Upper Valday sediments within the Kotlyne horizon consist of thinly bedded gray-colored sandstones, siltstones, and argillites with wavy layering. Unlike the Gdov horizon, the thickness of the Kotlyne horizon increases from east to west, reaching up to 200 meters. This observation suggests a change in paleogeographic conditions during the Kotlyne time, which influenced the sediment accumulation and spatial distribution. It is worth noting that no aquifers were identified within the sediments of this particular section.

Paleozoic erathem

Cambrian. Cambrian sediments lie everywhere on Ediacaran rocks and overlap with a stratigraphic break Silurian, and in places – Ordovician and Upper Cretaceous formations. The boundaries between the Upper Proterozoic and Lower Paleozoic are drawn along the sole of the Rivne formation.

In the section of the Cambrian, the rocks of the lower part and the sediments, which conditionally belong to the middle-upper parts, are distinguished. The lower division is divided into two series: Baltic, composed of the Rivne and Stokhid formations, and Berezhky, which unites the Dominopol, Liuboml, and Svitiaz formations. The most complete section of the Cambrian sediments was revealed by deep wells in the Lviv depression. At the base of the section lies a pack of fine-grained quartzite sandstones of the Rivne formation. The upper part and the entire above-lying Stokhid formation are composed of a thin layering of argillites and siltstones, with rare layers of sandstones. A peculiar textural feature of argillites is the presence of slip mirrors. The thickness of Rivne and Stokhid formations is 100–240 m.

The boundaries between the deposits of the Baltic and Berezhky series are clearly recorded on the well log diagrams by a sharp change in the physical and mechanical properties of the rocks of the overlying Dominopol formation. The lower part of this formation is characterized by packs (thickness up to 20 m) of fine-grained quartz sandstones with layers of siltstones and, to a lesser extent, argillites. Clay varieties predominate up the section. Rocks of the Liuboml formation are represented by alternating low-thick packs of fine-grained, in places quartzite-like, fractured sandstones and siltstones with rare layers of argillites. In the sediments of Svitiaz, argillites and siltstones with interlayers of fine-grained sandstones prevail. The thickness of the rocks that make up the Berezhky series is 280–500 m and more.

The monotonous stratum of the Middle-Upper Cambrian with a thickness of 90–260 m is mainly fine-grained quartz sandstones and siltstones. Argillites are found in subordinate quantities.

In general, Cambrian rocks are light gray, gray, and dark gray to black in color. The strength is not constant, and the stratigraphic integrity of the section is not the same. In the western and southwestern directions from the Ukrainian shield, the thickness of these deposits is constantly increasing, exceeding 1000 m in the area of Lviv.

The aquifer of the Cambrian period lies deep from the surface, but its waters are under pressure and during their development can reach static levels shallow from the surface. The horizon extends over almost the entire territory of the region, but it is absent only in the northeast of the region. The conditional boundary of the spread of the aquifer can be drawn along the line village of Kortelisy – village of Zhyrychi – village of Vydrychi – village of Datyn – village of Nuino – village of Pishchane – village of Nova Ruda – village of Kopyllya – village of Tsuman. Wells are opened near the urban-type settlement Turiysk and the village of Turopyn at a depth of 250–300 m [11, p. 26]. In connection with the significant depth of occurrence, the water resources of the research horizon are not sufficient and are not used in the economy.

Ordovician. Formations of the Ordovician system are widespread. They overlie Cambrian and Ediacaran sediments in a transgressive manner and are discordantly overlain by Silurian rocks. Ordovician deposits are most extensively exposed in the northern part of the region, where they are divided into three units. Based on lithological characteristics, two rock assemblages can be distinguished: a lower unit composed of terrigenous clastic and glauconitic sandstones, and an upper unit predominantly consisting of multicrystalline limestones. The thickness of Ordovician deposits in the Volyn uplift area reaches 90 m. There are no aquifers in this system.

Silurian. Silurian deposits transgressively lie on Ordovician, Cambrian, and Ediacarian rocks and are overlain by younger Paleozoic and Mesozoic-Cenozoic formations. The lower part of the Silurian system is formed by accumulations of the Wenlock layer in the Kytaihorod horizon, the upper part by the Ludlow and Skal stages. The first includes deposits of the Bahovytsya and Malynovets horizons, the second – the formation of the horizon of the same name.

Silurian sediments consist of clay-carbonate rocks that are abundant in brachiopod fauna, ostracods, graptolites, conodonts, and other skeletal remains. There is a gradual transition from the carbonate type to the clay type of the section when moving from east to west. Within the distribution area of the carbonate section, a belt of reefogenic limestones is present, extending from the northwest to the southeast, spanning from the city of Volodymyr to the region of Chernivtsi. The thickness of the Silurian deposits progressively increases in the western and southwestern directions, reaching 730 m in the Lviv depression.

Due to the peculiarities of Silurian deposits and the territory of the Volyn region, the aquifer of the system is also discontinuous. The horizon is present in the central and western regions of the region (Fig. 1). In Silurian argillite, limestone, and dolomite deposits, water reserves and well flow rates increase with depth [11, p. 26]. Wells were opened near the village of Stavok of Lutsk district and village Hodomychi of the Kamin-Kashyrskyi district, however, are not used in water supply.

Devonian. Formations of the Devonian system are represented by the middle and upper series. The Middle Devonian deposits are composed of the Eifelian and Givetian stages. In general, these are terrigenous-carbonate accumulations, which alternate unevenly, have a heterogeneous composition and a rather variegated color. The Upper Devonian deposits are represented by the Frasnian and Famennian layers, composed almost entirely of gray carbonate rocks with a small admixture of colorful terrigenous material. The total thickness of Devonian sediments in the western part of the Volyn-Podillya plate is, 3200 m or more.

Two aquifers were formed in the limestone, dolomite, and siltstone deposits of the Middle and Upper Devonian. They lie in the south of the region, and the limit of their distribution runs along the line of the village of Stenzharychi – village of Bilyn – village of Tulychiv – village of Drozdni – village of Pisochne – village of Litohoshcha – town of Kivertsi – village of Piddubtsi. Enrichment of the horizon with water resources is sufficient for their use in water supply. So, in the city of Lutsk and the city of Kivertsi, there are wells in which water is pressurized and used for economic purposes.

Carboniferous. Deposits of the Carboniferous System are developed in the Lviv Depression, where the lower and part of the middle divisions (Bashkirian stage) are distinguished. They are represented by a limnic-paralic polyfacies layer composed of terrigenous and chemogenic rocks, which is characterized by a rhythmic structure. The constituents of this stratum, including limestone, argillite, siltstone, and coal, form a series of repeating rhythms. Deposits of this age include significant coal seams, forming the Lviv-Volyn basin deposit. The total thickness of the deposits exceeds 1000 m.

The aquifer of the Carboniferous system is located in the southwest of the region, its boundaries tentatively run along the line of the village of Stenzharychi – village of Ovadne – village of Viinytsya – village of Shel'viv – town of Horokhiv. Water resources are contained in the Viséan and Namurian stages. However, due to the weak enrichment of sediments with water and insignificant flow rates of wells, the horizon is not used for water supply.

Mesozoic erathem

Cretaceous. Cretaceous deposits are widely distributed. The area of their development is called the Lviv Cretaceous Trough. In the section of the Cretaceous system, the lower and upper divisions are distinguished. Formations of the Early Cretaceous age, which are represented by the Neocomian and Albian stages, are limited in distribution. Neocomian deposits are composed of terrigenous carbonate rocks: clays, sandstones, and limestones. The Albian stage is formed by quartz-glauconite sands and weakly cemented sandstones with mossy-echinoderms and organogenic-detrital limestones. The Cenomanian, Turonian, Coniacian, Santonian, Campanian, and Maastrichtian stages are distinguished as part of the Upper Cretaceous deposits. The sedimentary layer of the upper part of the Cretaceous system is represented by carbonate and terrigenous rocks. The total thickness of Cretaceous deposits on the southwestern edge of the ancient platform reaches 900 m.

In the Upper Cretaceous deposits, the aquifers were formed in the Cenomanian and Cenon-Turonian stages. The Cenomanian horizon is deep, not thick, flow rates of water points are insignificant, it is not used for water supply [11, p. 27].

In contrast, the Cenon-Turonian aquifer is the most important for the water supply of the region. This is the most water-enriched horizon, with the thickness of the aquifer from 10 to 80 m and the flow rate of wells 3–10 m^2/h [11, p. 28]. It is the main source of centralized water supply for industrial enterprises and large settlements such as Lutsk, Kovel, Novovolynsk, Volodymyr, etc. The horizon is spread over the entire territory of the region, and its waters are contained in chalk and marl deposits. Renewal of the horizon's water resources occurs through infiltration of surface and ground water, as well as inflow of water from tectonic disturbances.

Cenozoic erathem

A relatively low-thickness (up to 30.0 m) complex of terrigenous-carbonate rocks of Paleogene age crowns the section of the sedimentary cover of the southwestern edge of the East European platform. Metasomatic limestones containing sulfur, gypsum, and anhydrites, characterized by barium-strontium mineralization, are distinguished as part of carbonate rocks. Terrigenous rocks are represented by sandstones and clays.

In Cenozoic sediments, Paleogene and Quaternary sediments are aquifers. The Paleogene aquifer was formed in the deposits of the Kharkiv formation of the Upper Paleogene, it is sporadically distributed in the northern regions of the region, where Paleogene deposits were formed in places of lowering of the Cretaceous relief. For economic purposes, the horizon is practically not used.

The waters of Neopleistocene and Holocene sediments, which are interconnected and form a single complex, are of great importance for the region [6, p. 12]. They form the first aquifer from the surface (groundwater) and are closely related to the level regime of surface waters and the regime of precipitation. The temperature of groundwater during the warm period of the year ranges from 12 °C to 15 °C [3, p. 269]. The depth varies from a few tens of centimeters in the floodplains of rivers to more than 10 m in the territory of the Volyn upland. The horizon is formed in modern swamp and alluvial deposits in river floodplains; in Upper Quaternary alluvial deposits on floodplain terraces of medium and large rivers; in mid-Quaternary water-glacial sediments at interfluves. The boundary of the distribution of the aquifer runs along the conditional line of the village of Ludyn – village of Glybyna – village of Lukovychi – village of Pryvitne – village of Oderady – city of Lutsk – village of Romaniv – village of Zhornyshche. South of the line, the first aquifer from the day surface is formed in the Turonian – Senonian deposits of the Upper Cretaceous.

The water resources of the considered horizon are used by the local population to meet economic and drinking needs. However, for centralized water supply of large settlements and industrial productions, the horizon is not used due to the unstable discharge of wells and the threat of runoff contamination of agricultural lands and urban areas.

In the studied aquifers, there are layers of both fresh and mineralized waters. The Volyn region belongs to the hydrogeological province of nitrogen, nitrogen-methane and methane artesian basins and hydrogeological regions [1, p. 139]. At the beginning of the 1990s, the Rivne Geological Exploration Expedition completed an assessment of the territory of Volyn in relation to the distribution of mineral waters. The most common are sodium chloride, sodium sulfate and calcium bicarbonate-chloride waters.

1. Chloride-sodium drinking water of the Myrhorod type (DST 13273–73) is the most common. These waters are confined mainly to volcanic-terrigenous sediments of the Ediacaran and Paleozoic, lying at a depth of up to 750 m. Water reserves have been explored in Lutsk and Zhuravychi.

2. Chloride-sodium highly mineralized waters (in many cases, brines) – have widespread development at depths of more than 1000 m. Chloride-sodium brines were studied at the Zhobryn deposit (the border between the Rivne and Volyn regions), on which the approved reserves of SCR of Ukraine reach 240 m³/day at mineralization 32 g/dm³, and the important microcomponents in the water are iodine and bromine, which determine the main balneological value of the water. Bromine content in brine is 104 mg/dm³, iodine is 8.5 mg/dm³.

The Shatsk deposit of mineral waters has reserves of 16.7 m³/day with water mineralization of 70.4 g/dm³. The well operating in the Kovel sanatorium “Turia” has the ability to produce 90 m³/day of brine from a depth of 1300–1400 m, the mineralization of which reaches 124 g/dm³ with a bromine content of up to 1000 mg/dm³ and iodine – up to 20 mg/dm³. Higher concentrations of bromine (up to 1500 mg/dm³) were recorded in oil exploration wells drilled in the south-western part of the region. Low water capacity of rocks and great depths (1500–3000 m) significantly reduce the prospects of their use. According to the conclusions of the Odesa Institute of Spas, sodium chloride waters are recommended for balneological purposes of a wide therapeutic range.

3. Sulfate sodium drinking quality waters with mineralization of 3–6 g/dm³ are confined to Devonian, rarely Silurian gypsum-bearing deposits, which are distributed in the southeastern part of the region. These waters were studied in individual wells, which indicates their presence, but a comprehensive study for wide consumption was not carried out.

4. Hydrocarbonate-chloride calcium waters with a mineralization of 1.4 g/dm³, similar to the well-known “Slavutych” water (Cherkasy region).

Both mineralized and fresh underground waters often have healing properties, and their natural exits to the earth's surface (springs) are objects of worship and form so-called sacred landscapes. Thus, according to O.V. Mishchenko's calculations, there are more than 84 springs operating in the territory of the Volyn region, the most famous of which is a spring near the village of Budyatychi, a fresh source of the Holy Spirit near the village of Stara Lishnya, the fresh spring of the prophet Elijah and John the Baptist, near the village of Laskiv, a well 7 km from the village of Syl'ne, fresh spring near the village of Kusnyshcha [10, p. 91].

Groundwater is the main source of centralized and decentralized water supply for the population, and is also used in industry and agriculture. During 2015–2020, they account for 77.8% of water withdrawals from all natural sources. It should be noted that the share of groundwater in the water intake structure is constantly increasing. Thus, in 2015 they accounted for 72.0% of all water intake, and in 2020 their share increased to 85.2%.

The population of all 11 cities, 18 settlements (82%), and 319 villages (30%) in the region is provided with centralized water supply [13, p. 43]. For this purpose, water wells are utilized, drawing from Upper Cretaceous sediments as well as other aquifers. Decentralized water sources cater to the freshwater needs of the population, certain enterprises, and organizations. It is worth noting that the decentralized water withdrawal by the population occurs without accounting and taxation, whereas organizations and enterprises pay rent for the utilization of specialized water sources. The majority of the region's population, relying on decentralized water supply, utilizes groundwater that lacks protection from water-resistant layers, thus posing a risk of contamination from agricultural runoff and urban areas. Enterprises and organizations typically rely on artesian wells for their water supply.

In general, the Volyn region has significant underground water reserves, which are estimated at 900 million m^3 [15, p. 51]. When studying underground water reserves, it is advisable to consider forecast and balance reserves. Predicted reserves reflect the real possibilities of groundwater extraction with a rational arrangement of water intakes and stable conditions of their operation. Balanced reserves are reserves that, at the time of assessment, according to technical and economic calculations, can be economically efficiently extracted and used [7]. Estimated operational resources amount to 2,586.3 thousand m^3/day, of which 354.1 thousand m^3 are balance [12, p. 14]. Accordingly, 0.34 m^3/day and 125.7 m^3/year of balance operational groundwater reserves per 1 inhabitant of the region (calculated based on the average population during 2015–2020). According to the standards of the UN European Commission, regions with less than 1.500 m^3/year per inhabitant are considered the least water-provided [16, p. 5]. Therefore, the Volyn region can be classified as the least equipped with underground water reserves.

However, water reserves are sufficient to meet the economic and drinking, industrial and agricultural needs of the region. There are 549 enterprises participating in water use in the region, of which 134 are municipal enterprises, 107 are agricultural enterprises, 101 are industrial enterprises, 54 are fisheries enterprises, and 11 are energy enterprises [8, p. 65]. Yes, only 50 million m^3 is withdrawn from underground sources every year (calculated for 2015–2020). During the studied years, a general trend towards a decrease in the volume of water resources withdrawal from underground sources is characteristic (Fig. 2).

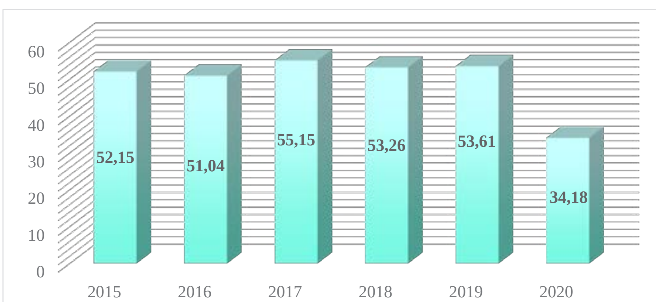


Fig. 2. Volumes of water intake from underground sources during 2015–2020, million m^3 (compiled based on [4, p. 14; 5, p. 14])

Thus, compared to 2015, water intake in 2020 decreased by 18 million m^3, which is 35%. We observe that the least amount of water was collected in 2020, which is due to a decrease in production volumes by various sectors of the economy due to the introduction of quarantine restrictions during the spread of the COVID-19 coronavirus disease.

The reduction in the volume of water intake from underground sources is due to a decrease in water consumption by economic sectors (Fig. 3). Analyzing the proposed schedule, we observe that most of the water is spent on household and drinking needs. On average, they account for 33.9% of all water intake (calculated for 2015–2020). A significant share of domestic and drinking water in the water intake structure is explained by the weak development of the industrial complex, the lack of need for irrigation in agriculture, as well as the impossibility of introducing circulating water supply in the industry.

On average, agriculture accounted for 21.3% of the withdrawn water during 2015–2020. By 2019, there was a noticeable increase in the volume of water intake, attributed to the region's agricultural development and the growing demand for fresh water for livestock complexes, product storage, and processing [9, p. 308]. However, in 2020, there was a sharp decline in the volume of water intake, reaching 0.15 million m^3.

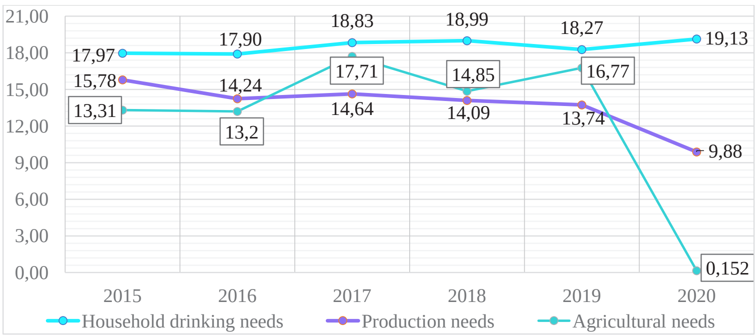


Fig. 3. Volumes of water resource use by economic sectors during 2015–2020, million m^3 (compiled based on [4, p. 14; 5, p. 14])

In recent years, the industrial sector has been the least water-intensive among the considered sectors of the economy. Industries such as sugar and food production are the most water-intensive. Production accounts for 25.8% of water withdrawals, and these withdrawals are decreasing. It is worth noting that recycled water is also used for production needs, resulting in a 51.4% reduction in fresh water consumption. During the studied period, the percentage of fresh water savings through recycled water has been increasing (from 21.8% in 2015 to 61.6% in 2019 and 45.7% in 2020).

In addition, water resources are used for irrigation and fisheries, however, the volumes of withdrawal are insignificant. Thus, water intake for irrigation is 9.5% of the total water intake, and for fisheries – 6.5%. Water needs for irrigation tend to decrease, while for fish farming, on the contrary, they increase.

Significant costs of the collected water are observed during their transportation. They make up an average of 13% of the total water intake. A characteristic trend is the increasing share of water consumption during transportation (from 14% in 2015 to 16% in 2020). The phenomenon is explained by the obsolescence of the water supply systems, which have been operating since the 60s of the last century, are morally and technically obsolete, and require repair and modernization.

Despite the region's sufficient resources of underground aquifers, their high quality and the reduction of consumption by economic sectors, their condition is constantly deteriorating under the conditions of technogenesis. In particular, irrational use of groundwater leads to its depletion. Carrying out drainage reclamation in Polissia, reducing forested areas leads to a decrease in the level of groundwater, drying up of wells, which, in turn, affects the level of interlayer waters, which replenish their reserves due to infiltration of surface and groundwater.

In addition, human economic activity leads to deterioration of the quality of groundwater. In particular, along with surface runoff from agricultural lands and settlements, pollutants infiltrate underground horizons. Yes, agricultural wastes contain mineral and organic fertilizers.

Therefore, groundwater needs rational use and protection. An important direction for solving water management and environmental problems is a comprehensive approach to the protection of all surface and underground water sources from pollution, exhaustion and exhaustion [14, p. 164]. In our opinion, the main measures that will contribute to the preservation and restoration of water resources of underground aquifers include:

- introduction of low-water and water-free production technologies;
- expansion of the practice of recycled water use;
- repair and modernization of water pipes.

In order to improve the quality of groundwater, it is necessary to carry out a number of measures to prevent the ingress of pollutants into groundwater and infiltration into interlayer waters. In particular, such measures should include:

- rational use of mineral fertilizers and plant protection products in agriculture; modernization of treatment facilities of industrial enterprises and communal enterprises;
- implementation of modern systems of wastewater treatment of rainwater from urban areas.

Conclusion. The Volyn region exhibits a diverse geological structure, characterized by a substantial sedimentary cover comprising deposits from various geological periods, hosting multiple aquifers. The primary aquifer is situated within the Turonian-Senonian deposits of the Upper Cretaceous, serving as a crucial source for centralized water supply, industrial activities, and agricultural production. Additionally, other interlayer waters are utilized, while groundwater plays a significant role in decentralized water supply systems.

During the period from 2015 to 2020, there has been a notable increase in the proportion of groundwater in the overall water intake, rising from 72% in 2015 to 85% in 2020. The residential and communal sector stands out as the largest consumer of water resources, supplying the region's population with the necessary water for drinking and other domestic purposes. Due to the limited economic development in the region, water usage for industrial purposes is relatively low, with the majority being allocated to the food and sugar industries, as well as agricultural activities.

The region is facing various environmental challenges resulting from the unsustainable utilization of natural resources, particularly in relation to water. These issues include the depletion, contamination, and deterioration of groundwater, rendering it unsuitable for use. In order to safeguard and restore water resources, it is crucial to adopt sustainable practices such as employing low-water and water-free production technologies, promoting reversible water usage, and upgrading water supply infrastructure. Additionally, preserving and improving the quality of underground water necessitates the rational application of mineral fertilizers and pesticides, upgrading wastewater treatment facilities, and implementing advanced systems for treating both wastewater and rainwater.

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ПІДЗЕМНІ ВОДИ ВОЛИНСЬКОЇ ОБЛАСТІ: УМОВИ ЗАЛЯГАННЯ, ОСОБЛИВОСТІ ВИКОРИСТАННЯ, ШЛЯХИ ЗБЕРЕЖЕННЯ Й ПОЛІПШЕННЯ

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Стаття присвячена дослідженню підземних вод Волинської області, умов їх залягання й особливостей використання населенням та економікою регіону. Охарактеризовано різновікові водоносні горизонти, їх ареали й межі поширення на території області. Досліджено особливості залягання кожного водоносного горизонту у зв’язку з геологічною будовою території в геохронологічній послідовності. Описано мінералізовані підземні води, визначено, що найбільш поширеними є хлоридно-натрієві, сульфатні, натрієві та гідрокарбонатно-хлоридні кальцієві води.

Для дослідження сучасного стану підземних вод обрано часовий проміжок із 2015 по 2020 роки, визначено основні тенденції використання водних ресурсів. Так, установлено, що частка підземних вод у структурі водокористування постійно зростає, але обсяги водозабору з підземних джерел, навпаки, скорочуються. Проаналізовано динаміку використання водних ресурсів за галузями господарства. Виявлено основного водокористувача протягом досліджуваних років, яким є житлово-комунальне господарство, що зумовлено слабким розвитком економіки регіону й, відповідно, незначними обсягами використання водних ресурсів галузями господарства. Так, досліджено, що на виробничі та сільськогосподарські потреби в середньому витрачається 25,8% і 21,3% відповідно від усіх забраних вод. З’ясовано, що найменше водних ресурсів використовується для потреб зрошення й рибного господарства (9,5% і 6,5% відповідно), однак значними є витрати води під час її транспортування, на які припадає 13% усього водозабору.

З метою раціонального використання, збереження й покращення якості підземних вод запропоновано низку заходів. Зокрема, для раціоналізації водокористування доцільним є впровадження маловодних і безводних технологій у виробництво, перехід до зворотного водокористування, реконструкція систем водопостачання. Збереження та поліпшення якості підземних вод вимагають модернізації очисних споруд комунальних підприємств, упровадження очищення стічних дощових вод, ефективного використання в сільському господарстві засобів захисту рослин і мінеральних добрив тощо.

Ключові слова: підземні води, геологічний вік, водоносний горизонт, мінеральні води, водозабір, водопостачання, раціональне водокористування, заходи збереження.