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The Impact of Natural and Anthropogenic Factors on the Chemical Composition of Groundwater in the Kakhovka Reservoir Area

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SUMMARY

Data on the chemical composition of groundwater in aquifers within the Neogene and Paleogene deposits of the Kakhovka Reservoir region were collected and analyzed to assess the impact of natural and anthropogenic factors on their chemical composition. Spatial analysis identified three general zones with varying levels of mineralization and well yield. The first zone (mineralization of 2,000–6,000 mg/dm³, yields up to 100 m³/day) is located within the Ukrainian Shield in the Dnipropetrovsk region and partly in the Zaporizhzhia region. The second zone covers the far south of the study area – the lower Dnieper River basin in the Kherson region (predominantly fresh water, though right-bank mineralization reaches 2,000–2,500 mg/dm³, with yields of 200–1,200 m³/day). Increased mineralization in specific wells in this area stems from the inflow of highly mineralized water driven by intensive abstraction far from the Dnieper River, and seawater intrusion in coastal wells near the Black Sea. The third zone serves as a transition zone between the first and second zones, featuring mineralization of up to 1,500 mg/dm³ (occasionally exceeding 2,000 mg/dm³). Yields range from 100 to 300 m³/day, and can exceed 500 m³/day along the banks of the Dnieper River. The impact of well abstraction intensifies toward the south.

Keywords: Kakhovka Reservoir; Mineralization; Well yield; Spatial analysis; Aquifers; Neogene and Paleogene deposits.

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Introduction

Most settlements in the lower Dnieper reaches drew their water supply from the Kakhovka Reservoir and the Dnieper River. As a result of the destruction of the Kakhovka Hydroelectric Power Plant, the water intakes were left high and dry, and the ongoing hostilities make it impossible to safely restore the water supply from the new channel of the Dnieper River. Between 2023 and 2026, local communities began drilling wells to provide water to the population. The chemical composition of groundwater across such a large area is varied and is subject to various natural and anthropogenic influences. The destruction of the Kakhovka Reservoir and the increased use of groundwater highlight the risks of man-made and environmental threats and require a certain degree of foresight regarding changes in the condition of groundwater in the main aquifers. Intensive exploitation of these aquifers, which are considered the primary alternative for the region's water supply following the destruction of the Kakhovka Hydroelectric Power Plant. A worsening of the chemical composition of groundwater is predicted as a result of the intrusion of mineralized or anthropogenically altered water.

The objective of this study was to assess the impact of natural and anthropogenic factors on the chemical composition of the waters of the two main aquifers in the Neogene and Paleogene deposits of the Kakhovka Reservoir region.

Method and Theory

The study area is located within the Dnipropetrovsk, Zaporizhzhia, and Kherson regions and covers parts of two geological structures: the Ukrainian Shield and the Black Sea Basin. During the research, data on more than 200 wells were analyzed, drawn from reports by the State Scientific and Production Enterprise "Geoinform of Ukraine" on the regional assessment of groundwater reserves in the Black Sea Artesian Basin (Kapinos et al., 1977). Two main aquifers in the Neogene and Paleogene deposits were studied in the region; the water-bearing rocks in these systems consist of sands, sandstones, and limestones.

This study employed methods of statistical and spatial analysis. Based on data from more than 200 wells (Kapinos et al., 1977), an assessment was conducted of the main characteristics of aquifer systems in the Neogene and Paleogene deposits of the Kakhovka Reservoir region and the patterns of their spatial variation.

Results

The results of the analysis revealed significant variability in the chemical composition and other parameters of the groundwater in both aquifers within the study area (Table 1).

The impact of natural and anthropogenic factors was assessed using spatial analysis based on maps of various groundwater indicators in the Kakhovka Reservoir area.

The maps (Fig. 1) clearly show an improvement in the chemical composition of the waters in the aquifer within the Neogene deposits, as well as an increase in well yield from north to south. Three distinct zones with different properties are clearly identified:

1. The first zone is located within the Ukrainian Shield in the Dnipropetrovsk region and partly in the Zaporizhzhia region. Water salinity in the wells ranges from 2,000 to 6,000 mg/dm^3, with well yield of up to 100 m^3/day; only a few wells have more or less acceptable salinity levels.

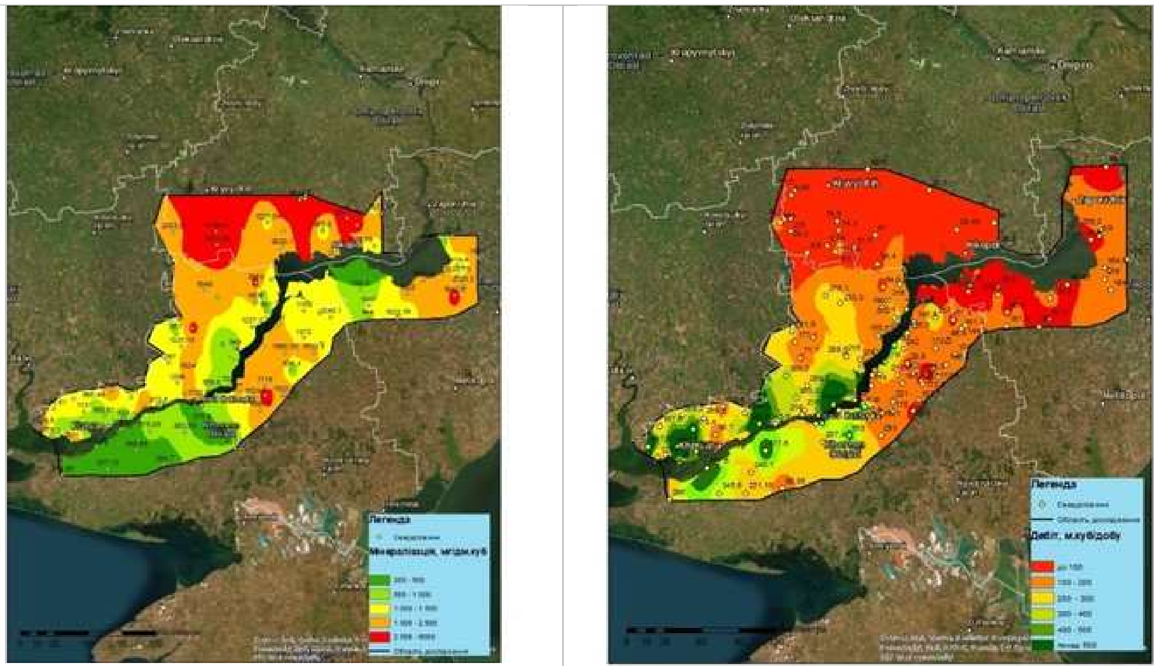
2. The second distinct zone is located in the very south of the study area – in the lower reaches of the Dnieper River basin, in the Kherson region. The water is predominantly fresh, but on the right bank there are wells with a mineralization level of 2,000–2,500 mg/dm^3 and high well yields ranging from 200 to 1,200 m^3/day.

Table 1. *Key indicators of groundwater in aquifers in Neogene and Paleogene deposits*

Indicator		***Variation intervals***	
		Aquifer within the Neogene deposits	***Aquifer within the Paleogene deposits***
pH		6 – 8.6	6.8 – 8.7
Well yield	m³/day	24 – 1200	0.9 – 1176
Mineralization	mg/dm³	137 – 6850	667 – 6017
Na^{+}	mg/dm³	1 – 1840	94 – 1251
K^{+}	mg/dm³	1 – 205	11 – 139
Ca^{2+}	mg/dm³	7 – 578	4 – 224
Mg^{2+}	mg/dm³	0 – 457	4 – 276
Cl^{-}	mg/dm³	7 – 2862	103 – 1956
HCO_3^{-}	mg/dm³	43 – 1000	1 – 1194
HSO_4^{2-}	mg/dm³	1 – 3892	19 – 1987

There are two reasons for the increase in mineralization in certain wells: the draw-in of more mineralized water from areas farther from the Dnieper River due to intensive exploitation, and the draw-in of seawater from wells located near the Black Sea coast.

3. The third zone is a transitional zone between the first and second zones. Mineralization in most wells is up to 1,500 mg/dm³, though there are areas with mineralization exceeding 2,000 mg/dm³. Well yields are predominantly 100–300 m³/day, but on the banks of the Dnieper River, they can exceed 500 m³/day.

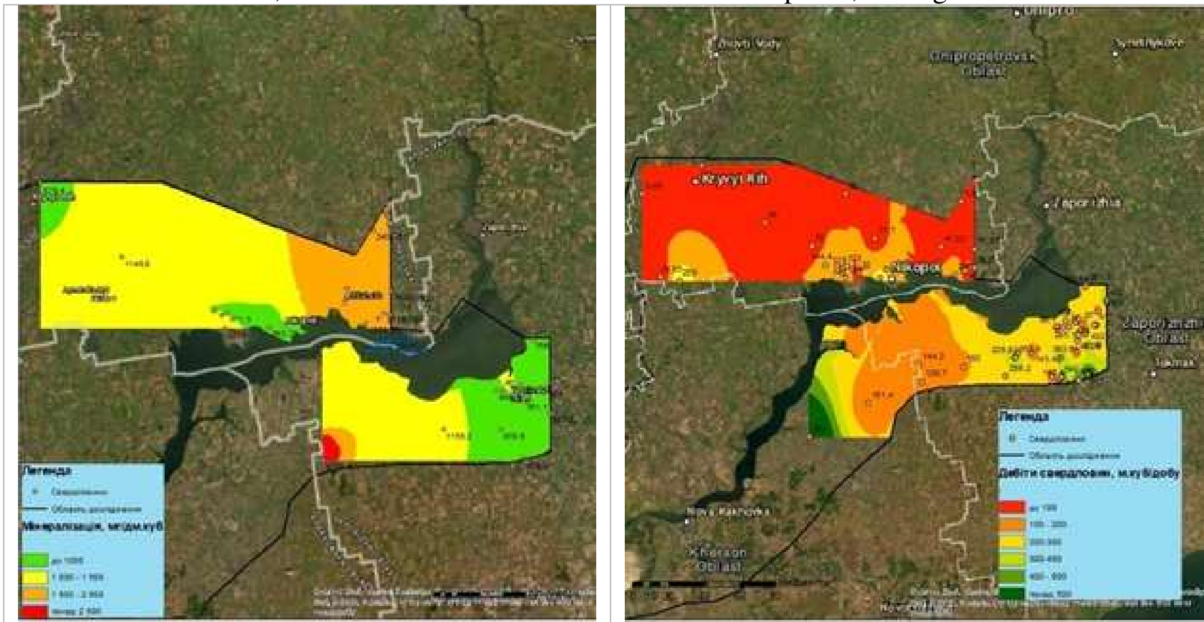


a) Mineralization *b) Well yields*

Figure 1. *Map showing the distribution of mineralization and well yields in the aquifer in the Neogene deposits*

The aquifer in the Paleogene deposits is much less widespread – it is found only in the northern part of the study area (Fig. 2). Data on mineralization and well yields in the Paleogene aquifer within the study area are significantly scarcer, as water extraction from this horizon is limited to the right bank of the Dnipropetrovsk region and the central part of the Zaporizhzhia region.

The available data indicate a lower level of mineralization: up to 2,400 mg/dm³ on the right bank, while on the left bank, most wells have mineralization levels of up to 1,500 mg/dm³.



a) Mineralization	b) Well yields

Figure 1. *Map showing the distribution of mineralization and well yields in the aquifer in the Paleogene deposits*

Well yields in the waters of the aquifer in the Paleogene deposits are distributed similarly to mineralization: within the Ukrainian Shield, they are low – a maximum of 258 m³/day – while on the left bank, they reach up to 690 m³/day. Both banks are characterized by an increase in well yields closer to the Kakhovka Reservoir, and on the left bank, there is also an increase in discharge rates toward the south – as the Black Sea Basin deepens.

Conclusions

The results obtained allow us to draw the following conclusions:

Spatial data analysis reveals a clear correlation between natural conditions and water quality, as well as specific zonation and the influence of the Kakhovka Reservoir and the Dnieper River. Within the Ukrainian Shield, groundwater has low well yields (up to 100–150 m³/day) and high salinity (over 2,000 mg/dm³). Further south, discharge rates increase, while salinity decreases.

There is a noticeable increase in the impact of intensive groundwater extraction toward the south. In the lower reaches of the Dnieper River, near the city of Kherson, the impact of intensive groundwater extraction is manifested in increased mineralization resulting from the draw-up of more mineralized waters from other aquifers and the inflow of seawater along the Black Sea coast.

The aquifer in the Paleogene deposits is more hydrochemically homogeneous and has a higher well yield potential than the Neogene aquifer complex. However, the Paleogene aquifer complex is limited in its distribution, so these waters cannot serve as a full-fledged alternative to the Dnieper as a water supply source.

The aquifer in the Neogene deposits is highly heterogeneous; however, it extends throughout the study area and is of good quality in the lower reaches of the Dnieper River and the Kakhovka Reservoir. The significant variation in discharge rates may indicate varying degrees of hydraulic connectivity with local recharge zones, which potentially determines the varying sensitivity of water intakes.

In the end, it can be summarized that within the Ukrainian Shield, well yields generally do not exceed 100 m^3/day, which is due both to the shallow depth of Precambrian crystalline rocks and to the fact that settlements received centralized water supply primarily from the Kakhovka Reservoir. To the south, well yields gradually increase and reach their maximum downstream of the Kakhovka Reservoir. This is due to improved hydrogeological conditions and the greater use of groundwater in the centralized water supply systems of cities, as it is precisely in regional centers that the intensity of groundwater exploitation is increasing.

Since the study uses data collected during the initial phase of the reservoir's operation and its period of intensive use – partially including information from before its construction – the resulting estimates can serve as a basis for comparing the outcomes of different strategies for its restoration (or non-restoration).

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